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CONTENTS

Research Article

Gül Eda Kılınç Yasemin Gülgün İşgör Ecem Nur Sakar	Changes in vitamin c and carbohydrate contents of commercially supplied orange juice and nectars during storage	249-258
Oluropo Ayotunde Apalowo Olusegun Balogun Nkechi Betsy Izuogu Abisola Banji Halimat Shola Baba Maduabuchi Johnbosco Okafor Emmanuel C Nnabuihe Duyilemi Anthony Akinyemi	Occurrence of virus in some watermelon growing areas of Kwara State, Nigeria	259-267
Zeki Kara Osman Doğan Kevser Yazar ¹	Effects of sodium nitroprusside and gibberellic acid applications on direct germination of fully mature grapevine seeds and seedling growth	268-279
Hasan Can	Potential of silicon and melatonin amendments to enhance the tolerance of lettuce plants to water deficit stress	280-296
Fatma Zumbul Nur Koç Koyun Ahmet Tamkoç	The determination of agronomic characteristics of pea lines in F ₄ generation	297-309
Abdirizak Ali Abdullahi	Agriculture and sustainability in Somalia: Challenges and pathways to sustainable development	310-319
Mehmethan Şişman Songül Kal Burak Avşar Musa Seymen	Interactive effects of water salinity and water-deficit on biochemical content and photosynthetic activity of melon (<i>Cucumis melo</i> L.) seedlings	320-333
Osman Doğan Bulut	Investigating the expectation meeting ratio of partners: The case of Edirne Province agricultural development / irrigation cooperatives	334-343
Paul Orobosa Orobator	Impact of bushfire on soil heavy metals in oil palm plantations in Edo State, Nigeria	344-356
Ümit Yasin Köksal Haydar Haciseferoğulları	Determination of the agricultural mechanization level of agricultural enterprises in Eskil District of Aksaray Province	357-373
Mine Çetinkaya Tamer Marakoğlu	Investigation of medium-scale enterprises manufacturing agricultural machinery in Konya Province in terms of occupational health and safety	374-390
Dilek Kubat Şengel Mehmet Mamay	Population development and infestation rate of pistachio twig borer [<i>Kermania pistaciella</i> Amsel (Lepidoptera: Tineidae)] in pistachio orchards in Middle Euphrates Valley, Türkiye	391-406
Seyfi Taner	Relationships between tillering, grain yield and yield components in durum wheat genotypes	407-417



Emrah Sönmez Yeter Çilesiz	Genetic variation analysis of selected grape (<i>Vitis vinifera</i> L.) accessions through SCoT markers	418-426
Sibel Day Nilüfer Koçak-Şahin	Titanium dioxide impact on growth and yield parameters of sunflower	427-433
Thierry Keringingo Zuhal Karakayacı	Risk assessment in paddy rice cultivation: The case of Gihanga, Burundi	434-445
Gürhan Özeydin Aysun Yener Ögür	The effects of earthquakes on occurring in Türkiye on demographic structure and agricultural sector	446-458
Tuğçe Melda Temrel Yeter Çilesiz	Investigation of genetic polymorphism in selected thyme (<i>Thymus vulgaris</i> L.) accessions using SCoT molecular markers	459-466
Furkan Çoban Bülent Çetin Hakan Özer Zehra Toktay Beyzanur Budak Hilal Angın Ali Kandemir	Chemical composition of hydrodistillated essential oil of <i>Heracleum antasiaticum</i> MANDEN (L.) and its antimicrobial activity against food-borne microorganisms	467-475
Rabia Albayrak Delialioğlu Ayşe Övgü Şen	Prediction of lactation milk yield in simmental cattle milked with robotic milking system using CHAID and CART algorithms	476-486
İrem Ayran Çolak Sadiye Ayşe Çelik	<i>Silybum marianum</i> L. Gaertner.: A review of its traditional uses, phytochemistry and pharmacology	487-493



Changes in Vitamin C and Carbohydrate Contents of Commercially Supplied Orange Juice and Nectars during Storage

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HIGHLIGHTS

- This study will help raise consumers' awareness about the vitamin C and sugar contents in market orange juices and nectars.
- This study aims to inform the appropriate storage conditions for market orange juices and nectars, providing guidance on preserving their nutritional value.

Abstract

Orange juice and nectars are important sources of vitamin C for human health, and their consumption is becoming increasingly widespread due to ease of transportation. This study aimed to trace the quality change of orange juice and nectars from two different brands, focusing on vitamin C and sugar contents, after 3 days of storage at two different temperatures (4 °C, 20 °C). 100% orange juices and orange nectars were used as study materials. Fruit juice samples prepared from concentrates with a production year of 2022 and packaged in cardboard boxes with aseptic filling technique were provided from two different companies. Unpackaged orange juices and nectars were stored for 3 days in total, and vitamin C, invert sugar, total sugar, and sucrose contents were evaluated as quality change criteria on 1st, 2nd, and 3rd days of storage. One-way ANOVA test was used to compare all groups, and post hoc Tukey test was used for differences between pairwise comparisons. Statistically, a $p < 0.05$ value indicates a level of significance. Statistically significant differences were observed in orange juices and nectars across all brands and temperatures, varying by storage time. The results showed that as storage time increased, vitamin C content decreased ($p < 0.05$). In comparisons made according to storage temperature, it was determined that orange nectar and orange juices of brands A and B had a statistically significantly higher amount of invert sugar at 4 °C compared to 20 °C ($p = 0.008$; $p = 0.001$); ($p = 0.018$; $p = 0.039$). As a result, it was determined that as storage time and temperature increased, the vitamin C and sugar contents of orange juices and nectars decreased. It is thought that this study will be a useful resource in raising awareness in our society about the consumption of ready-made fruit juices, particularly orange juice and nectars, and their nutritional preferences.

Keywords: Carbohydrate; orange juice; orange nectar; vitamin C

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1. Introduction

Fruits are one of the main food groups in food pyramids and healthy plate models and are among the important food groups that should be included in our diet due to their taste and health benefits, as well as their nutritional values. Based on dietary recommendations from countries and organizations regarding fruit consumption, there is consensus that increasing fruit consumption can improve overall health and reduce the risk of major non-communicable diseases (Angelino et al. 2019; Sarac and Butnariu 2020). In recent years, with increasing chronic diseases, individuals' tendency towards fruit consumption has increased and an economic market area for fruit production has come to the fore worldwide (Sun et al. 2021; Wallace et al. 2020).

Fruit juice is a beverage made from the extraction or pressing of the natural liquid found in fruits and is one of the most efficient ways to evaluate fruit production (Nighojkar et al. 2019; Ruxton and Myers 2021). Fruits constitute essential components of a healthy diet (Jaglan et al. 2022). The World Health Organization (WHO) recommends consuming 400 g of fruits and vegetables per day to prevent cancer, cardiovascular diseases, diabetes, obesity and diseases caused by nutritional deficiencies, especially seen in underdeveloped countries (WHO 2005). In our country, based on nutritional guidelines, it is stated that at least 5 portions of vegetables and fruits should be consumed per day (at least 400 g / day), and 2-3 portions of these should be fruit. In addition to fresh, frozen and dried fruits, they can also be consumed by processing them into fruit juice. Fruit juice is a popular beverage option and the juice economy is a market area that has grown significantly in recent years (TSB 2016; Besler et al. 2015).

In addition to the increasing interest in fruit juice, we also encounter a conceptual confusion regarding fruit juice. When it comes to fruit juice in society, all fruit-derived drinks come to mind. However, beverages within the scope of fruit juice sold in the market are divided into 4 different groups in the Turkish Food Codex. The main differences between these groups stem from the difference in the fruit ratios they contain. While fruit juice is mainly obtained from the whole fruit, fruit nectar can be obtained from fruit concentrate, fruit juices, fruit powders, etc. It is also stated that fruit nectar should have a fruit content between 25-99%. Fruit juices below this ratio are included in the fruit juice concentrate category. In addition, fruit juices containing 100% fruit are expressed with the phrase "100% fruit juice" (Demir et al. 2020; TKG 2014).

Fruits are basically very rich sources of vitamins and are extremely important nutrients in the realization of many biochemical functions (Arias et al. 2022). Since most of them are not synthesized in the body, they must be taken externally through foods and nutritional supplements (Zhang et al. 2020). One of these vitamins is vitamin C (L-ascorbic acid), which can cause scurvy when not taken in sufficient amounts into the body which manifests itself as bleeding, including perifollicular bleeding, ecchymoses and gingival bleeding, as a result of fatigue, disorders in bone growth and improper formation of connective tissue. Vitamin C also has an important role in modulating neurotransmitter synthesis and release in the brain. The functions of vitamin C in the brain include it as a co-factor for dopamine beta-hydroxylase in the conversion of dopamine to noradrenaline, and it also regulates the release of catecholamine and acetylcholine from synaptic vesicles by taking part in the modulation of dopaminergic and glutamatergic neurotransmission. Vitamin C also has antioxidant properties, including limiting damage to the brain caused by ischemia-reperfusion injury and protecting against glutamate excitotoxicity (Carr and Rowe 2020; Plevin and Galletly 2020). The daily dietary intake (RDA) amount of vitamin C may vary depending on various factors such as age, gender and physiological state (Carr and Lykkesfeldt 2021). In Turkey, the recommended amount of vitamin C is 110 mg for adult men and 95 mg for adult women (TSB 2016).

Evaluating the vitamin C level in fruit juices and especially orange juices is considered one of the important quality criteria when determining the quality (Polydera et al. 2003). Among fruits and juices, oranges in particular are very popular, and the commercial value of orange juice is due to its sensory qualities and, above all, its high content of natural antioxidants such as vitamin C. Additionally, phenolic acids and flavanones are the two main groups of phenolic compounds found in orange juice. Orange juice contains significant amounts of hydroxycinnamic acid and antioxidant compounds including ferulic acid, p-Coumaric acid, sinapinic acid,

caffeic acid and chlorogenic acids. In addition, vitamin C found in orange juice is a nutrient that is very sensitive to heat treatment and can easily lose its stability. Therefore, significant losses in vitamin C content occur during the processing and storage stages, especially in orange juice production. In addition, storage temperature and duration, oxygen contact, salt concentration, pH, sugar and various enzymes can cause significant losses in vitamin C in orange juice (Gomes et al. 2022; Romeo et al. 2020). In addition, the production of bad taste as a result of microbial spoilage, degradation of vitamin C causes quality loss and a decrease in the shelf life of orange juice (Kaddumukasa et al. 2017).

In addition to the vitamin C content of fruits and fruit juices, their carbohydrate content is also very important in terms of nutritional value and microbial properties (Li et al. 2020). Fruits mainly contain carbohydrate types such as glucose and fructose, but also contain some sucrose and mannose. The ratio of these components may vary depending on the type of fruit (Brizzolara et al. 2020). It is stated that carbohydrate content is an important indicator in evaluating the quality of fruits and fruit juices. Since fruit juices are very prone to adulteration and imitation due to their properties, carbohydrate analyzes are frequently used to detect fraud in the fruit juice industry and can prevent this situation. It is stated that temperature and time are very important on the carbohydrate content of fruit juices, especially on biochemical activity and microbial proliferation during storage and processing (Li et al. 2020; Tezcan et al. 2009; Tüfekci and Fenercioğlu 2010). In the light of this information, this study aimed to trace the quality change of orange juices and nectars of two different brands, which are widely consumed in our country, with vitamin C and carbohydrate contents after 3 days of storage and two different storage temperatures (4 °C, 20 °C).

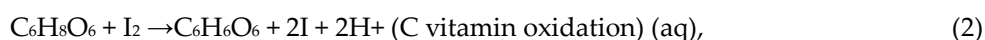
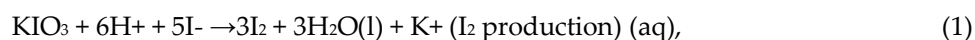
2. Materials and Methods

2.1. Research Design

In the study, 100% orange juices and orange nectars were used as study materials. Fruit juice samples prepared from concentrates with a production year of 2022 and packaged in cardboard boxes with aseptic filling technique were provided from two different companies. Packaging in metal and glass boxes was not included in the study due to low usage prevalence according to consumer data. Care was taken to ensure that the expiration dates of the samples taken for all brands were similar. Based on the information that the recommended consumption period of fruit juices is 3 days after opening the packaging, the unpackaged samples were stored at two different temperature storage conditions (4 °C, 20 °C). In order to monitor the quality change, orange juice and nectars were analyzed every day, based on the 3-day storage period after the samples were put into use. All laboratory analyzes were conducted in duplicate. Vitamin C and carbohydrate contents of fruit juice and nectar samples were analyzed as quality change criteria.

2.2. Determination of Vitamin C (Ascorbic Acid)

Vitamin C content in orange juice and nectar was determined using the iodine titration method. This method is based on two formulations. In the first formulation, iodine production is carried out in an aqueous medium with potassium iodate, and in the second reaction, oxidized vitamin C is obtained as a result of the interaction of the produced iodine with the sample. Both reactions were carried out with dilute sulfuric acid. In the first reaction stage, potassium iodide solution was added for the dissolved iodide ion source (Dioha et al. 2011). By adapting the method to this study, vitamin C analyzes in orange juices and nectars were carried out based on 0.005 mol L⁻¹ iodine solution and 5% starch indicator solution. The values obtained as a result of the analysis are expressed as mg/100 mL.



2.3. Determination of Total Carbohydrate, Invert Sugar

It was determined using the Lane-Eynon method and colorimetric method for the determination of carbohydrates in orange juice and nectar according to storage time and temperature. Carbohydrate determination in the method is based on the reduction of Copper-II oxide in the Fehling solution to water-insoluble Copper-I-oxide. According to the method, since copper oxide is insoluble in water, the water-soluble complex salt of copper (synthetic salt) is used in the determination. NaOH provides the basicity of the medium. The soluble copper tartrate ion is blue in this solution. Since the copper ions formed by the reduction of copper do not form complex ions with tartrate, they separate and precipitate as copper-I oxide. Methylene blue, used as an indicator, is blue in basic media and colorless in the presence of sugar. Therefore, it becomes colorless at the end point of the titration and the medium becomes copper red (Sewwandi et al. 2020). The values obtained as a result of the analysis are expressed as g/100 mL.



2.4. Determination of Sucrose Amount

Sucrose content was obtained by multiplying the difference between the total carbohydrate and reducing sugar amounts obtained as a result of the analysis by 0.95.

2.5. Statistical Analysis

All analyses carried out in the study were performed in duplicate. In the statistical evaluation of the study, the normality distributions of the samples to be used were evaluated with the Shapiro–Wilk Test in terms of their suitability for the number of samples. One-way ANOVA test was used to compare all groups, and post hoc Tukey test was used for differences between pairwise comparisons. As a result of the analyses, quantitative variables are shown with mean and standard deviation (SD) values. The data obtained was analyzed using SPSS (Statistical Package for the Social Sciences) 26 package program. Statistically, $p < 0.05$ value indicates the level of significance.

3. Results and Discussion

The change in the amount of vitamin C in orange juices and nectars according to storage time, temperature and brands is summarized in Table 1. Statistically significant differences were obtained in orange juices and nectars in all brands and temperatures, according to storage times, and it was determined that as storage time increased, vitamin C content decreased ($p < 0.05$). No significant results were obtained in pairwise comparisons between storage temperatures and brands ($p > 0.05$). The change in vitamin C loss percentages of orange juices and nectars according to storage time, temperature and brands is shown in Figure 1.

In a study conducted in Poland, it was determined that the vitamin C content of orange juices, regardless of their type, decreased within 24 hours (Kujawińska et al. 2022). In similar studies, it was determined that the vitamin C content of orange juices decreased as the storage time increased (Kabasakalis et al. 2000; Klimczak et al. 2007). In a study examining the effect of storage temperature on vitamin C levels in citrus juices, it was found that vitamin C levels decreased as storage temperature increased. It has been determined that as vitamin C loss increases, hydroxydimethylfurfural (HMF) levels in fruit juices increase (Burdurlu et al. 2006). In this study, similar to the literature, it was determined that there were decreases in the vitamin C values of orange juice and nectars from the first day of storage. In addition to storage time and conditions, it is thought that vitamin C losses in orange juice and nectar may be due to the heat produced by the juicer device, including during production and packaging. In this study, vitamin C levels were lower at 20 °C compared to 4 °C, confirming the possible thermal instability of vitamin C. In addition, it can be stated that vitamin C losses occur even during the production phase through the oxidation of ascorbic acid by catalyzing trace amounts of iron from the cutting parts of the juicer. Orange juice is one of the sources of vitamin C containing strong antioxidant properties, and vitamin C concentration is an important indicator of orange juice quality. When the literature is reviewed, it is known that storage temperature and duration, oxygen contact, salt

concentration, pH, sugar and various enzymes cause significant losses in vitamin C in orange juice. In addition, citrus variety, fruit maturity, climate, juice processing and storage conditions can affect the amount of vitamin C, carbohydrate composition and other characteristic properties of the juice (Gomes et al. 2022; Kujawińska et al. 2022; Romeo et al. 2020).

Table 1. Change in vitamin C amounts (mg/100 mL) in orange juices and nectars according to storage time, temperature and brands

		A Brand Orange Nectar	p	A Brand 100% Orange Juice	p	B Brand Orange Nectar	p	B Brand 100% Orange Juice	p
4 °C	1st day	0.62 ± 0.03 ^a		0.53 ± 0.04 ^a		0.34 ± 0.05 ^a		0.72 ± 0.03 ^a	
	2nd day	0.19 ± 0.01 ^b	<0.001	0.34 ± 0.05 ^b	0.006	0.19 ± 0.01 ^b	0.013	0.53 ± 0.04 ^b	0.003
	3rd day	0.11 ± 0.02 ^b		0.19 ± 0.01 ^b		0.11 ± 0.02 ^c		0.39 ± 0.02 ^c	
20 °C	1st day	0.58 ± 0.04 ^a		0.43 ± 0.04 ^a		0.29 ± 0.01 ^a		0.58 ± 0.04 ^a	
	2nd day	0.19 ± 0.01 ^b	0.001	0.29 ± 0.01 ^b	0.007	0.15 ± 0.01 ^b	0.001	0.39 ± 0.02 ^b	0.001
	3rd day	0.07 ± 0.02 ^c		0.19 ± 0.01 ^c		0.1 ± 0.01 ^c		0.19 ± 0.01 ^c	

Results are expressed as the mean±SD of two replicates. a,b,c: Different letters in the same column indicate statistically significant difference between samples (p<0.05).

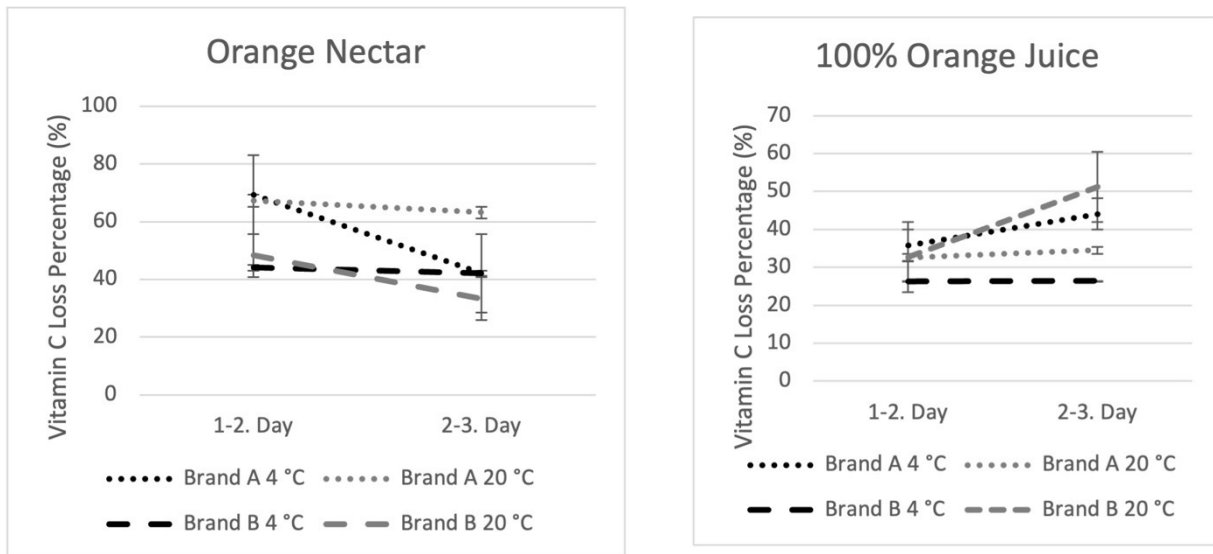


Figure 1. Change in vitamin C loss percentages of orange juices and nectars according to storage time, temperature and brands

The change in the amount of invert sugar in orange juices and nectars according to storage time, temperature and brands is summarized in Table 2. Although no statistically significant differences were observed in orange juices and nectars in all brands and temperatures according to storage times, it was determined that as storage time increased, decreases in invert sugar content were observed (p>0.05). In addition, in comparisons made according to storage temperature, it was determined that orange nectar and orange juices of brands A and B had a statistically significantly higher invert sugar content at 4 °C compared to 20 °C (p=0.008; p= 0.001); (p=0.018; p=0.039). No significant results were obtained in comparisons made according to brands (p>0.05).

It is stated in the literature that invert sugar contents may change with storage (Schnepel and Hoffmann 2013; El-Geddawy et al. 2024). According to the results of this study, it is thought that there may be microbial increases depending on the storage time and temperature, and that the invert sugar content may be converted into smaller particles by being used by these microbial components. It should be stated as one of the important results of this study that there is no need for very long periods of time in the storage period for microbial

degradation and as can be understood from the invert sugar values in this study, it has been observed that decreases may occur in a short period of time such as 3 days. While this result emphasizes the importance of storage time and temperature, it may indicate that such rapid degradation does not provide sufficient microbiological protection not only after the packaging is opened but even before the packaging is opened.

Table 2. Change in invert sugar amounts (g/100 mL) in orange juices and nectars according to storage time, temperature and brands

		A Brand Orange Nectar	p	A Brand 100% Orange Juice	p	B Brand Orange Nectar	p	B Brand 100% Orange Juice	p
4 °C	1st day	5.61 ± 1.13		4.95 ± 1.00		5.21 ± 1.05		3.91 ± 0.78	
	2nd day	3.94 ± 0.79	0.115	3.49 ± 0.70	0.209	4.07 ± 0.82	0.054	2.66 ± 0.54	0.137
	3rd day	2.94 ± 0.59		3.2 ± 0.65		1.86 ± 0.38		2.23 ± 0.45	
20 °C	1st day	2.73 ± 0.55		2.13 ± 0.43		2.07 ± 0.42		2.39 ± 0.48	
	2nd day	1.99 ± 0.40	0.169	2.04 ± 0.42	0.189	1.85 ± 0.37	0.253	1.94 ± 0.39	0.167
	3rd day	1.61 ± 0.33		1.28 ± 0.26		1.33 ± 0.27		1.37 ± 0.28	

Results are expressed as the mean±SD of two replicates. a,b,c: Different letters in the same column indicate statistically significant difference between samples (p<0.05).

The change in the total carbohydrate amount in orange juices and nectars according to storage time, temperature and brands is summarized in Table 3. Total carbohydrate content could not be determined as storage time increased and in all samples at 20 °C. The carbohydrates found in orange are basically glucose, fructose and sucrose (Cywińska-Antonik et al. 2023). During processing and storage, sucrose can turn into glucose and fructose under the influence of acidic conditions. The average total carbohydrate content in orange juice is approximately 8.9 g/100 mL (Zhang and Ritenour 2016). In addition, it has been stated that the total sugar composition, concentration and ratios in orange fruit can be affected by many factors such as the citrus varieties used, the maturity of the fruit, climatic conditions, juice processing and storage conditions (Cancalon 1994; Grierson 2006). For example, in one study, the effect of climatic conditions was determined that glucose, fructose and sucrose had a ratio of 1:1:2 (by weight) from December to April, but the ratios changed to 1:1:3 from May to June of the same season (Cancalon 1994). It was stated that similar results were obtained in another study (Lee and Coates 2006). In this study, the total sugar contents between commercial brands may have differed due to similar factors.

Table 3. Change in total carbohydrate amounts (g/100 mL) in orange juices and nectars according to storage time, temperature and brands

		A Brand Orange Nectar	A Brand 100% Orange Juice	B Brand Orange Nectar	B Brand 100% Orange Juice
4 °C	1st day	8.71 ± 1.76	9.02 ± 1.82	12.16 ± 2.45	7.48 ± 1.51
	2nd day	6.58 ± 1.33	7.42 ± 1.49	6.56 ± 1.32	-
	3rd day	-	-	-	-

Results are expressed as the mean±SD of two replicates. a,b,c: Different letters in the same column indicate statistically significant difference between samples (p<0.05). "-": No content detected.

The change in the amount of sucrose in orange juices and nectars according to storage time, temperature, and brands is summarized in Table 3. When the storage period was more than 24 hours, sucrose content could not be detected in all samples at 20 °C. In this study, it was determined that the sucrose content varied between 2.36-6.6 g/100 mL. In a study, it was determined that sucrose levels in the orange juices examined varied between 3.3 and 5.3 g/100 mL (average 4.4 g/100 mL) (Zhang and Ritenour 2016). It is thought that the reason for these differences in sucrose content in the literature may be due to differences in the orange variety used to obtain orange juice and nectar. Additionally, in this study, it was determined that carbohydrate contents decreased as storage time increased, and this could be attributed to possible microbial formations. HMF formations, which have been proven to be a cancer agent and have been found in fruit juices through literature

review, are an issue that should not be ignored. It is obvious that beneficial nutrients in fruit juices decrease and harmful nutrients increase due to the effect of microbial proliferation. For this reason, it may be important to be careful about consuming ready-made fruit juices, including orange juice and nectars.

Table 4. Change in sucrose amounts (g/100 mL) in orange juices and nectars according to storage time, temperature and brands

		A Brand Orange Nectar	A Brand 100% Orange Juice	B Brand Orange Nectar	B Brand 100% Orange Juice
4 °C	1st day	2.94 ± 0.59	3.88 ± 0.78	6.6 ± 1.34	3.4 ± 0.69
	2nd day	2.51 ± 0.5	3.74 ± 0.76	2.36 ± 0.48	-
	3rd day	-	-	-	-

Results are expressed as the mean±SD of two replicates. a,b,c: Different letters in the same column indicate statistically significant difference between samples ($p < 0.05$). "-": No content detected.

3.1. Limitations and Strengths

The strengths of this study lie in the authors' consideration of vitamin C and carbohydrate contents in orange juices and nectars, examining not only their analytical significance but also their nutritional role. There is very little research in the literature on the content of fruit juices and nectars, but it is thought that this research will make important contributions to nutrition and society. In addition, this study has an important practical dimension as it provides information to the consumer about which storage condition and duration will be best in terms of the bioavailability of vitamin C. A Short storage period can be shown as a study limitation. However, the experiment planning was made considering that the recommended consumption period for the consumer is a maximum of two days after opening the package.

4. Conclusions

Considering the results of this study, in terms of consuming orange juice and nectar, opening the packaging and consuming the product will be more beneficial in terms of benefiting from the nutrients it contains. In addition, when evaluated in terms of vitamin C content, orange juices and nectars are thought to be rich in vitamin C throughout our society, and these products are frequently included in children's lunchboxes. However, the results of this study also showed that many factors, from the processing stage to the consumption stage, can cause vitamin C loss when obtaining juice from fruits in these products. Turkey's Food and Nutrition Guide accepts 95 mg/day vitamin C intake for adult women and 110 mg/day vitamin C intake for adult men as the recommended adequate intake level, although it varies in different age groups and during pregnancy and lactation periods (TSB 2016). In children, the need for vitamin C varies depending on the developmental period: preschool, school age and adolescence. While the maximum vitamin C value was determined as 0.7 mg/100 mL in the measurements made, vitamin C values as high as 95-110 mg/day cannot be met with these products. For this reason, it is a misconception that fruit juices, especially orange juices and nectars, in our society are thought to be rich in vitamin C. Therefore, it is very important to inform and raise awareness of the society in this regard by expert dietitians. Foods such as citrus fruits, strawberries, kiwi, tomatoes, cabbage and green leafy vegetables are rich in vitamin C and are additionally a source of fiber. In fruit juice production, in addition to vitamin C, one of the important nutrients, pulp is also lost. For this reason, consuming foods with their pulp is important for health and to benefit from vitamins. In addition, this study shows that orange juices and nectars have very high sugar content in their label value. Considering that these products are mostly consumed by children in their developmental age, this much sugar intake will be quite harmful. Market fruit juices may be economically affordable, ready-made and easily accessible, but it should not be forgotten that many factors such as storage temperature and storage time can change the nutritional contents in fruit juices. It is thought that this study will be a useful resource in terms of raising awareness in our society regarding the consumption of ready-made fruit juices, especially orange juice and nectars, in their nutritional preferences.

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References

- Angelino D, Godos J, Ghelfi F, Tieri M, Titta L, Lafranconi A, Marventano S, Alonzo E, Gambera A, Sciacca S (2019). Fruit and vegetable consumption and health outcomes: An umbrella review of observational studies. *International Journal of Food Sciences and Nutrition* 70(6), 652-667. <https://doi.org/10.1080/09637486.2019.1571021>
- Arias A, Feijoo G, Moreira MT (2022). Exploring the potential of antioxidants from fruits and vegetables and strategies for their recovery. *Innovative Food Science and Emerging Technologies* 102974. <https://doi.org/10.1016/j.ifset.2022.102974>
- Besler H, Rakicioğlu N, Ayaz A, Büyüktuncer Demirel Z, Gökmen Özel H, Samur F, Yıldız E, Bilgiç P, Dikmen D, Göktaş Z (2015). Türkiye'ye Özgü Besin ve Beslenme Rehberi. <https://tekinakpolat.com/wp-content/uploads/2017/12/turkiye-beslenme-rehberi.pdf>.
- Brizzolara S, Manganaris GA, Fotopoulos V, Watkins CB, Tonutti P (2020). Primary metabolism in fresh fruits during storage. *Frontiers in Plant Science* 11, 80. <https://doi.org/10.3389/fpls.2020.00080>.
- Burdurlu HS, Koca N, Karadeniz F (2006). Degradation of vitamin C in citrus juice concentrates during storage. *Journal of Food Engineering* 74(2), 211-216. <https://doi.org/10.1016/j.jfoodeng.2005.03.026>
- Canclon PF (1994). Changes in the saccharide composition of citrus juice and anatomical fractions during fruit maturation. *Proceedings of the Florida State Horticultural Society* 107, 253–256.
- Carr AC, Lykkesfeldt J (2021). Discrepancies in global vitamin C recommendations: A review of RDA criteria and underlying health perspectives. *Critical Reviews in Food Science and Nutrition* 61(5), 742-755. <https://doi.org/10.1080/10408398.2020.1744513>
- Carr AC, Rowe S (2020). Factors affecting vitamin C status and prevalence of deficiency: A global health perspective. *Nutrients* 12(7), 1963. <https://doi.org/10.3390/nu12071963>
- Cywińska-Antonik M, Chen Z, Groele B, Marszałek K. (2023). Application of emerging techniques in reduction of the sugar content of fruit juice: current challenges and future perspectives. *Foods* 12(6), 1181. <https://doi.org/10.3390/foods12061181>
- Demir F, Kipçak AS, Dere Özdemir O, Moroydor Derun E (2020). Determination of essential and non-essential element concentrations and health risk assessment of some commercial fruit juices in Turkey. *Journal of Food Science and Technology* 57, 4432-4442. <https://doi.org/10.1007/s13197-020-04480-9>
- Dioha I, Olugbemi O, Onuegbu T, Shahru Z (2011). Determination of ascorbic acid content of some tropical fruits by iodometric titration. *International Journal of Biological and Chemical Sciences* 5(5), 2180-2184. <https://doi.org/10.4314/ijbcs.v5i5.37>
- El-Geddawy MA, Hamdy RM, Moftah RF (2024). Monitoring Invertase Activity and its Impact on Sugar Beet Roots (*Beta vulgaris* L.) During Extended Storage Under Controlled Conditions. *Assiut Journal of Agricultural Sciences* 55(1), 61-73. <https://doi.org/10.21608/ajas.2024.254659.1314>
- Gomes A, Costa ALR, Rodrigues PD, de Castro RJS, Silva EK (2022). Sonoprocessing of freshly squeezed orange juice: Ascorbic acid content, pectin methylesterase activity, rheological properties and cloud stability. *Food Control* 131, 108391. <https://doi.org/10.1016/j.foodcont.2021.108391>

- Grierson W. (2006). Maturity and grade standards, In: W.F. Wardowski, W.M. Miller, D.J. Hall, and W. Grierson (eds.). *Fresh Citrus Fruits*, Second Ed. Florida Science Source, Inc., Longboat Key, FL, 23-48.
- Jaglan P, Buttar HS, Al-bawareed O, Chibisov S. (2022). Potential health benefits of selected fruits: Apples, blueberries, grapes, guavas, mangos, pomegranates, and tomatoes. In *Functional Foods and Nutraceuticals in Metabolic and Non-Communicable Diseases* pp. 359-370. Elsevier. <https://doi.org/10.1016/B978-0-12-819815-5.00026-4>
- Kabasakalis V, Siopidou D, Moshatou E. (2000). Ascorbic acid content of commercial fruit juices and its rate of loss upon storage. *Food Chemistry* 70(3), 325-328. [https://doi.org/10.1016/S0308-8146\(00\)00093-5](https://doi.org/10.1016/S0308-8146(00)00093-5)
- Kaddumukasa PP, Imathiu SM, Mathara JM, Nakavuma, JL (2017). Influence of physicochemical parameters on storage stability: Microbiological quality of fresh unpasteurized fruit juices. *Food Science and Nutrition* 5(6), 1098-1105. <https://doi.org/10.1002/fsn3.500>
- Klimczak I, Małecka M, Szlachta M, Gliszczyńska-Świgło A. (2007). Effect of storage on the content of polyphenols, vitamin C and the antioxidant activity of orange juices. *Journal of Food Composition and Analysis* 20(3-4), 313-322. <https://doi.org/10.1016/j.jfca.2006.02.012>
- Kujawińska M, Kawulok I, Szczyrba A, Grot M, Bielaszka A, Nieć-Leśniak J, Grajek M (2022). Vitamin C content in orange juices obtained by different methods. *Journal of Education, Health and Sport* 12(6), 253-267. <https://doi.org/10.12775/JEHS.2022.12.06.025>
- Lee HS, GA Coates. (2000). Quantitative study of free sugars and myo-inositol in citrus juices by HPLC and a literature compilation. *Journal of Liquid Chromatography & Related Technologies* 23, 2123-2141. <https://doi.org/10.1081/JLC-100100476>
- Li J, Zhang C, Liu H, Liu J, Jiao Z (2020). Profiles of sugar and organic acid of fruit juices: A comparative study and implication for authentication. *Journal of Food Quality* 2020, 1-11. <https://doi.org/10.1155/2020/7236534>
- Nighojkar A, Patidar MK, Nighojkar S (2019). Pectinases: production and applications for fruit juice beverages. In *Processing and Sustainability of Beverages* pp. 235-273. Elsevier. <https://doi.org/10.1016/B978-0-12-815259-1.00008-2>
- Plevin D, Galletly C.(2020). The neuropsychiatric effects of vitamin C deficiency: a systematic review. *BMC psychiatry* 20(1): 1-9. <https://doi.org/10.1186/s12888-020-02730-w>
- Polydera A, Stoforos N, Taoukis P. (2003). Comparative shelf life study and vitamin C loss kinetics in pasteurised and high pressure processed reconstituted orange juice. *Journal of Food Engineering* 60(1), 21-29. [https://doi.org/10.1016/S0260-8774\(03\)00006-2](https://doi.org/10.1016/S0260-8774(03)00006-2)
- Romeo R, Bruno AD, Piscopo A, Medina E, Ramírez E, Brenes M, Poiana M (2020). Effects of phenolic enrichment on vitamin C and antioxidant activity of commercial orange juice. *Brazilian Journal of Food Technology* 23. <https://doi.org/10.1590/1981-6723.13019>
- Ruxton CH, Myers M (2021). Fruit juices: Are they helpful or harmful? An evidence review. *Nutrients* 13(6), 1815. <https://doi.org/10.3390/nu13061815>
- Sarac I, Butnariu M (2020). Food pyramid-the principles of a balanced diet. *International Journal of Nutrition* 5(2), 24. <https://10.14302/issn.2379-7835.ijn-20-3199>
- Schnepel K, Hoffmann C (2013). Calculation of invert sugar content based on the glucose content of sugar beet. *Sugar Industry* 138(7), 463-470.
- Sewwandi S, Arampath P, Silva A, Jayatissa R (2020). Determination and comparative study of sugars and synthetic colorants in commercial branded fruit juice products. *Journal of Food Quality* 2020, 1-11. <https://doi.org/10.1155/2020/7406506>

- Sun C, Liu Y, Zhan L, Rayat GR, Xiao J, Jiang H, Li X, Chen K (2021). Anti-diabetic effects of natural antioxidants from fruits. *Trends in Food Science and Technology* 117, 3-14. <https://doi.org/10.1016/j.tifs.2020.07.024>
- Tezcan F, Gültekin-Özgüven M, Diken T, Özçelik B, Erım FB (2009). Antioxidant activity and total phenolic, organic acid and sugar content in commercial pomegranate juices. *Food Chemistry* 115(3), 873-877. <https://doi.org/10.1016/j.foodchem.2008.12.103>
- TGK (2014). Türk Gıda Kodeksi Meyve Suyu ve Benzeri Ürünler Tebliği. Resmi Gazete, 29080(1). <https://www.resmigazete.gov.tr/eskiler/2014/08/20140806-17.htm>.
- TSB (2016). Türkiye beslenme rehberi TÜBER 2015. TC Sağlık Bakanlığı Yayın, 1031, 172-217. https://okulsagligi.meb.gov.tr/meb_iys_dosyalar/2017_01/27102535_tyrkiye_beslenme_rehberi.pdf
- Tüfekci HB, Fenercioğlu H (2010). Türkiye’de üretilen bazı ticari meyve sularının kimyasal özellikler açısından gıda mevzuatına uygunluğu. *Akademik Gıda* 8(2), 11-17.
- Wallace TC, Bailey RL, Blumberg JB, Burton-Freeman B, Chen CO, Crowe-White KM, Drewnowski A, Hooshmand S, Johnson E, Lewis R (2020). Fruits, vegetables, and health: A comprehensive narrative, umbrella review of the science and recommendations for enhanced public policy to improve intake. *Critical Reviews in Food Science and Nutrition* 60(13), 2174-2211. <https://doi.org/10.1080/10408398.2019.1632258>
- WHO (2005). Fruit and vegetables for health: report of the Joint FAO. <https://openknowledge.fao.org/home>
- Zhang FF, Barr SI, McNulty H, Li D, Blumberg JB (2020). Health effects of vitamin and mineral supplements. *Bmj* 369. <https://doi.org/10.1136/bmj.m2511>
- Zhang J, Ritenour MA (2016). Sugar composition analysis of commercial citrus juice products. *Proceedings of the Florida State Horticultural Society* 129, 178-180



Occurrence of Virus in Some Watermelon Growing Areas of Kwara State, Nigeria

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HIGHLIGHTS

- Viruses associated with watermelon.
- Pathogenic viruses in Ilorin.
- Mixed infections observed.
- CMV is most prevalent.

Abstract

A survey was carried out in September and October 2019 in 8 locations of Kwara State noted for watermelon cultivation to determine the incidence, severity, and distribution of viruses infecting watermelons on the field. Thirty leaf samples showing symptoms like mosaic, chlorosis, stunting, leaf deformation, and necrosis were collected randomly per each farm and analyzed using antigen-coated plate enzyme-linked immunosorbent assay (ACP-ELISA). Seven viruses were detected across different locations: Cucumber Mosaic Virus (CMV), Watermelon Mosaic Virus (WMV), Cowpea Mottle Virus (CMoV), Cowpea Mild Mosaic Virus (CPMMV), Southern Bean Mosaic Virus (SBMV), Zucchini Yellow Mosaic Virus (ZYMV), and Papaya Ringspot Virus (PRSV). CMV had the highest incidence (100%), followed by CMoV (50%). However, ZYMV and PRSV recorded the lowest incidence with 12.5% and 25%, respectively. The result also revealed that the location with the highest incidence was Agric AJ1 (80%), with the lowest coming from Onireke (35%). The average severity score across the locations was 2.9, with Agric AJ1 and Unilorin having the highest score (4), while Olomu, Eyenkorin, and Lafiaji 1 had the lowest (2). Findings from this research underscore the need to educate farmers on the importance of using resistant cultivars as well as proper cultural practices.

Keywords: Incidence; severity; survey; virus; watermelon

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1. Introduction

Citrullus lanatus (Watermelon) is a member of the family Cucurbitaceae. It is one of the most important fruit crops cultivated across the world for its vegetative and fruit parts, which are highly nutritious (Okunola et al. 2011). Watermelon provides an easy source of vitamins, potassium, iron, and manganese, especially in developing nations of the world where it isn't easy to meet daily nutritional requirements (Dantata 2014). It also contains lycopene, which serves as an antioxidant that neutralizes free radicals. Watermelon rind (outer layer) contains citrulline, which is a non-protein amino acid that helps in blood circulation and heart rate stabilization (Reetu and Tomar 2018). In Sub-Saharan Africa, watermelon is vital to the socioeconomic status of farmers as it serves as a source of income and employment (Enujeke 2013).

Notwithstanding the nutritional and economic benefits of the crop, production in Nigeria has been low as a result of poor adoption of technology, declining soil fertility (Ibrahim et al. 2014), and infection by disease-causing organisms (pathogens). On their part, pathogens cause about 14.1% production loss annually on a global scale by disrupting the function of the crop, resulting in a significant reduction in yield (Agrios 2005).

Plant pathogenic virus alone causes an estimated US\$60 billion yield loss annually worldwide. In watermelons, the symptoms of the virus include mosaic, mottling, necrosis, lesions, and distortion of leaves and other plant parts (Roossinck 2011). This poses a threat to food security. Some of the viruses identified to be causing disease in watermelon include Watermelon mosaic virus (WMV), Zucchini yellow mosaic virus (ZYMV), Alfalfa mosaic virus (AMV), Bean pod mottle virus (BPMV), Papaya ringspot virus-W (PRSV-W), Cucumber mosaic virus (CMV), Squash mosaic virus (SqMV), Melon necrotic spot virus (MNSV), Cucurbit yellow stunting disorder virus (CYSDV), Cucurbit aphid born yellows virus (CABYV), Squash vein yellowing virus (SqVYV), Squash leaf curl virus (SLCuV) and Tobacco ringspot virus (TRSV) (Ali et al. 2012). Nigeria has a population of about 200 million people (the largest in Africa), hence, there is a need to identify those factors that serve as impediments to sustainable food security and satisfy the dietary needs of the population. Unfortunately, watermelon production in Nigeria is about 175.34 metric tons per year, which is hugely less than those in other African regions (Egypt – 1.8 metric tons) as well as those in West Africa (Mali – 551,648, Senegal – 259,225) Sub-region (World Atlas 2019). Nonetheless, there is inadequate information about viruses and other pathogens infecting watermelons in Nigeria.

Therefore, this research aimed to study the viruses that infect watermelon and serve as constraints to the optimization of its production in Kwara state, Nigeria. Kwara State was selected due to its location in the North Central region of Nigeria, and its proximity to Northern and Southern states, necessitating a baseline knowledge of the viruses in the area to enhance production in the state and other Southern states where they are consumed extensively.

2. Materials and Methods

2.1. Area of Study

The experiment was carried out in Kwara State, Nigeria. Kwara covers an estimated area of 32,500km while about 75.3% can be cultivated. The two main climates are the wet and dry seasons. Rainfall spans between 1000 and 1500mm yearly, while the mean temperature ranges between 30 °C and 35 °C. Kwara State falls within the Woodland and tall grass agroecological zone in Nigeria. The state is further subdivided by the Kwara State Agricultural Development Program (ADP) into four ecological zones based on the ecology of the area, cultural beliefs, and ease of administration. The zones are Kaima/Baruteen, which belongs to Zone A, Patigi/Edu, which belongs to Zone B, Moro, Ilorin/Asa, which belongs to Zone C. In contrast, Oke-Ero, Ifelodun, Ekiti, Irepodun, Ifelodun, Isin, and Offa all belong to Zone D (KWADP 2006).

2.2. Sampling Technique

Field sampling was carried out in three agroecological zones of the state: Zone B, C, and D. These zones are the major watermelon-producing areas of Kwara state. The sampling was carried out in September and October 2019, during the cropping season. The criteria used for the selection of the survey area were

availability, accessibility of the farm, and willingness of the farmer to allow sample collection on their farm. The average farm size in each location is not less than 2 acres. All the farms visited intercrop watermelon with other crops: Ajase-Ipo (cucumber, tomato, pepper, cabbage, and maize), Eyenkorin (Palm tree and maize), Unilorin (cucumber), and Lafiagi (tomato). In each location, the Global Positioning System (GPS) coordinate was recorded (Figure 1).

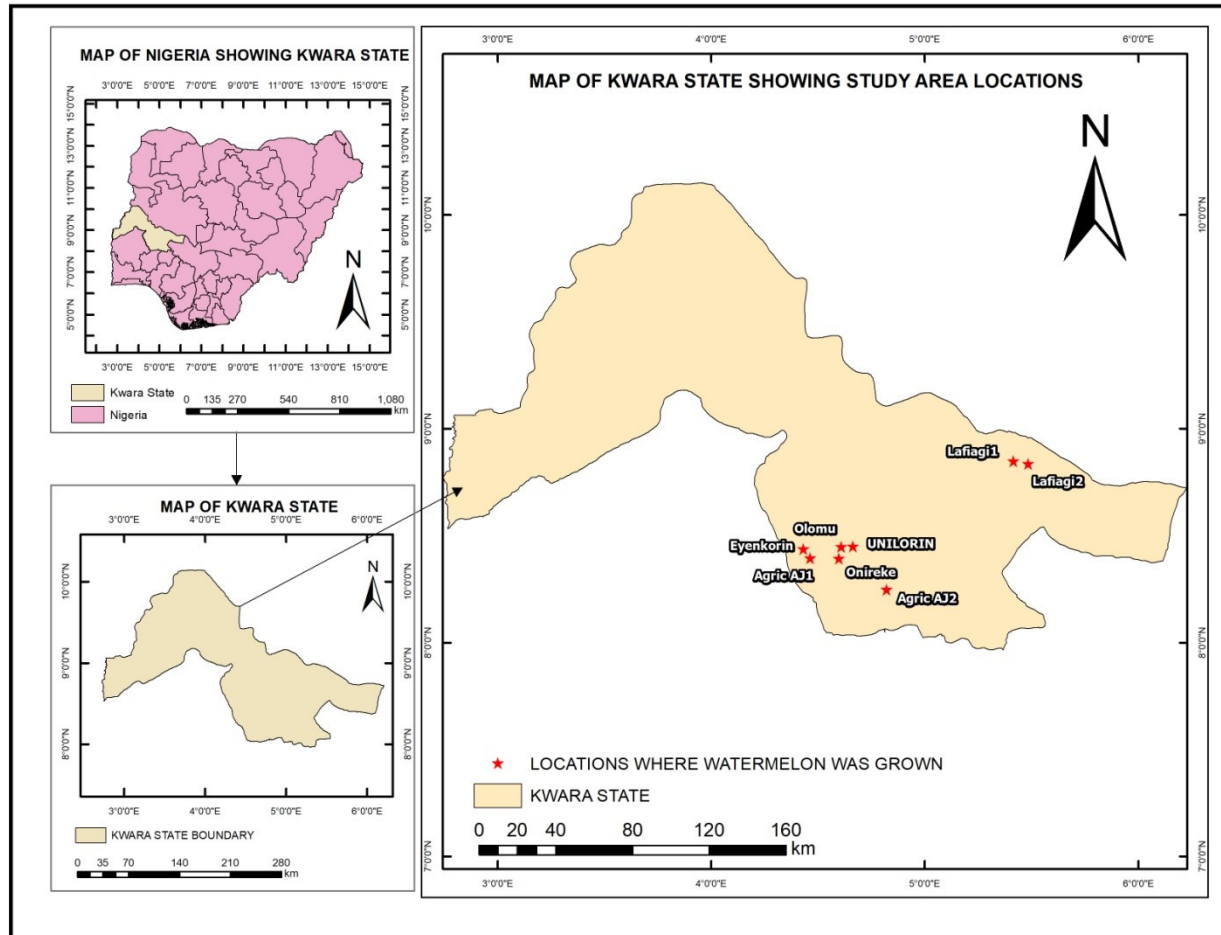


Figure 1. A map showing the locations where the watermelon survey was carried out in Kwara State, Nige

2.3. Virus sampling

Thirty plants per farm were sampled randomly by moving through the field in a “W” shape pattern with five plants each at the same distance from one another (Arogundade et al. 2016). This represents 6 replicates per each area. Young trifoliate leaves showing symptoms of virus infection such as mosaic, chlorosis, stunting, necrosis, and leaf deformation were taken per field (Aliyu 2014). Each of the sampled leaves was kept inside a vial with a silica gel and cotton wool before virus identification in the laboratory. Part of the samples was used for ELISA in other to identify viruses present while the remaining samples were kept for molecular study of the most prominent virus in the areas sampled (Aliyu et al. 2013).

2.4. Estimation of virus incidence and severity rating

The percentage incidence of the virus in each location is determined by using the following formula;

$$\text{Percentage incidence} = \frac{\text{Number of infected plants}}{\text{Number of plants sampled (30)}} \times 100, \quad (1)$$

The severity of infection was estimated based on the percentage number of leaves showing symptoms of the virus out of 30 plants observed on a farm. The samples were scored on a scale of 1-5 using a modified method by Eni et al. (2009);

1 = 1 to 20% (exceedingly mild), 2 = 21 to 40% (mild), 3 = 41 to 60% (severe), 4 = 61 to 80% (extremely severe). 5 = 81 to 100% (nearly dead)

The mean of the scores was used to ascertain the severity of each location. The Kruskal-Wallis test was used to determine the differences in seriousness across the area. In contrast, the Chi-square test was used to examine the relationship between the severity of each location. The software, Statistical Package for Social Sciences (SPSS) was used for the analysis.

2.5. Identification of virus using Enzyme-linked immunosorbent assay (ELISA)

The Antigen-coated plate (ACP) – ELISA method was used in detecting the viruses associated with watermelon: Watermelon mosaic virus (WMV), Cucumber mosaic virus (CMV), Papaya ringspot virus-W (PRSV-W), Zucchini yellow mosaic virus (ZYMV), Cowpea Mottle Virus (CMoV), Cowpea Mild Mosaic Virus (CPMMV), Southern Bean Mosaic Virus (SBMV), Zucchini Yellow Mosaic Virus (ZYMV), and Papaya Ringspot Virus (PRSV). The homologous rabbit polyclonal antisera were used to test the leaves.

Coating ELISA plates with antibodies: CMV polyclonal antiserum was diluted to 1:10,000 in carbonate coating buffer and dispensed to 100 μ l into an individual well inside ELISA plate. Then, the ELISA plate was wrapped and transferred into a humid chamber for one hour at 37°C. It was washed with three changes of Phosphate-Buffered Saline-Tween (PBS-T) and allowed 3 minutes at each wash.

2.6. Preparation of leaf extract and virus detection

Symptomatic leaf sample of 0.1 g was ground inside a buffer of carbonate coating (0.015 M Na_2CO_3 and 0.0349 M NaHCO_3) of 1 ml. Then, 100 μ L was dispensed into each well of the antibody-coated ELISA plates and incubated in a humid chamber for one hour at 37 °C. The plate was washed with three changes of PBS-T (comprising 0.05% (v/v) and Tween-20), allowing 3 min per wash. The Polyclonal antisera were cross-adsorbed using uninfected watermelon extract from the leaf (1:20 w/v) and diluted in a buffer that is conjugated (PBS-T had 0.02% (w/v) egg albumin and 0.2% (w/v) PVP-40,000). The plates were kept in a humid chamber and incubated at 37 °C for one hour. Then, plates were washed with three changes of PBS-T, allowing 3 min for each wash.

So, rabbit antibody of alkaline phosphatase was employed as a secondary antibody at the rate of 100 μ l and 1:15000 (v/v) dilutions. It was kept for one hour at 37 °C. PBS was used three times while 100 μ l p-nitrophenyl phosphate (0.001 g/ml) in 10% (v/v) diethanolamine buffer (pH 9.8) was added to each well of the ELISA plate and incubated for one hour. The healthy watermelon plant was used as a negative control. The measurement of absorbance was done after one hour at 405 nm in a BIO-RAD multiscan ELISA reader. Each sample was counted as positive only when the ELISA reading was twice that of a healthy watermelon (control). In case of a positive reaction, the colorless substrate will change to a light yellow, then a deep yellow colour.

3. Results

The serological analysis showed the viruses associated with watermelon and the locations where they were detected in Kwara State (Table 1, and Figure 2). Seven viruses were detected across all the areas sampled which are: Cucumber mosaic virus (CMV), Watermelon Mosaic Virus (WMV), Cowpea Mottle Virus (CMoV), Cowpea Mild Mosaic Virus (CPMMV), Southern Bean Mosaic Virus (SBMV), Zucchini Yellow Mosaic Virus (ZYMV), Papaya Ringspot Virus (PRV). Results also revealed that Cucumber Mosaic Virus had the highest prevalence which was detected in all locations (100%). Meanwhile, Zucchini Yellow Mosaic Virus (ZYMV) was only detected in Unilorin but absent in other locations (12.5%).

Table 1. The distribution of viruses detected on watermelon in Kwara state, Nigeria

S/n	Area	Location	Cucumber mosaic virus	Watermelon Mosaic Virus (WMV)	Cowpea Mottle Virus (CMoV)	Cowpea Mild Mosaic Virus (CPMMV)	Southern Bean Mosaic Virus (SBMV)	Zucchini Yellow Mosaic Virus (ZYMV)	Papaya Ringspot Virus (PRSV)
1	Olomu	8°26'16"N 4°26'1"E	+	+	+	-	+	-	+
2	Eyenkorin	8°23'38"N 4°27'55"E	+	+	+	-	+	-	+
3	Agric AJ1	8°23'33"N 4°35'55"E	+	+	-	+	-	-	-
4	Agric AJ2	8°14'47"N 4°49'19"E	+	-	+	+	-	-	-
5	Unilorin	8°26'57"N 4°39'52"E	+	-	+	-	+	+	-
6	Onireke	8°26'52"N 4°36'36"E	+	-	-	-	-	-	-
7	Lafiaji 1	8°50'56"N 5°24'58"E	+	-	-	-	-	-	-
8	Lafiaji 2	8°51'10"N 5°24'59"E	+	-	-	-	-	-	-

Note: Positive = +, Negative = -

Agric AJ= Agricultural settlement Ajase-ipo

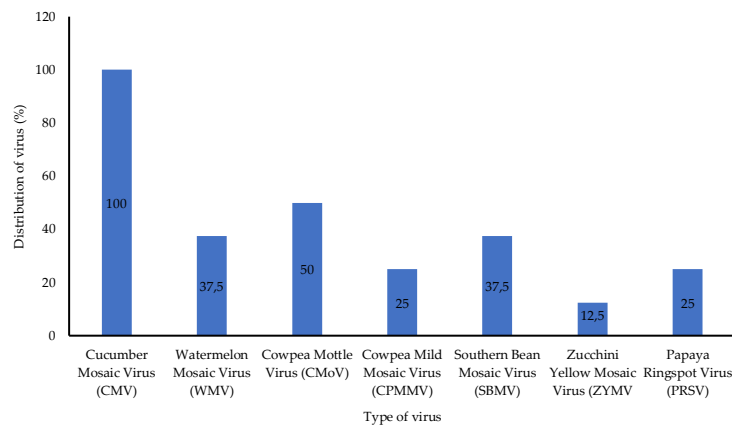

Figure 2. The percentage distribution of different viruses infecting different watermelon-in Kwara State, Nigeria

Table 2 showed that locations visited have a severity score that ranges from mild to very severe (2 to 4). The highest severity score (4) was detected in Agric AJ2 and Unilorin, while the least severe (2) locations were Olomu, Eyenkorin, and Lafiaji_1. The remaining locations were rated 'severe' (3). The average score across different locations was 2.9.

Table 2. Severity score from watermelon growing areas of Kwara State

S/n	Area	Severity score
1	Olomu	2
2	Eyenkorin	2
3	Agric AJ1	3
4	Agric AJ2	4
5	Unilorin	4
6	Onireke	3
7	Lafiaji1	2
8	Lafiaji2	3

The result of the Kruskal-Wallis test to determine the severity rank differences in the severity of locations sampled is shown in Table 3. Agric AJ2 and Unilorin had the highest rank while Olomu, Eyenkorin and Lafiaji 1 had the lowest. Result also showed there was no significant difference in the severity scores across the group.

Figure 3 showed that the Percentage incidence was highest in Agric AJ1 (80%), which Agric AJ2 followed with a 78% percentage. Olomu was next with an incidence of 70%, while Eyenkorin followed with a percentage incidence of 63%. Unilorin followed this with a 63% incidence rate. Lafiaji 2 was next with 52% incidence while Lafiaji 1 had an incidence of 48%. Onireke had the lowest percentage incidence of 35%.

Table 3. Kruskal-Wallis test to rank the severity score in each area and determine their differences

Mean rank of severity score		Test statistics	
Olomu	2	Chi-square	7
Eyenkorin	2	df	7
Agric AJ1	5	Asymptotic Significance	0.42
Agric AJ2	7.5		
Unilorin	7.5		
Onireke	5		
Lafiaji1	2		
Lafiaji2	5		

Figure 4 shows that Zone C had the highest percentage incidence of 79%. This was followed by Zone D with a percentage incidence of 66.5%. Zone B had the least incidence, with an average percentage of 50%.

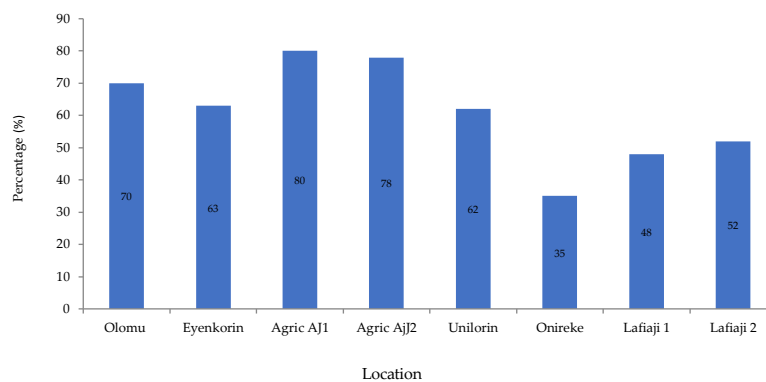


Figure 3. The percentage incidence of virus on watermelon from different locations in Kwara State

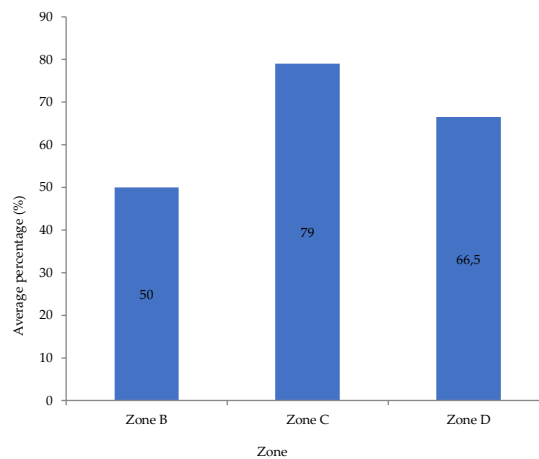


Figure 4. The percentage incidence of virus in three watermelon-producing zones of Kwara state, Nigeria

4. Discussion

This investigation revealed that infection of watermelon on the field is mixed rather than a single infection (Table 1). For instance, three or more infections were observed in Olomu, Eyenkorin, Unilorin, Agric AJ1, and Agric AJ2. Multiple-virus infections are a common phenomenon in the field that could further increase plant susceptibility and symptom severity. This could have been the reason samples taken from the surveyed area have severe symptom that ranges from mosaic, yellowing, mottling, shoestring, etc which are diagnostic symptoms of different viruses (Ziebell et al. 2011). Adediji et al. (2020), reported similar results when they observed co-infections of a potyvirus and several other viruses on tomato and pepper hosts. This also agrees with the observation of Raimundo et al. (2015), when they reported mixed infections of viruses in watermelons on the field in Tocantins, Brazil.

CMV had 100% distribution in all the locations which makes it the most prevalent virus across all the area surveyed (Figure 2). This was followed by CMeV with 50% of the locations, WMV and SBMV with 37.5%, CPMMV, and PRV with 25%, and ZYMV with 12.5%. The high distribution of CMV implies that the rate of transmitting the virus is high in those areas. Since there is no evidence of vertical transmission of CMV in watermelon, one major factor to be considered in this case is the possibility that vectors of the virus may be prevalent in those areas. Although the vector population was not sampled, nevertheless, there is a high probability of increased incidence of their vectors. Inadequate cultural practices could be another reason for the prevalence of CMV in those areas. Crops with similar host ranges were noticeably cultivated close to watermelon, which could have served as an alternate host to the virus. For instance, cucumber, tomato, pepper, cabbage, and maize were planted around the area where the watermelon was planted. These crops are natural hosts of CMV (Pratap et al. 2012), and planting them close to each other could have increased their chances of transmission from one plant to another. CMV has been reported to have the most extensive range among plant viruses (Roossinck 2001), and is particularly pathogenic to cucurbits in both temperate and tropical regions (Ali et al. 2012; Milojevic et al. 2012). This could also be another reason incidence was highest in Zone C which had 79% infection (Figure 4). Notably, intercropping watermelon with other cucurbits was most common in Agric AJ1, Agric AJ2, Olomu, and Eyenkorin which are in the same zone and were also the areas with the highest incidence of the disease (Figure 3). This study also corroborates the report of Arogundade et al (2015), that the proximity of pepper to other host plants of CMV contributed greatly to a high incidence of the virus. Mechanical transmission could also be another reason for the high rate of CMV infection. Unlike many viruses, CMV is fairly stable and can be sap-transmitted by farmers when infected tools and clothing are used during farm operations like weeding, transplanting, and thinning (Akhtar et al. 2008). Notwithstanding, the severity score was not significantly different across the group which suggests that the differences in severity across locations may be due to random variation or possibly the plant genotype planted in those areas. A previous study by Kimani et al. (2024), suggested that plant genotype has effect on the transmission and epidemiology of virus diseases. This study necessitates the need to educate farmers more on disease management practices.

5. Conclusions

This study revealed the susceptibility of watermelon to different viruses as well as the wide spread of the viruses in different areas of the state. The occurrence of symptoms in all the locations indicates the susceptibility of the varieties cultivated in the study area. Though different viruses were detected in this study, however, there are more other viruses that were not tested. Therefore, more tests should be conducted to determine viruses and other pathogens that limit watermelon production. In order to attain sustainable food production, there is a need to also up-scale extension services to educate farmers on proper cultural practices in plant disease management.

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References

- Adediji OA, Temitope IF, Atiri G (2020). Occurrence and molecular characterization of pepper veinal mottle virus from solanaceous crops. *International Journal of Vegetable Science* 27(2), 187-197. <https://doi.org/10.1080/19315260.2020.1756552>
- Agrios GN (2005). Plant pathology, 5th edn. Academic Press, USA. 922 pp.
- Akhtar KP, Ryu KH, Saleem MY, Asghar M, Jamil FF, Haq MA (2008). Occurrence of *Cucumber Mosaic Virus* sub group IA in tomato in Pakistan. *Journal Plant Disease Protection* 115 (1), 2-3. <https://doi.org/10.1007/bf03356231>
- Ali A, Mohammad O, Khattab A (2012). Distribution of viruses infecting cucurbit crops and isolation of potential new virus-like sequences from weeds in Oklahoma. *Plant Disease* 96 (2), 243-248. <https://doi.org/10.1094/pdis-05-11-0419>
- Aliyu T (2014). The incidence, severity, and occurrence of four viruses infecting pepper (*Capsicum* spp.) in the southern guinea savannah agro-ecological zone of Nigeria. *Agriculturae Conspectus Scientificus* 79 (4), 233-237.
- Aliyu T, Balogun O, Uddin R (2013). Cowpea virus disease occurrence: Implication for food security and sustainable development in Kwara State-Nigeria. *Albanian Journal of Agricultural Science* 12(4): 633-639.
- Arogundade O, Oresanya A, Matthew JO, Kareem KT, Onyeausi H (2019). Natural occurrence of cucumber mosaic virus in Ogeira (*Eleutheranthera ruderalis*) in Nigeria. *Archives of Phytopathology and Plant Protection* 52 (1-2), 108-113.
- Dantata IJ (2014). Assessing watermelon cultivars under different planting distances in Bauchi North, Nigeria. *Asian Journal of Applied Sciences* 2(3), 381-386.
- Eni AO, Hughes J, Robert A, Rey C (2009). Survey of the incidence and distribution of viruses infecting yam (*Dioscorea* spp.) in Ghana and Togo. *Annals of Applied Biology* 156(2), 243-251.
- Enujeke EC (2013). An assessment of some growth and yield indices of six varieties of watermelon (*Citrulus Lanatus* Thumb) in Asaba area of Delta State, Nigeria. *International Research Journal Agricultural Soil Science* 3(11), 376-382.
- Ibrahim UW, Umar ASS, Ahmed B (2014). Technical efficiency and its determinants in watermelon production in Borno State, Nigeria. *Journal of Economics and Sustainable Development* 5(27): 205-211.
- Kimani EN, Micheni CM, Muriki LG, Kiarie SM, Miano DW, Macharia I, ... Wangai, A (2024). Influence of genotypes and crop growth stage at time of infection on seed transmission of maize chlorotic mottle virus. *Archives of Phytopathology and Plant Protection* 57(2), 95-111. <https://doi.org/10.1080/0323-5408.2024.2331040>
- Kwara State Agricultural Development Project, KWADP (2006). Agronomic Survey Report.
- Milojevic K, Stankovic I, Vucurovic. Ristic D, Nikolic D, Bulajic A, Krstic B (2012). First Report of Cucumber mosaic virus Infecting Watermelon in Serbia. *Plant Disease* 96(11), 1706-1706. <https://doi.org/10.1094/pdis-07-12-0631-pdn>

- Okunlola A, Adejoro S, Fakanlu G (2011). Evaluation of some manure types for the growth and yield of watermelon in Southwestern Nigeria. *Researcher* 38(3), 61-66.
- Pratap D, Kumar S, Raj SK (2008). First molecular identification of a *Cucumber mosaic virus* isolate causing shoestring symptoms on tomato in India. *Australasian Plant Disease Notes* 3, 57–58. <https://doi.org/10.1071/DN08023>
- Raimundo WSA, Adelmo R, Augustus CFP, Magnolia ML, Mirtes FL, Renato OR, Tatsuya N (2015). Serological identification of virus in watermelon production fields in the Tocantins state. *Brazilian Archives of Biological Technology* 58(2),192-197. <http://dx.doi.org/10.1590/S1516-8913201400219>
- Reetu D, Tomar M (2018). Watermelon: A valuable horticultural crop with nutritional benefits. *Popular Kheti* 5(2), 5-9.
- Roossinck MJ (2011). The good viruses: viral mutualistic symbioses. *Nature Reviews Microbiology* 9(2), 99-108. <https://doi.org/10.1038/nrmicro2491>
- World Atlas (2020). World's leading watermelon producing countries. <https://www.atlasbig.com/en-gb/countries-by-watermelon-production> (Access date: 29.03.2020)
- Ziebell H, Murphy AM, Groen SC, Tungadi T, Westwood JH, Lewsey MG, Moulin M, Kleczkowski A, Smith AG, Stevens M, Powell G, Carr JP (2011). *Cucumber mosaic virus* and its 2b RNA silencing suppressor modify plant-aphid interactions in tobacco. *Scientific Reports* 1,187. <https://doi.org/10.1038/srep00187>



Effects of Sodium Nitroprusside and Gibberellic Acid Applications on Direct Germination of Fully Mature Grapevine Seeds and Seedling Growth

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HIGHLIGHTS

- The in vivo germination protocol of fully mature grapevine seeds just after harvest was determined.
- The grapevine seeds separated from the berries just after harvest, before drying, were germinated in vivo.
- Drying the mature seeds reduced the germination rate.
- NO generator Sodium nitroprusside (SNP) and GA₃ increased germination and plant transformation rates and vegetative development parameters of seedlings.
- Genotypic differences in germination rates and vegetative growth characteristics were significant.

Abstract

Seeds are widely used in grapevine breeding to obtain new genotypes; however, physical and physiological constraints in seeds reduce the germination rate and slow down breeding programs. The germination rate of mature grapevine seeds and in vitro methodologies that shorten the process of obtaining seedlings have been described. Still, the early germination of fully mature seeds in vivo has not been adequately studied. In this study, the effects of Sodium nitroprusside (SNP) and Gibberellic Acid (GA₃) on germination stimulation were examined. At the same time, fresh (F) and dried (D) seeds were used to determine the drying effect of the seeds separated from the fruit flesh. The effects of control (pure water), SNP (100–500 µM), and GA₃ (1–5 gL⁻¹) 24-hour immersion applications on seed germination, vegetative development, and seedling development were evaluated. While SNP (F-500 µM SNP in cv. Gök Üzümlü, 77.94%) and GA₃ (F-GA₃ 1 gL⁻¹ in cv. Royal 70.87%) applications increased germination and plant transformation rates, the effects of applied dose were relatively limited. GA₃ treatments promoted germination more in cv. Royal and SNP in cv. Gök Üzümlü. GA₃ (2.5 gL⁻¹) and SNP (500 µM) applications also increased shoot growth and leaf chlorophyll contents. The technique of SNP and GA₃ applications can contribute to and accelerate breeding programs carried out with seed-producing vines, as it provides higher germination rates and seed germination and seedling production immediately after the fully mature clusters are harvested.

Keywords: Vine; fully matured seed; seedling; germination; stimulants

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1. Introduction

Vines are commercially propagated by grafting and cuttings. Seed propagation is used in breeding programs to obtain new hybrids (Ritschel et al. 2014; dos Santos et al. 2019). Dormancy of grapevine seeds results in low germination rates, which disrupts grapevine breeding programs (Ellis et al. 1983; Maeda et al. 1985; Pommer et al. 1988; Conner 2008; Generoso et al. 2019;). Physical dormancy in grapevine seeds is due to the waterproof seed coat (Eriş and Düring 1978; Conner 2008), and it is associated with high endogenous abscisic acid (ABA) levels (Rajasekaran et al. 1982). Cold stratification can lead to a decrease in ABA levels. To eliminate dormancy in grape seeds, stratification is done for 75-90 days in a humid environment at temperatures between 0-5 °C (Ellis et al. 1983; Pommer et al. 1988; Selim et al. 2016; do Brasil and Brasília 2016; Çelik 2014) or with GA₃ pre-applications (Kang 1968; Kachru 1969; Manivel and Weaver 1974; Selim et al. 1981) where the benefits of cold stratification can be combined (Kachru 1969; Manivel and Weaver 1974; Pal and Singh 1976; Chohan and Dhillon 1976; Selim et al. 1981; Ergenoglu et al. 1996) have been reported. Recommended GA₃ doses are 0.05 - 8 gL⁻¹ and application time varies from 15 seconds to 24 hours (Kang 1968; Manivel and Weaver 1974; Selim et al. 1981; Kara et al. 2020). These methods require significant time, and germination rates often remain below 50%.

Levels of plant growth regulators are effective in stimulating germination or breaking dormancy in seeds, especially GA inactivates ABA in dormant seeds, accelerates the hydrolysis of starch and storage proteins, and stimulates seed germination (Cardemil and Reinero 1982; Hopkins 1995).

Endogen GA₃ application to seeds accelerates germination by increasing α -amylase activity (Wurzbürger et al. 1974), initiates germination by replacing environmental effects such as stratification (Özen and Onay 1999), light and temperature, and directly stimulates embryo growth by providing hydrolysis events in the endosperm (Ünal et al. 2004), ensures elongation by enlarging the cells in the elongation zone (Hopkins 1995). Significant differences have been determined between germination rates and processes depending on factors of applications and grapevine genotypes (da Costa Júnior et al. 2022; Ergenoglu et al. 1996).

Reactive oxygen species (ROS) play an important role in regulating germination under both normal and stress conditions. ROS accumulation is required to break seed dormancy in many plant species (Bailly et al. 2008; Gniazdowska et al. 2010a; Leymarie et al. 2012). H₂O₂, a ROS, accumulates more in seeds germinated in saline conditions (Lee et al. 2010; Lin et al. 2012). Hydrogen peroxide mediates the interaction between ABA and GA₃ in the stimulation of seed germination in *Arabidopsis* (Leymarie et al. 2012).

Nitric Oxide (NO) acts as a signaling molecule involved in the control and regulation of various plant responses to environmental stresses at almost all stages of development (Delledonne et al. 1998; Durner and Klessig 1999; García-Mata and Lamattina 2001; Beligni et al. 2002; Zhao et al. 2004; Shi et al. 2005; Zhao et al. 2007; Wang et al. 2009), seed germination, root development, cell senescence and stomatal closure (Garcia-Mata et al. 2003) depending on the concentration and the metabolic state in which it is involved, protective or it is also toxically involved in apoptosis (Beligni and Lamattina 2002). The protective effects of NO have been associated with the regulation of ROS levels and toxicity, which are involved in lipid peroxidation (Sharpe et al. 2003; Hung and Kao 2004; Hummel et al. 2006).

NO protects cell subunits of membrane-bound enzymes and substrates by regulating tissue antioxidant capacity and lipid peroxidation (Duan et al. 2007), often providing its regulatory activity through tight coordination with other molecules such as ROS (Wang et al. 2009; Gniazdowska et al. 2010b). Cyanide (CN) is the primary volatile dormancy-breaking compound produced by NO. The donor SNP (Bethke et al. 2006) stimulates germination by enabling ethylene production (Gniazdowska et al. 2007; Ahlfors et al. 2009; García et al. 2011; Soltys et al. 2012) under various conditions such as ozone stress and ion deficiency (Gniazdowska et al. 2010b; Liu et al. 2010). However, there is a lack of information on the effects of NO on the germination of fully matured grape seeds. Although low (10⁻⁴-10⁻⁸ M) doses of SNP significantly increased germination percentage, root length and shoot control, high doses (10⁻³-1 M) inhibited seed germination, root and shoot growth, and maximum inhibition was recorded when seeds were soaked in 1 M SNP. 10⁻⁵ M SNP provided significant increases in germination rate, root and shoot length (Hayat et al. 2014).

To accelerate breeding programs, *in vitro*, germination of immature embryos has been used in different species such as grapevine (Val et al. 2010; Generoso et al. 2019; Costa Júnior et al. 2022), pepper (Walter et al. 2018), palm (Mbi et al. 2016). For the same purpose, the production of seedlings from immature embryos has also been studied (Yang et al. 2007; Tian et al. 2008; Tang et al. 2009; Li et al. 2015; Li et al. 2020). However, there is a paucity of studies investigating the early germination of mature grapevine seeds *in vivo*.

We aimed to develop methodologies that increase the germination rate of fully matured grapevine seeds and shorten the process of obtaining seedlings. For this purpose, we examined the effects of GA₃ and SNP (NO donor) applications on the promotion of germination in both F and D seeds of cv. Gök Üzümleri and cv. Royal immediately after harvest.

2. Materials and Methods

In the experiment, two grape varieties (cv. Gök Üzümleri and cv. Royal), two seed types (F and D), (0 (Control), three SNPs (100 µM, 250 µM, and 500 µM), and three GA₃ (1 gL⁻¹, 2.5 gL⁻¹ and 5 gL⁻¹) was applied by immersion for 24 hours. In the control, the seeds were soaked in pure water for 24 hours. The seeds were germinated in petri dishes in an environment adjusted to 25°C temperature and 16:8 h (dark: light) photoperiod.

Germinated seeds were grown by planting them in 8*8*10 cm plastic containers in a 3:1 peat: perlite mix media. The study was conducted in a randomized parcel trial design with three replications. Variance analysis was performed on the numerical data obtained in the SPSS 17.0 statistical program and compared with the Student's t-test at the p=0.05 significance level. The effects of pre-germination treatments on seedling development were evaluated with three-way ANOVA.

In the experiment, the seeds of cv. Gök Üzümleri (autochthonous variety of Konya Türkiye) and cv. Royal (Karistvala Kolkhuri × Muscat Hamburg) were taken from grapevines in the Selcuk University Faculty of Agriculture Collection and Used. Fully matured clusters of both grape varieties were harvested (August 25, 2021), the clusters were squeezed, the seeds were removed and washed to remove the fruit flesh, and the empty seeds were removed by dipping into water and excluded from the experiment (Olmo 1934). F seeds were forced to germinate by pre-treatments. To determine the effect of drying the seeds after harvest, the washed seeds were laid on drying papers in room temperature without direct sunlight, dried for 72 hours in room conditions, and then used in pre-germination applications as dried (D) seeds. Germination stimulating chemicals GA₃ (Cas No. 77-06-5) and SNP (Cas No: 13755-38-9) were obtained from Ciba-Geigy AG.

2.1. Effects on seed germination and plant transformation rates

When the root tips of the seeds germinated in petri dishes containing agricultural perlite reached approximately 2 mm in length, they were considered germinated and transferred to the growth medium. % germination values were determined by the ratio of germinated seeds to the number of seeds treated before germination. Among the plants that developed from germinated seeds planted in growing containers, those that formed their first true leaves were considered to have turned into plants, and their conversion rates to plants were determined by counting them.

2.2. Shoot length (cm) and diameter (mm)

The lengths of the seedlings grown for 70 days were measured with a tape measure, and the shoot lengths (cm), and the diameters were determined by measuring the distance between the 1st and 2nd nodes from two directions with a digital caliper.

2.3. Leaf area (cm²), fresh and dry weights (g)

The leaves in the middle 1/3 of the shoots were taken from each replicate and evaluated as leaf samples. Leaf areas were determined with the Photoshop portable (PS 12.1) package program. Fresh leaf weights were determined by weighing leaf samples. Leaf dry weight was determined by drying in an oven at 70 °C for 72 hours and weighing.

2.4. Leaf chlorophyll content (SPAD value)

Chlorophyll contents of 3-4 leaves from the shoot tip of the seedlings were determined with a chlorophyll meter (SPAD-502, Minolta, Japan).

2.5. Root fresh and dry weight (g)

All roots of the seedlings grown in containers for 70 days were cut 3 cm away from the root branching point. After washing, the root fresh weights were determined (g), and these roots were kept in the oven (70 °C) for 72 hours and weighed to determine the root dry weights.

3. Results

3.1. Germination and Seedling Rate (%)

GA₃ and SNP were applied to the F and D seeds of cv. Gök Üzümlü and cv. Royal immediately after harvest affected the germination rates (Figure 1a). While the lowest germination rate of cv Gök Üzümlü was recorded in the control, the highest germination rate was in the D-GA₃ 5 gL⁻¹ application. The highest germination rate in F seeds was obtained in the F-GA₃ 5 gL⁻¹ application.

In the D seeds in the cv. Royal, the lowest germination rate was in the control and the highest was in the D-GA₃ 5 gL⁻¹ application. In the F seeds, the lowest germination rate was in control, while the highest germination rate was again in the F-GA₃ 5 gL⁻¹ application (Figure 1a).

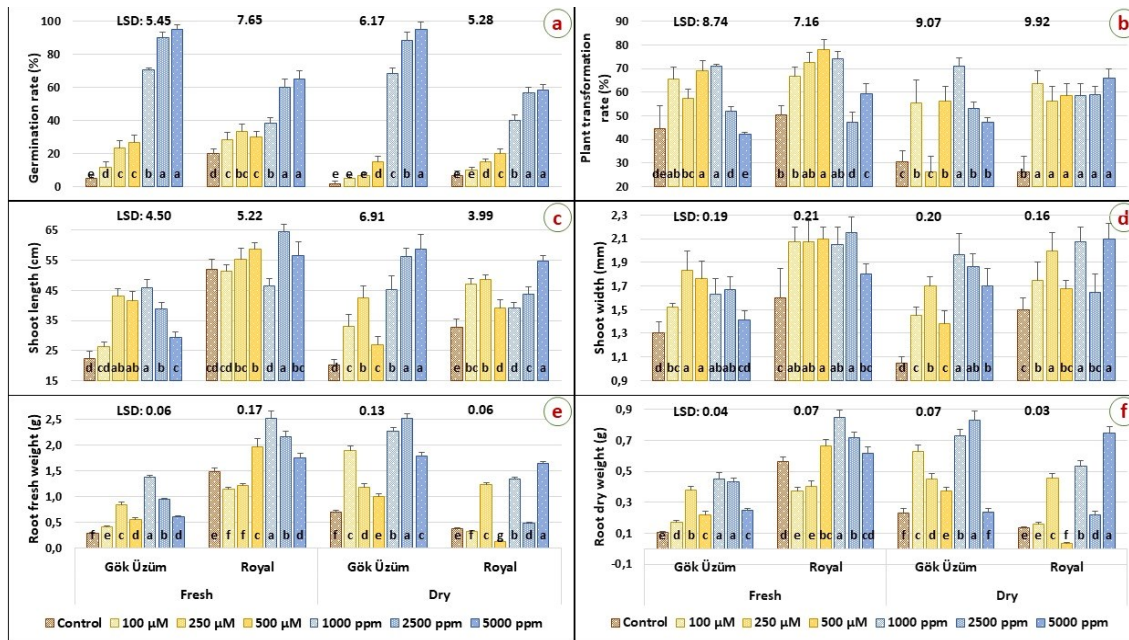


Figure 1. Effects of SNP and GA₃ treatments on germination rate (a), plant transformation (b), shoot length (c), shoot width (d), root fresh weight (e), and root dry weight (f). Statistically significant ($p < 0.05$) differences were indicated by different letters on the bars. Standard error values are given one-sided on the bars.

GA₃ and SNP applications affected seedling emergence rates in both grapevine varieties (Figure 1b). Considering only the control, the seedling conversion rate of both cultivars in applications using F seeds was higher in the cv. Royal (50.23%) than in the cv. Gök Üzümlü (44.44%). In cv. Gök Üzümlü, the effects of SNP applications on the seedling rate were higher in F seeds than in D seeds. The highest seedling rates were determined in F-500 μM SNP (68.93 ± 4.32) and F-GA₃ 1 gL⁻¹ (70.87 ± 0.96) applications.

In the F seeds of the cv. Royal, all SNP applications increased the seedling conversion rates (Figure 1b), and the maximum value was obtained from the F-500 μM SNP application ($77.94 \pm 4.34\%$). In the F-GA₃ 1 gL⁻¹ application, the seedling conversion rate was $74.01 \pm 3.22\%$. In general, in applications where F seeds are used,

the rate of transformation into plants is higher than that of D seeds. SNP applications increased the rate of transformation into plants more than GA₃ applications.

3.2. Shoot Length (cm) and Width (mm)

GA₃ and SNP applications to F and D seeds of both grape varieties before germination increased shoot growth, although it varied according to the applied dose (Figure 1c). In F seeds, the maximum shoot length was determined in the F-250 μ M SNP application (43.25 ± 2.38 cm) in the Royal cultivar, while it was 42.52 ± 4.03 cm in the D-250 μ M SNP application in the Gök Üzümlü cultivar. This value was 45.83 ± 2.93 cm in the F-GA₃ 1 gL⁻¹ application, and 45.33 ± 4.48 cm in the D-GA₃ 1 gL⁻¹ application (Figure 1c).

The height of the seedlings developed from cv. Royal F-seeds were greater in all treatments using control, SNP, and GA₃ than in all treatments using D-seeds. In general, the shoot length of cv. Royal seedlings were longer than those of cv. Gök Üzümlü seedlings. The maximum shoot length was determined as 58.57 ± 2.40 cm in the F-500 μ M SNP application and 64.51 ± 2.59 cm in the F-GA₃ 2.5 gL⁻¹ application, while it was 48.75 ± 1.25 cm in the D-250 μ M SNP application and 54.67 ± 2.02 cm in the D-GA₃ 5 gL⁻¹ application.

GA₃ and SNP applications to the seeds of both grape varieties affected the shoot width (Figure 1d). Control and F-SNP applications increased shoot width. In D-seeds that were used, a thicker shoot width was obtained in the control and SNP treatments. In other words, shoot width remained weaker in D-GA₃ applications. All doses of both SNP and GA₃ applications supported shoot thickening. The maximum shoot width was 2.15 ± 0.13 mm in the F-GA₃ 2.5 gL⁻¹ application, and 2.08 ± 0.13 mm in the D-GA₃ 5 gL⁻¹ application in Royal.

3.3. Root Fresh and Dry Weight (g)

GA₃ applications increased the root fresh weight of seedlings developed from F-seeds and D-seeds of both grape varieties more than SNP. This increasing effect was more evident in those treated with D-GA₃, but no significant change could be noticed with the increase in dose.

In the seedlings developed from cv. in Royal F-seeds, the highest fresh root weight (2.52 ± 0.14 g) was obtained from the F-GA₃ 1 gL⁻¹ application, while in the seedlings developed from the D-seeds, the highest value (1.65 ± 0.04 g) was obtained from D-GA₃ 5 gL⁻¹ application (Figure 1e).

While pre-germination applications to F and D seeds increased root dry weights, the highest values were in F-GA₃ 1 gL⁻¹, D-GA₃ 2.5 gL⁻¹ and F-250 μ M SNP applications (Figure 1f).

In the cv. Royal F-seeds applications, F-100 μ M SNP and F-250 μ M SNP, gave lower root dry weight than the control (0.56 ± 0.03 g), while the highest value was obtained from the F-GA₃ 1 gL⁻¹ (0.85 ± 0.05 g) application. In the D seeds applications, the lowest root weight (0.04 ± 0.00 g), including the control (0.13 ± 0.01 g), was obtained from the D-500 μ M SNP application, while the highest value (0.75 ± 0.04 g) was recorded in the D-GA₃ 5 gL⁻¹ application.

3.4. Leaf Fresh and Dry Weight

The leaf dry weights of the seedlings developed from the cv. Gök Üzümlü F-seeds were higher in the control and SNP-applied ones. D-GA₃ applications increased fresh leaf weights in seedlings. While the fresh leaf weight was 0.45 ± 0.06 g in the control of F-seeds, it was recorded as 0.89 ± 0.04 g in the F-500 μ M SNP application. The fresh leaf weight was 0.18 ± 0.02 g in the D-seeds control and 0.84 ± 0.08 g in the D-GA₃ 2.5 gL⁻¹ application (Figure 2a).

The fresh leaf weight of the cv. Royal seedlings of F-seeds were determined as 0.54 ± 0.04 g in the control, 0.74 ± 0.01 g in the F-500 μ M SNP application, and 0.94 ± 0.06 g in the F-GA₃ 2.5 gL⁻¹ application, while it was 0.48 ± 0.06 g in the D-seeds control. D-500 μ M SNP and D-GA₃ in 2.5 gL⁻¹ applications were recorded as 0.60 ± 0.08 g and 0.69 ± 0.03 g, respectively (Figure 2a).

The effects of SNP and GA₃ applications on F and D seeds of both grape cultivars on leaf dry weight were significant and similar to fresh leaf weights (Figure 2b). In the cv. Gök Üzümlü, the lowest (0.050 ± 0.008 g) leaf dry weight was determined in the F-GA₃ 5 gL⁻¹ application, which was also below the control. While the lowest leaf dry weight of this variety was determined as 0.026 ± 0.004 g in the D-seeds control, it was 0.132 ± 0.021 g and 0.168 ± 0.011 g in D-SNP 500 μ M and D-GA₃ 2.5 gL⁻¹ applications, respectively (Figure 2b).

The dry leaf weight of the cv. Royal seedlings developed from F-seeds was 0.087 ± 0.005 g (F-250 μ M SNP) and 0.194 ± 0.011 g (F-GA₃ 2.5 gL⁻¹), and in D-seeds, it was 0.098 ± 0.015 g (control) and 0.147 ± 0.006 g (D-GA₃ 2.5 gL⁻¹) and no significant change could be determined between applied doses (Figure 2b).

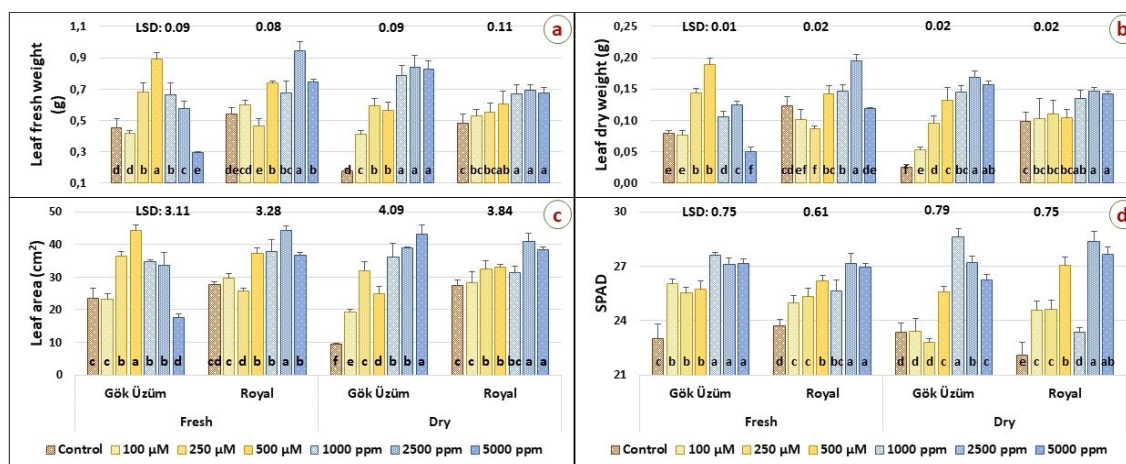


Figure 2. Effects of SNP and GA₃ treatments on leaf fresh weight (a), leaf dry weight (b), leaf area (c), and leaf chlorophyll content (SPAD value) (d). Statistically significant ($p < 0.05$) differences were indicated by different letters on the bars. Standard error values are given one-sided on the bars.

3.5. Leaf Area

In the cv. Gök Üzümlü F and D seeds, 250 μ M and 500 μ M SNP, GA₃ 1 gL⁻¹ and GA₃ 2.5 gL⁻¹ applications increased the leaf area (Figure 2c). In the cv. Royal F and D seeds, the highest leaf area was obtained from the D-GA₃ 2.5 gL⁻¹ application. Only in the F 250 μ M SNP application, the average leaf area remains below control (Figure 2c).

3.6. Leaf Chlorophyll Content (SPAD Value)

SNP and GA₃ applications increased leaf chlorophyll content in the cv. Gök Üzümlü F-seeds seedlings (Figure 2d), and in the D-seeds seedlings, the highest leaf chlorophyll content was obtained by D-GA₃ 1 gL⁻¹ application. In both cultivars F and D-seeds applications, GA₃ increased leaf chlorophyll content more than SNP, but the effects of dosages were not clear.

3.7. Effects of Pre-applications on Germination and Seedling Development

The effects of pre-germination treatments on germination and seedling development were examined by genotype (two grape cultivars), use of seeds in fresh (F) and dried (D), and pre-germination treatments (0 (Control), three SNPs (100 μ M, 250 μ M, and 500 μ M), and three GA₃ (1 gL⁻¹, 2.5 gL⁻¹ and 5 gL⁻¹) data were evaluated by three-way analysis of variance (Table 1). In the germination rate, genotype*drying*application was insignificant, other parameters and the relationships between them were important. In the seedling conversion rate, genotype*drying was unimportant, other parameters and the relationships between them were important. All parameters examined and the relationships between them regarding shoot length and root dry weight were important.

In assessing effects on shoot width, genotype*treatment was unimportant. Other parameters evaluated in this context and the relationships between them were important. In terms of root and leaf fresh weight, drying was unimportant, other parameters and the relationships between them were important. In leaf dry weight evaluation, drying and genotype*drying were insignificant, other parameters and the relationships between them were important. In leaf area evaluation, genotype*drying was unimportant, other parameters and their relationships were important. In the evaluation of leaf chlorophyll content effects, genotype was unimportant, while other parameters and their relationships were important. When the applications were evaluated as a whole, SNP and GA₃ applications applied to F and D seeds before germination increased the germination rate and plant transformation rates in the seeds of both grape cultivars and generally encouraged seedling development.

Table 1. Three-way Anova for relationships between treatments

	Germination rate	Plant transformation rate	Shoot length	Shoot width	Root fresh weight	Root dry weight	Leaf fresh weight	Leaf dry weight	Leaf area	SPAD
Genotype (G)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.192
Drying (D)	0.000	0.000	0.000	0.006	0.053	0.000	0.074	0.111	0.010	0.000
Application (A)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
G*D	0.015	0.950	0.000	0.008	0.000	0.000	0.000	0.079	0.776	0.044
G*A	0.000	0.000	0.000	0.120	0.000	0.000	0.000	0.000	0.000	0.000
D*A	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
G*D*A	0.053	0.003	0.000	0.003	0.000	0.000	0.000	0.000	0.000	0.000

4. Discussion

Since physical and physiological dormancy in grapevine seeds (Rajasekaran et al. 1982; Ellis et al. 1983; Maeda et al. 1985; Pommer et al. 1988; Conner 2008; Val et al. 2010; Generoso et al. 2019) reduces or delays seed germination (Generoso et al. 2019), GA₃ soaking and beak cutting (Wang et al. 2022), SNP and for 90 days of stratified seeds GA₃ application (Kara et al. 2020), for remove seeds from berries five weeks after flowering GA₃ and Kinetin applications (Pandey and Singh 1988), for removed immature zygotic embryos 80 days after flowering keeping them in 2.5 gL⁻¹ GA₃ + 55 °C water for 15 minutes and then keeping them at room temperature for 24 hours (Zhang et al. 2023) were recommended.

In a previous study, cv. Romi seeds that were intended to germinate immediately after harvest did not germinate. When the seeds were stratified at 5 - 18 °C for 30 - 120 days, as the stratification time increased and at the same time the dose of GA₃ was increased from 0.05 gL⁻¹ to 5 gL⁻¹ the germination rate increased. By soaking in pure water for 24 hours, the germination rate reached 4.2% recorded (Selim et al. 1981).

Ergenoglu et al. (1996), reported that stratification at 5 °C for 21 days increased the germination rate and shortened the germination time and that GA₃ applications caused excessive elongation and poor development in seedlings. In previous studies, stratification was accepted necessary to break dormancy in seeds (Ellis et al. 1983; Pommer et al. 1988), and the proposed methodologies were time-consuming and relatively low-yield (Ellis et al. 1983; Pommer et al. 1988; Conner 2008) and depends on the genotype (da Costa Júnior et al. 2022).

GA₃ applied to seeds generally increases germination. It promotes growth by increasing the plastids in the cell walls, converts carbohydrates into sugar, and reduces the pressure on the cell wall. Thus, it ensures water intake into the cell and cell elongation (Arteca 1996; Hopkins 1995). Moreover, GA₃ applications also promote the production of some hydrolase enzymes such as α -amylase (Arif et al. 2008). Moreno et al. (2011) indicated that GA₃ promotes net carbon fixation and transport, promoting correct carbon allocation to roots and fruits. Dormancy was broken in *in vitro* GA₃ applications (Val et al. 2010; Generoso et al. 2019; da Costa Júnior et al. 2022), but in our study, *in vivo* grapevine seeds germination was achieved at high rates (in cv. Gök Üzümlü F control 5.00±1.67, in cv. Royal 20.00±2.89) with GA₃ and (in cv. Gök Üzümlü GA₃ 5 gL⁻¹ 95.00±2.89, in cv. Royal GA₃ 5 gL⁻¹ 65.00±5.00) SNP (in cv. Gök Üzümlü SNP 500 μ M 26.67±4.41, in cv. Royal SNP 250 μ M 33.33±4.41) pre-applications to fresh seeds.

Grape seeds have a physical and physiological rest requirement (Cadot et al. 2006; Val et al. 2010; Çelik 2014; Generoso et al. 2019; Kara et al. 2020; Wang et al. 2022). Since physiological dormancy is not found in the embryo, but in the tissues surrounding it (da Costa Júnior et al. 2022), it was possible to break dormancy with SNP and GA₃ applications immediately after harvest, before completely drying the seeds.

We broke physical and physiological dormancy in *in vivo* culture with SNP and GA₃ applications to seeds with mature zygotic embryos in two grape cultivars immediately after harvest. We obtained a high rate of germination and seedlings from matured grape seeds in the harvest season. Both factors are known to naturally inhibit germination. The decrease in germination rate even after 72 hours of drying proved by this.

In the control of F and D seeds, 24-hour of soaking in water contributed to overcoming both physical and physiological barriers.

There is a great need for new varieties of cultivated plant species that can be produced in a short time. These new genotypes, the products of breeding programs, may be more resistant to biotic and abiotic factors, and productive and high-quality varieties. Methods that will accelerate this process will contribute to the acceleration of plant breeding.

Our results may be a good indication that matured seeds can be used for seed germination regardless of the cultivar or species of the *Vitis* genus. However, further studies with other species, hybrids, and varieties should be conducted for verification.

When our results were evaluated together, applications of NO donor SNP and GA₃ to grapevine F and D seeds immediately after harvesting increased germination and plant transformation rates. The effects of SNP and GA₃ dosage on germination and transformation into plants remained at relatively limited levels. GA₃ treatments promoted germination more compared to SNP. GA₃ and SNP applications positively affected shoot length and leaf chlorophyll content.

According to these results, GA₃ and SNP can be used to reduce losses in the process of converting seeds obtained through hybridization into plants, especially in grapevine breeding. With the protocol created in our study, a stable and repeatable method was presented that could prevent wasting time during the rest period for seed germination, which is especially necessary for grapevine breeding and other biotechnological studies.

5. Conclusions

In this study, the methodology for in vivo germination of fully matured grapevine seeds immediately after harvest was described. Although GA₃ promoted the germination of F and D seeds by approximately 40% even at the lowest application, this effect was more limited in the conversion rates to plants (55-65%).

Germination rates were higher in both grape varieties in treatments using F seeds. In D-GA₃ treatments, the germination rate was over 65% in the cv. Royal and over 95% in the cv. Gök Üzümlü. In mature seeds, drying after harvest reduced the germination rate.

The germination-stimulating effect of SNP treatments was significant, and this activity was higher in D seeds of both grape cultivars.

The stimulatory effect of SNP applications to F seeds was more evident in plant conversion rates, shoot length and diameter, leaf fresh weight, and leaf area.

This methodology increased the number of germinating seeds. By shortening the time required for germination and seedling production, the time required to obtain new grapevine varieties can be reduced and grapevine breeding programs can be accelerated.

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References

Ahlfors R, Brosché M, Kangasjär J (2009). Ozone and nitric oxide interaction in *Arabidopsis thaliana*, a role for ethylene? A role for ethylene?. *Plant Signaling & Behavior* 4(9), 878-879. <https://doi.org/10.4161/psb.4.9.9428>

- Arif İ, Kaya MD, Gürbüz B (2008). Çemen *Trigonella foenum-graecum* L. ve kimyon *Cuminum cyminum* L. tohumlarının çimlenmesi üzerine tohum yaşı ve gaz uygulamalarının etkileri. *Tarım Bilimleri Dergisi* 14(01), 57-61.
- Arteca RN (1996). Plant growth substances: principles and applications. Springer Science & Business Media.
- Bailly C, El-Maarouf-Bouteau H, Corbineau F (2008). From intracellular signaling networks to cell death: the dual role of reactive oxygen species in seed physiology. *Comptes Rendus Biologies* 331(10), 806-814. <https://doi.org/10.1016/j.crvi.2008.07.022>
- Beligni M, Lamattina L (2002). Nitric oxide interferes with plant photo-oxidative stress by detoxifying reactive oxygen species. *Plant Cell Environ* 25(6), 737-748. <https://doi.org/10.1046/j.1365-3040.2002.00857.x>
- Beligni MV, Fath A, Bethke PC, Lamattina L, Jones RL (2002). Nitric oxide acts as an antioxidant and delays programmed cell death in barley aleurone layers. *Plant Physiology* 129(4), 1642-1650. <https://doi.org/10.1104/pp.002337>
- Cardemil L, Reinero A (1982). Changes of Araucaria araucana seed reserves during germination and early seedling growth. *Canadian Journal of Botany* 60(9), 1629-1638. <https://doi.org/10.1139/b82-211>
- Chohan G, Dhillon B (1976). Seed dormancy and endogenous growth substances in Anab-e-Shahi grapes. *Vitis* 15(1), 5-10.
- Conner PJ (2008). Effects of stratification, germination temperature, and pretreatment with gibberellic acid and hydrogen peroxide on germination of 'Fry' muscadine (*Vitis rotundifolia*) seed. *HortScience* 43(3), 853-856. <https://doi.org/10.21273/HORTSCI.43.3.853>
- Çelik M (2014). The effects of stratification periods and GA₃ (Gibberellic acid) applications on germination of seeds of some grape cultivars. *Turkish Journal of Agricultural and Natural Sciences* (Özel Sayı-1), 1118-1122.
- da Costa Júnior OD, Carvalho VS, Generoso AL, da Silva LM, de Sales RA, Viana AP (2022). Overcoming germination barriers through in vitro culture of mature zygotic embryos of grapevine cultivars. *Plant Cell Culture & Micropropagation* 18(18), e182-118. <https://doi.org/10.46526/pccm.2022.v18.182>
- Delledonne M, Xia Y, Dixon RA, Lamb C (1998). Nitric oxide functions as a signal in plant disease resistance. *Nature* 394(6693), 585-588. <https://doi.org/10.1038/29087>
- do Brasil F, Brasília D (2016). Ministério da agricultura, pecuária e abastecimento. *Secretaria de Defesa Agropecuária. Disponível em: Acesso em, 5(10):2016.*
- dos Santos PR, Viana A, Santos, EA, de Barros Walter FH, Riaz S, Walker AM (2019). Molecular genetic diversity in segregates of Vitis: implications for the breeding of grapevine aiming at resistance to *Pratylenchus brachyurus*. *Euphytica* 215, 1-10. <https://doi.org/10.1007/s10681-019-2403-8>
- Duan X, You Y, Su X, Qu H, Joyce D, Jiang Y (2007). Influence of the nitric oxide donor, sodium nitroprusside, on lipid peroxidation and anti-oxidant activity in pericarp tissue of longan fruit. *The Journal of Horticultural Science and Biotechnology* 82(3), 467-473. <https://doi.org/10.1080/14620316.2007.11512260>
- Durner J, Klessig DF (1999). Nitric oxide as a signal in plants. *Current Opinion in Plant Biology* 2(5), 369-374. [https://doi.org/10.1016/S1369-5266\(99\)00007-2](https://doi.org/10.1016/S1369-5266(99)00007-2)
- Ellis R, Hong T, Roberts E (1983). A note on the development of a practical procedure for promoting the germination of dormant seed of grape (*Vitis* spp.). *Vitis* 22(3), 211-219.
- Ergenoglu F, Tangolar S, Gök S (1996). The effects of some pre-treatments for promoting germination of grape seeds. *V Temperate Zone Fruit in the Tropics and Subtropics* 441, 207-212. <https://doi.org/10.17660/ActaHortic.1997.441.27>
- Eriş A, Düring H (1978). Hamburg misketi üzüm çeşidi çekirdeklerinde katlama uygulamaları ile değişen absizik asit (ABA) miktarının yüksek basınçlı sıvı Kromatografi cihazı ile saptanması. *Ankara Üniversitesi Ziraat Fakültesi Yıllığı* 27(3-4), 489-498.

- García MJ, Suárez V, Romera FJ, Alcántara E, Pérez-Vicente R (2011). A new model involving ethylene, nitric oxide and Fe to explain the regulation of Fe-acquisition genes in Strategy I plants. *Plant Physiology and Biochemistry* 49(5), 537-544. <https://doi.org/10.1016/j.plaphy.2011.01.019>
- Garcia-Mata C, Graziano M, Pagnussat G (2003). Nitric oxide: the versatility of an extensive signal molecule. *Annual Review Plant Biology* 54, 109-136. <https://doi.org/10.1146/annurev.arplant.54.031902.134752>
- García-Mata C, Lamattina L (2001). Nitric oxide induces stomatal closure and enhances the adaptive plant responses against drought stress. *Plant Physiology* 126(3), 1196-1204. <https://doi.org/10.1104/pp.126.3.1196>
- Generoso AL, Viana AP, Carvalho VS, Costa Júnior ODD (2019). *In vitro* germination to overcome dormancy in seeds of 'Red Globe', 'Italia' and 'Niagara Rosada' grapes. *Revista Brasileira de Fruticultura* 41, e-495. <https://doi.org/10.1590/0100-29452019495>
- Gniazdowska A, Dobrzyńska U, Babańczyk T, Bogatek R (2007). Breaking the apple embryo dormancy by nitric oxide involves the stimulation of ethylene production. *Planta* 225(4), 1051-1057. <https://doi.org/10.1007/s00425-006-0384-z>
- Gniazdowska A, Krasuska U, Bogatek R (2010a). Dormancy removal in apple embryos by nitric oxide or cyanide involves modifications in ethylene biosynthetic pathway. *Planta* 232(6), 1397-1407. <https://doi.org/10.1007/s00425-010-1262-2>
- Gniazdowska A, Krasuska U, Dębska K, Andryka P, Bogatek R (2010b). The beneficial effect of small toxic molecules on dormancy alleviation and germination of apple embryos is due to NO formation. *Planta* 232(4), 999-1005. <https://doi.org/10.1007/s00425-010-1214-x>
- Hayat S, Yadav S, Alyemeni M, Ahmad A (2014). Effect of sodium nitroprusside on the germination and antioxidant activities of tomato (*Lycopersicon esculentum* Mill). *Bulgarian Journal of Agricultural Sciences*, 20(1), 140-144.
- Hopkins W (1995). Introduction to Plant Physiology. John Wiley and Sons, Inc, USA.
- Hummel SG, Fischer AJ, Martin SM, Schafer Q, Buettner GR (2006). Nitric oxide as a cellular antioxidant: a little goes a long way. *Free Radical Biology & Medicine* 40(3), 501-506. <https://doi.org/10.1016/j.freeradbiomed.2005.08.047>
- Hung KT, Kao CH (2004). Nitric oxide acts as an antioxidant and delays methyl jasmonate-induced senescence of rice leaves. *Journal of Plant Physiology* 161(1), 43-52. <https://doi.org/10.1078/0176-1617-01178>
- Kachru R (1969). Physiological studies on dormancy in grape seeds (*Vitis vinifera*) 1. On the naturally occurring growth substances in grapes and their changes during low temperature after ripening. *Vitis* 8, 12-18.
- Kang Y (1968). Effect of low temperature and growth regulators on germination of seeds of 'Tokay grapes' grapes. *Proceedings of the American Society for Horticultural Science*, 323-330. <https://doi.org/10.6964/JCSHS.196712.0066>
- Kara Z, Yazar K, Doğan O, Vergili E (2020). Sodium nitroprusside and gibberellin effects on seed germination and seedling development of grapevine (*Vitis vinifera* L.) cvs. Ekşi Kara and Gök Üzümleri. *Erwerbs-Obstbau* 62, 61-68. <https://doi.org/10.1007/s10341-020-00497-8>
- Lee S, Kim SG, Park CM (2010). Salicylic acid promotes seed germination under high salinity by modulating antioxidant activity in Arabidopsis. *New Phytologist* 188(2), 626-637. <https://doi.org/10.1111/j.1469-8137.2010.03378.x>
- Leymarie J, Vitkauskaitė G, Hoang HH, Gendreau E, Chazoule V, Meimoun P, Corbineau F, El-Maarouf-Bouteau H, Bailly C (2012). Role of reactive oxygen species in the regulation of Arabidopsis seed dormancy. *Plant & Cell Physiology* 53(1), 96-106. <https://doi.org/10.1093/pcp/pcr129>
- Li J, Wang X, Wang X, Wang Y (2015). Embryo rescue technique and its applications for seedless breeding in grape. *Plant Cell Tissue and Organ Culture* 120, 861-880. <https://doi.org/10.1007/s11240-014-0656-4>

- Li S, Li Z, Zhao Y, Zhao J, Luo Q, Wang Y (2020). New disease-resistant, seedless grapes are developed using embryo rescue and molecular markers. *3 Biotech* 10, 1-12. <https://doi.org/10.1007/s13205-019-1993-0>
- Lin Y, Wang J, Zu Y, Tang Z (2012). Ethylene antagonizes the inhibition of germination in Arabidopsis induced by salinity by modulating the concentration of hydrogen peroxide. *Acta Physiologiae Plantarum* 34(5), 1895-1904. <https://doi.org/10.1007/s11738-012-0989-8>
- Liu Y, Ye N, Liu R, Chen M, Zhang J (2010). H₂O₂ mediates the regulation of ABA catabolism and GA biosynthesis in Arabidopsis seed dormancy and germination. *Journal of Experimental Botany* 61(11), 2979-2990. <https://doi.org/10.1093/jxb/erq125>
- Maeda JA, Pereira MdFDA, Terra MM (1985). Effect of storage conditions on the viability and dormancy of grape seeds. *Bragantia* 44, 245-254. <https://doi.org/10.1590/S0006-87051985000100023>
- Manivel L, Weaver R (1974). Effect of growth regulators and heat on germination of Tokay grape seeds. *Vitis* 12(4), 286-290.
- Mbi KT, Tonfack LB, Ntsefong GN, Mir BA, Ebongue GFN, Ngaha D, Njembele C, Namuene KS, Youmbi E (2016). Mature zygotic embryo rescue improves *in vitro* germination and seedling production in high value oil palm (*Elaeis guineensis* Jacq.) cultivars. *Industrial Crops and Products* 94, 445-453. <https://doi.org/10.1016/j.indcrop.2016.09.002>
- Moreno D, Berli FJ, Piccoli PN, Bottini R (2011). Gibberellins and abscisic acid promote carbon allocation in roots and berries of grapevines. *Journal of Plant Growth Regulation* 30, 220-228. <https://doi.org/10.1007/s00344-010-9186-4>
- Olmo H (1934). Empty-seededness in varieties of *Vitis vinifera*. *Proceedings of the American Society for Horticultural Science* 376-385.
- Özen H, Onay A (1999). Bitki büyüme ve gelişme fizyolojisi. Dicle Üniversitesi Basımevi. Diyarbakır, 166.
- Pal R, Singh R (1976). Effect of gibberellins GA₃, GA+7 and GA13 on seed germination and subsequent seedling growth in Early Muscat grape (*Vitis vinifera*). *Vitis* 14(4), 265-268.
- Pandey S, Singh R (1988). Germination of seeds extracted from immature berries of grapes. *Indian Journal of Horticulture* 45(1 and 2), 56-60.
- Pommer CV, Maeda JA, Ribeiro IJA (1988). Capacidade de germinação e quebra de dormência em sementes de cultivares de videira. *Bragantia* 47, 143-157. <https://doi.org/10.1590/S0006-87051988000200001>
- Rajasekaran K, Vine J, Mullins M (1982). Dormancy in somatic embryos and seeds of *Vitis*: changes in endogenous abscisic acid during embryogeny and germination. *Planta* 154, 139-144. <https://doi.org/10.1007/BF00387907>
- Ritschel P, Maia JDG, Camargo UA, Zanús MC, Souza RTd, Fajardo TVM (2014). 'BRS MAGNA'-a novel grape cultivar for juice making, with wide climatic adaptation. *Crop Breeding and Applied Biotechnology* 14, 266-269. <https://doi.org/10.1590/1984-70332014v14n4c42>
- Selim H, Ibrahim F, Fayek M, El-Deen SS, Gamal N (2016). Effect of different treatments on germination of Romi red grape seeds. *Vitis* 20(2), 115-121.
- Sharpe MA, Robb SJ, Clark JB (2003). Nitric oxide and Fenton/Haber-Weiss chemistry: nitric oxide is a potent antioxidant at physiological concentrations. *Journal of Neurochemistry* 87(2), 386-394. <https://doi.org/10.1046/j.1471-4159.2003.02001.x>
- Shi S, Wang G, Wang Y, Zhang L, Zhang L (2005). Protective effect of nitric oxide against oxidative stress under ultraviolet-B radiation. *Nitric Oxide* 13(1), 1-9. <https://doi.org/10.1016/j.niox.2005.04.006>
- Soltys D, Rudzińska-Langwald A, Gniazdowska A, Wiśniewska A, Bogatek R (2012). Inhibition of tomato (*Solanum lycopersicum* L.) root growth by cyanamide is due to altered cell division, phytohormone balance and expansin gene expression. *Planta* 236(5), 1629-1638. <https://doi.org/10.1007/s00425-012-1722-y>

- Tang D, Wang Y, Cai J, Zhao R (2009). Effects of exogenous application of plant growth regulators on the development of ovule and subsequent embryo rescue of stenospermic grape (*Vitis vinifera* L.). *Scientia Horticulturae* 120(1), 51-57. <https://doi.org/10.1016/j.scienta.2008.09.018>
- Tian L, Wang Y, Niu L, Tang D (2008). Breeding of disease-resistant seedless grapes using Chinese wild *Vitis* spp.: I. *In vitro* embryo rescue and plant development. *Scientia Horticulturae* 117(2), 136-141. <https://doi.org/10.1016/j.scienta.2008.03.024>
- Ünal O, Gökceoğlu M, Topçuoğlu ŞF (2004). Antalya endemiği *Origanum* türlerinin tohum çimlenmesi ve çelikle çoğaltılması üzerinde araştırmalar. *Akdeniz University Journal of the Faculty of Agriculture* 17(2), 135-147.
- Val ADBd, Motoike SY, Alvarenga EM, Cecon PR (2010). Breaking the dormancy of Niagara Rosada seeds without stratification. *Revista Ceres* 57, 234-238. <https://doi.org/10.1590/S0034-737X2010000200015>
- Walter R, Carvalho VS, Generoso AL, Rodrigues R, Gravina GdA (2018). Cultivation of immature *Capsicum* spp. embryos for incompatible-crossing embryo rescue. *Acta Scientiarum Agronomy* 40. <https://doi.org/10.4025/actasciagron.v40i1.39474>
- Wang H, Liang X, Wan Q, Wang X, Bi Y (2009). Ethylene and nitric oxide are involved in maintaining ion homeostasis in *Arabidopsis* callus under salt stress. *Planta* 230(2), 293-307. <https://doi.org/10.1007/s00425-009-0946-y>
- Wang Z-L, Hui M, Shi, X-Q, Wu D, Wang Y, Han X, Cao X, Yao F, Li H, Wang H (2022). Characteristics of the seed germination and seedlings of six grape varieties (*V. vinifera*). *Plants* 11(4), 479. <https://doi.org/10.3390/plants11040479>
- Wurzbarger J, Leshem Y, Koller D (1974). The role of gibberellin and the hulls in the control of germination in *Aegilops kotschy* caryopses. *Canadian Journal of Botany* 52(7), 1597-1601. <https://doi.org/10.1139/b74-209>
- Yang D, Li W, Li S, Yang X, Wu J, Cao Z (2007). *In vitro* embryo rescue culture of F1 progenies from crosses between diploid and tetraploid grape varieties. *Plant Growth Regulation* 51, 63-71. <https://doi.org/10.1007/s10725-006-9148-9>
- Zhang J, Wu J, Hao X, Xie Y, Lv K, Xu W (2023). Establishment of a stable grape immature zygotic embryo-based genetic transformation system. *Scientia Horticulturae* 316, 112009. <https://doi.org/10.1016/j.scienta.2023.112009>
- Zhao L, Zhang F, Guo J, Yang Y, Li B, Zhang L (2004). Nitric oxide functions as a signal in salt resistance in the calluses from two ecotypes of reed. *Plant Physiology* 134(2), 849-857. <https://doi.org/10.1104/pp.103.030023>
- Zhao MG, Tian Q-Y, Zhang WH (2007). Nitric oxide synthase-dependent nitric oxide production is associated with salt tolerance in *Arabidopsis*. *Plant Physiology* 144(1), 206-217. <https://doi.org/10.1104/pp.107.096842>



Potential of Silicon and Melatonin Amendments to Enhance the Tolerance of Lettuce Plants to Water Deficit Stress

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HIGHLIGHTS

- Silicon treatments alleviated the impact of drought in lettuce.
- Melatonin induced significant improvement in lettuce under full irrigation.
- Silicon and melatonin together increased POD content in lettuce.

Abstract

Drought is one of the most significant problems nowadays, and it will be mandatory to cultivate crops with limited irrigation in the upcoming days. Some treatments are used to reduce the devastating effects of drought. Silicon (Si) and melatonin are popular treatments, and their efficacy was tested in lettuce under drought conditions for the purpose of this study. Thus, two doses of silicon (4 mM/8 mM), one dose of melatonin (150 μ M), and their co-treatments were conducted in lettuce under two full irrigations (I100)/water-deficient (I25) irrigation regimes. The physiological, photosynthetic, and basic growth parameters were measured in lettuce. Based on these data, 8 mM silicon treatment significantly mitigates the severity of drought stress. It was found that the 8mM silicon treatment resulted in leaf dry weights similar to those of non-drought-treated plants, and leaf fresh weight was also slightly affected by drought. 8 mM silicon treatment also significantly improved the values of chlorophyll a, chlorophyll b, total chlorophyll, protein, and chlorophyll fluorescence in lettuce under drought stress. Additionally, melatonin treatments (150 μ M) resulted in significant increases in the examined parameters of the non-drought-treated lettuce groups. Consequently, it was concluded that silicon fertilization alleviated the adverse effects of drought or limited irrigation conditions, whereas, under full irrigation conditions, silicon and melatonin treatments contributed significantly to lettuce cultivation.

Keywords: Silicon; Melatonin; Lettuce; Drought; Physiology

1. Introduction

The lettuce (*Lactuca sativa* L.) is a member of the Compositae family of leafy vegetables widely grown in cool seasons in Türkiye as well as in the world. It can be cultivated and accessed freshly throughout the year in Türkiye, and Türkiye is a significant lettuce producer (561.990 tons in 2022) due to its low calorie and high mineral and bioactive properties (Shi et al. 2022; TÜİK 2023). Lettuce groups commonly grown in Türkiye consist of leaf, Romaine (Cos), and Crisphead (iceberg). The common properties of lettuce that attract the attention of consumers are color, shape, and bioactive contents (Mampholo et al. 2016). While Michelon et al.

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(2020) reported an increase in yield and water use efficiencies in lettuce soilless cultivation. Casey et al. (2022) stated that the functioning of hydroponic systems requires a significant amount of energy and produces high environmental footprints. Hereby, the classical lettuce cultivation is more convenient and environmentally friendly for today (Casey et al. 2022). In any case, lettuce production with limited irrigation has come to the forefront in recent times. Especially, it is even more critical for producers located in a semi-arid climate zone such as Türkiye, where both classical (72.28%) and soilless (27.72%) lettuce cultivation is widely located in most production areas (TÜİK 2023).

The ever-increasing human population brings with it an enhanced demand for agricultural production. One of the most significant problems unveiled by the increasing population is the limited water resources used in agricultural irrigation due to climate change. These water limitations, known as drought, determine the fate of the ultimate usage of arable lands and the productivity of crops, together with salinization stress (Niu et al. 2014; Zhang et al. 2022). Some physiological impairments caused by drought stress, such as membrane damage, restricted cell enlargement, imbalanced redox homeostasis, cell respiration, and photosynthesis, lower yield and its components (Ahmad et al. 2018; Khan et al. 2021; Wahab et al. 2022). Particularly, vegetables containing 90% or more water and vegetables in the critical development period (fruit setting, flowering, etc.) were severely devastated by drought levels and durations (Khalid et al. 2023). To cope with the devastating effects of drought stress, two fundamental concepts are proposed by researchers: the development and usage of drought-resistance cultivars/genotypes (Li et al. 2023) and the usage of a mitigating agent approach (Tufail et al. 2023; Sun et al. 2023; Urbutis et al. 2023).

In the mitigating approach, some phytohormones, microelements, and amine/indoleamine derivatives applications have caused physiological and biochemical recoveries in plants under drought stress. Silicon is a highly abundant element in soil structure, available for plants in the form of monosilicic acid and stored as SiO₂ in the leaves of plants. Melatonin, or N-acetyl-5-methoxytryptamine, is an indoleamine compound and is a multi-role stress-protective bioactive molecule. It could activate various responsive mechanisms within the plant cell during drought conditions, including regulating ascorbate-glutathione, nitrogen assimilation, protein biosynthesis, recovering chlorophyll content, and photosynthesis (Tiwari et al. 2021; Ren et al. 2021; Altaf et al. 2022). Common responsive mechanisms against drought stress triggered by the application of Si (metalloid) and melatonin (bioactive molecule) are to decrease the Reactive Oxygen Species (ROS) accumulation via enhancing the activity of antioxidant enzymes such as SOD, POD, and CAT; non-enzymatic antioxidant; reduce the transpiration rates, regulate the water balance of plants; and regulate light energy during photosynthesis (Zhang et al. 2018; Mavrič Čermelj et al. 2021; Altaf et al. 2022; Urbutis et al. 2023).

New and practicable strategies need to be adopted in lettuce production to address the drought stress worsened by increasing climate change. Previous studies have revealed that exogenous melatonin and silicon treatment separately can improve photosynthetic processes, promote antioxidant enzyme activity, and consequently contribute to drought tolerance in various species (Korkmaz et al. 2022; Seymen et al. 2024). On the other hand, no previously published study has investigated the effects of Si and melatonin on lettuce in response to drought stress. The primary objective of this experiment is to evaluate the growth patterns of lettuce plants treated with Si and melatonin under drought stress. Therefore, two practically applicable stress mitigants were selected and used to test on lettuce against drought under greenhouse conditions.

2. Materials and Methods

2.1. The Experimental Conditions and Design

The trial was conducted in the greenhouses of Selcuk University, Faculty of Agriculture. The temperature in the greenhouse was monitored between 9.2 and 23.4°C throughout the experiment, with an average temperature of 16.5°C. During the experiment, the relative humidity (RH) in the greenhouse ranged between 22.3% and 60.5% with an average relative humidity of 40.4% (Figure 1). In the study, the lettuce (*Lactuca sativa* L.) cultivar Yörünge was used as plant material and was purchased from Yüksel Tohum Company. The pots with a 19 cm bottom, 29 cm upper diameter, and 24 cm height were used in the experiment. First, the pots were filled with 10.4 kg of soil, and then 3-week-old lettuce seedlings were planted in all plastic pots by the

experimental plan. Lettuce seedlings with a uniform and healthy structure were planted in pots. The lettuce seedlings were planted in April and harvested in May after treatments, and the measurements that were recorded. Fertilizers were supplied with the following instructions suggested by Şalk et al. (2008) for lettuce at the rate of 15 kg da⁻¹ nitrogen (N), 10 kg da⁻¹ phosphorus (P) and 18 kg da⁻¹ potassium (K) to the pot before planting lettuce seedlings.

The research was experimented on in (12 treatments x 6 replicates) 72 pots according to a completely randomized experimental design. Applications consist of the following categories: two foliar applications of possible protectants (S0, S4, S8, Mel0, and Mel150), and two irrigation levels (full irrigation = I100, deficient irrigation = I25). Considering the studies on melatonin in various species, including lettuce, it was observed that the optimum application dose varied between 100 and 200 µM (Can 2023; Kiremit et al. 2024). It was preferred to use a dose of 150 µM due to this perspective. AGRISILICA (26% soluble silicon) granule fertilizer was used as a silicon resource. Most of the studies on silicon have generally focused on concentrations of 2-4 mM Si (as SiO₂). In this study, considering the available research, 4 mM was selected as the optimum dose and 8 mM as the high Si dose. The lettuce seedlings were watered with tap water for the first eight days for adapting to the pots, and then drought stress was applied. Melatonin foliar and silicon application to pots were started 8 days after lettuce seedlings were planted together with drought stress. The silicon was applied once in the soil, and melatonin was applied once in the leaf throughout the experiment. Drought stress was applied to lettuce seedlings as described by Ünlükara et al. (2008). In this regard, the pots were weighed separately with a precision balance after being filled with soil, and then the pots were brought to field capacity and weighed again. Thus, the amount of water necessary to create drought stress was calculated using these weights. The lettuce seedlings were irrigated with 25% of the field capacity value to create drought stress while the control group was irrigated with full irrigation. In order to control the water loss due to evapotranspiration, the pots were checked daily with an electronic scale, and irrigation was provided for the deficient pots.

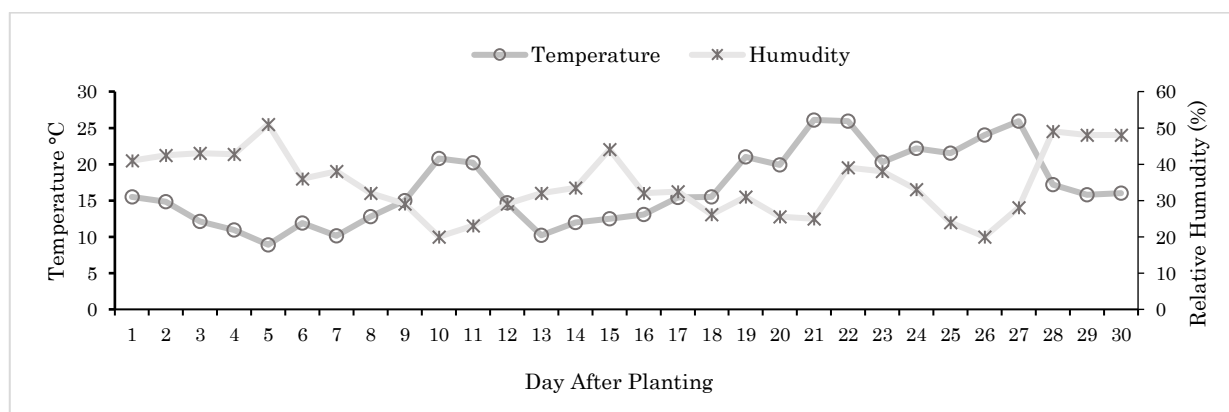


Figure 1. Average temperature and humidity records of experimental area

2.2. Morphological Parameters

During sampling, lettuce plants were carefully removed and washed with tap water and distilled water, respectively. After the wetness of the samples was dried, the fresh weights of lettuce leaves (LFW) and fresh weights of lettuce roots (RFW) were immediately weighed with a precision balance and expressed as grams (g). The lettuce roots and leaves were dried in a hot air oven at 70°C until they reached a constant weight, after which the leaf dry weight (LDW) and root dry weight (RDW) were weighed with a precision balance and expressed as grams (g).

2.3. Chlorophyll Fluorescence Measurements

Before harvesting, chlorophyll fluorescence was measured using a portable LI-600 fluorometer on fully expanded lettuce leaves between 9:00 and 11:00 under clear weather conditions. To measure photosynthetic activity, PhiPSII quantum yield, stomatal conductance, and leaf temperature were measured by a LI-600 fluorometer (Liang et al. 2019).

2.4. Physiological and Biochemical Analyses

The method proposed by Beyer Jr. and Fridovic (1987) was used to measure the SOD content in lettuce at the end of the experiment. Fresh leaves (0.5 g) were digested in liquid nitrogen and homogenized with 1.5 ml of extraction solution [100 mM K-PO₄ buffer (pH 7.0), 2% PVP (polyvinylpyrrolidone) and 1 mM Na₂ EDTA]. This mixture will be centrifuged at 14000 rpm for 20 minutes at +4°C and the supernatant will be mixed with 50 mM phosphate buffer (pH 7.8), 9.9 mM L-methionine, 57 µM NBT, and 1% Triton X-100, and 10 µL riboflavin will be added to start the reaction. Total SOD activity will be calculated in units mg protein⁻¹. The activity of one enzyme unit is defined as the amount of SOD required to produce a 50% inhibition of NBT reduction.

The method proposed by Chance and Maehly (1955) was used to measure the POD content in lettuce at the end of the experiment. The reaction mixture is 3 mL and contains 100 mM potassium phosphate buffer (pH 7.0), 20.1 mM guaiacol, 12.3 mM H₂O₂ and enzyme extract. The reaction will be triggered by the addition of the enzyme extract and monitored over a period of 10 min. Total POD enzyme activity will be calculated from the reaction initial rate (nmol H₂O₂ min⁻¹ mg protein⁻¹) using the extinction coefficient of guaiacol (26.6 mM cm⁻¹, 470 nm).

The protein content in the lettuce seedlings was determined by the Bradford method using 0.5 grams of leaves (Bradford 1976). Leaf samples were ground in 0.05 M phosphate buffer (pH 6.5), and the samples were centrifuged at 15,000 rpm for 20 minutes to quantify the protein. After centrifugation, 0.2 mL of the supernatant was added to 3 mL of Bradford dye, and the samples were measured at 595 nm.

Chlorophyll-a, chlorophyll-b, total chlorophyll, and total carotenoid contents in lettuce leaves were determined by the method described by Lichtenthaler and Buschmann (2001) and Witham et al. (1971), respectively. An amount of 0.2 g of leaf material was extracted in the dark place with 3 mL of 100% acetone solution in a pre-cooled mortar and pestle. After extraction, the homogenate was filtered, and the volume of the homogenate was made up to 5 mL using cold acetone. The absorbance values of the homogenate at 470, 645, and 662 nm were measured using a Shimadzu-UV1900i spectrophotometer. Lichtenthaler and Buschmann (2001) equations were used to calculate the amount of these photosynthetic pigments;

$$\text{Chl a} = 11.75 A_{662} - 2.350 A_{645}$$

$$\text{Chl b} = 18.61 A_{645} - 3.960 A_{662}$$

$$\text{Carotenoid} = 1000 A_{470} - 2.270 Ca - 81.4 Cb/230$$

2.5. Statistical Analysis

Statistical analysis of the data generated within the scope of the study was performed with the Minitab 19 software (Mathews 2004). The data were first subjected to ANOVA analysis. Then the results were tested at a 5% significance level according to Fisher's exact test to determine statistically significant differences between the means of different groups. The same variables were subjected to Principal Component Analysis (PCA) and Pearson correlation coefficient using R Statistical Software, and the parameters found to be significant for melatonin and silicon treatments under drought stress in lettuce seedlings were discussed in detail.

3. Results and Discussion

The results in Figure 1 and Figure 2 indicate that vegetative growth (root-leaf fresh weight) and dry matter (root-leaf dry weight) were significantly changed ($p \leq 0.05$) by different doses of silicon and melatonin treatment under drought stress. Considering Figure 1, 8 mM silicon (I100+S8+M0) and 4 mM silicone+150 mM melatonin (I100+S4+M150) treatments resulted in a significant increase in leaf fresh weight (LFW) of non-drought treated groups compared to the control group (I100+S0+M). In terms of drought stress and treatments, all treatments significantly increased the lettuce leaf fresh weight under drought stress compared to the untreated group (I25+S0+M0), and this increase was highest in the I25+S8+M0 group (relatively higher than I25+S0+M0).

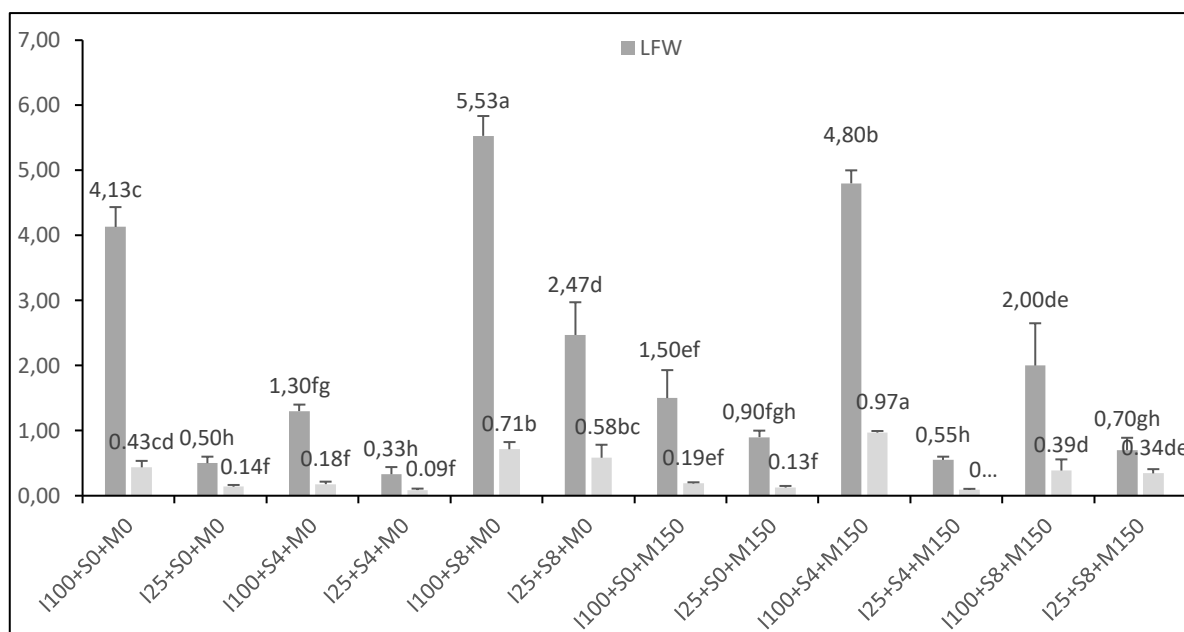


Figure 2. Leaf fresh and dry weight of lettuce (g), different letters represent statistical significance ($p < 0.05$). I100: full irrigation, I25: drought, S0: non-silicon, S4: 4 mM silicon, S8: 8 mM silicon, M0: non-melatonin, M150: 150 mM melatonin.

It is even noticed that the LFW of the I25+S8+M0 group is higher than that of the I100+S0+M150 and I100+S8+M150 groups respectively. In other words, the 8 mM silicon application resulted in about 5-fold higher fresh weight compared to the I25+S0+M0 group, which not only performed the best among the drought treatments but also competed with some of the full irrigation groups (I100+S0+M150 and I100+S8+M150). In the I25+S8+M0 group, the LDW of lettuce was significantly higher than the control group (I100+S0+M0) and other drought-treated groups (I25+S0+M0, I25+S4+M0, I25+S4+M150, I25+S0+M150, I25+S4+M150, I25+S8+M150).

In some studies, the application of silicon alone without stress caused decreases in plant fresh weights. The general trend is that silicon application together with stress reduces the decrease rate of shoot fresh weights (Pei et al. 2009; Haghighi and Pessarakli, 2013). From this perspective, it is seen that Si, which was applied with drought stress in this study, contributed to the dry and fresh weights at different rates and reduced the effect of drought.

Considering Figure 3, the highest root fresh weight (RFW) values of lettuce in all irrigation treatments were recorded in the 8 mM silicon application of I100+S8+M0. Figure 3 also indicates that the 8 mM silicon treatment in drought lettuce (I25+S8+M0) significantly contributed to root growth, even exceeding the performance of the control groups (I100+S0+M0, I100+S4+M0, I100+S8+M0, I100+S0+M150, I100+S4+M150, I100+S8+M150). In lettuce, silicon application alone significantly increased RFW both under drought conditions (I25+S8+M0) and under full irrigation (I100+S8+M0) conditions. However, this was not observed in melatonin treatment alone (I25+S0+M150, I100+S0+M150). In parallel with the fresh weight, the highest lettuce root dry weight was also determined in the I25+S8+M0 and then in the I100+S8+M0 group.

Drought is a worldwide stress factor, causing severe biomass losses in crops, including lettuce. Drought affects the mobilization of stored nutrients for the embryo by affecting α -amylase, β -amylase, and proteases in seed germination, and during growth and development by reducing water content in leaves, closing stomata, and reducing cell growth (Hameed et al. 2021; Razi and Muneer 2021). In order to mitigate the adverse effect of drought on biomass production, various practices, including biochar, plant growth-promoting bacteria (PGPR), microelements, and some chemical treatments, are being employed for that purpose. Previous studies have reported that the application of silicon and melatonin alone under water-limited conditions mitigates the reduction in biomass (Hidalgo-Santiago et al. 2021; Kiremit et al. 2024). In the present study, an 86% reduction in LFW and a 51% reduction in RFW were detected under drought stress. Hidalgo-

Santiago et al. (2021)'s research reported significant biomass reduction in lettuce irrigated at 75% of field capacity, and this reduction was lowered when a silicon-containing fertilizer was applied. Shaffique et al. (2024) research reported that melatonin treatment significantly restored the shoot and root length of tomato seedlings under drought stress. In the present study, silicon application alone (I25+S8+M0) lowered the rate of reduction in lettuce LFW from 86% to 40% compared to the control group (I100+S0+M150), while lettuce RFW increased (I25+S8+M0) approximately twice as much as the control group (I100+S0+M150). Although melatonin and silicon applications caused biomass reductions at varying rates in parallel with previous studies, the greatest effect was observed in the 8 mM silicon application, and silicon application under drought conditions caused the RFW to increase above the control group, unlike other studies. The most probable explanation for this increase in lettuce RFW is an increase in the content of aquaporin in the root zone and an increase in osmotic regulation agents to restore water balance. The dry weight results in this study also support this explanation. When the dry weight data were compared (I100+S0+M0 and I25+S8+M0), it was observed that lettuce root and leaf showed related results (Figure 1 and Figure 2). Therefore, it is possible to conclude that this difference is due to the water contents of the lettuce leaf and root, and Si application improved root and leaf water contents under drought conditions. It is known that silicon-supplied studies in lettuces have low canopy temperature and high-water potential (Villa e Vila et al. 2024).

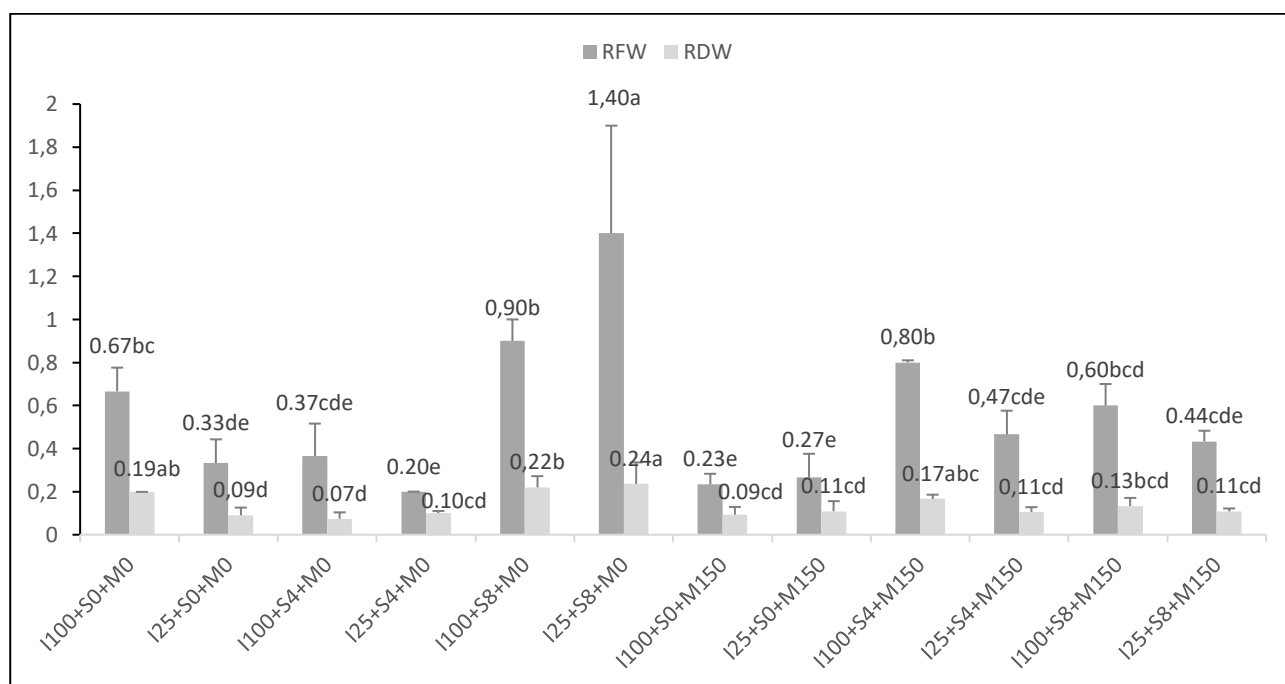


Figure 3. Root fresh and dry weight of lettuce (g), different letters represent statistical significance ($p < 0.05$). I100: full irrigation, I25: drought, S0: non-silicon, S4: 4 mM silicon, S8: 8 mM silicon, M0: non-melatonin, M150: 150 mM melatonin.

In Figure 4, while the total chlorophyll content of lettuce leaves decreased at varying rates (in I25+S0+M0, in I25+S4+M0, I25+S0+M150 and I25+S4+M150, I25+S8+M150) in limited irrigation treatments compared to the control group (I100+S0+M0). In contrast to this decrease pattern, it was observed that chlorophyll content was significantly higher in the I25+S8+M0 group compared to the I100+S0+M0 group. The highest total chlorophyll content was observed in the I100+S4+M0 (28.58) and I100+S4+M150 (37.46) full irrigation groups compared to control group (I100+S0+M0). The results indicated that 4 mM silicon treatment increased leaf chlorophyll pigment in non-drought-treated lettuce leaves, whereas 8 mM silicon treatment contributed highly to lettuce leaf chlorophyll content under drought conditions. However, melatonin + silicon treatments did not show a significant change in lettuce leaf total chlorophyll content under limited irrigation pattern (I25+S0+M0, I25+S0+M150, I25+S4+M150 and I25+S8+M150).

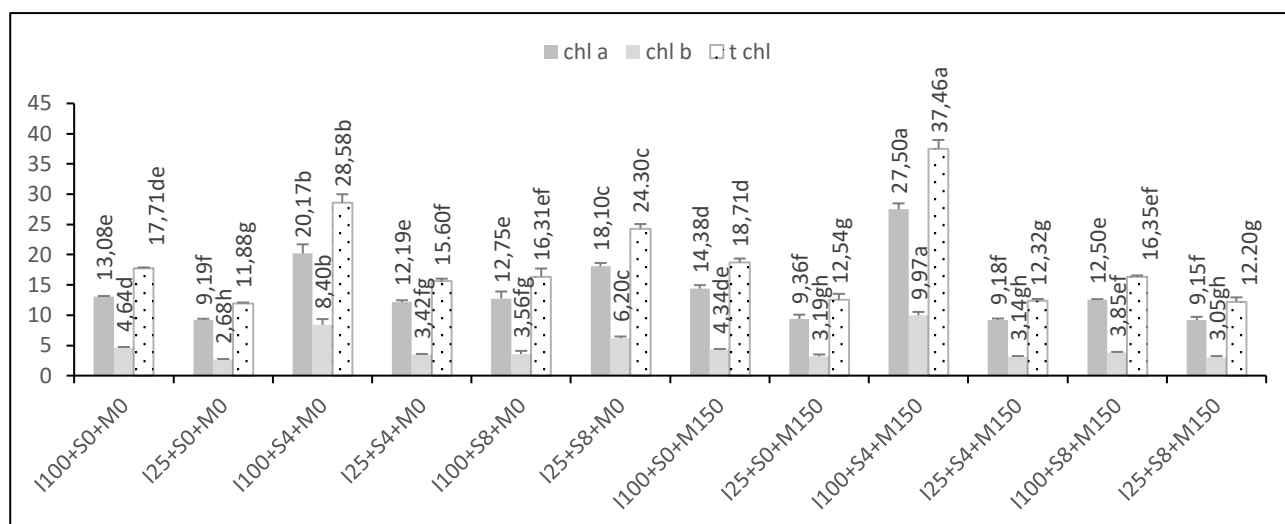


Figure 4. The pigments content (Units?) in lettuce, different letter represent statistical significance ($p < 0.05$). chl a: chlorophyll a, chl b: chlorophyll b, t chl: total chlorophyll, I100: full irrigation, I25: drought, S0: non-silicon, S4: 4 mM silicon, S8: 8 mM silicon, M0: non-melatonin, M150: 150 mM melatonin. (Chlorophyll contents expressed as mg g^{-1})

The melatonin and silicon-treated fully irrigated lettuce leaves carotenoid contents were increased significantly compared to the I100+S0+M0 group. Regarding carotenoid content in drought-treated lettuce seedlings, only the 8 mM silicon treatment caused improvement. In contrast to the carotenoid content, all silicon and melatonin treatments except for I25+S4+M150 significantly increased the protein content of lettuce seedlings under drought stress compared to the I100+S0+M0 group (Figure 5). As in the carotenoid content, this increase was highest in the I25+S8+M0 and I100+S8+M150 groups. Oxidative stress and subsequent reduction in chlorophyll activity and protein breakdown are among the first responses of lettuce plants against drought stress (Shaffique et al. 2022). Shin et al. (2021) found that drought stress did not affect the chlorophyll content of lettuce on the 4th day of drought, while significant decreases in chlorophyll content were reported on the 8th day of drought. Damage to the chloroplast membrane/structure, chlorophyll photo-oxidation, high chlorophyllase activity, and inhibition of chlorophyll synthesis were reported to be the factors reducing chlorophyll content under drought conditions (Chakhchar et al. 2018; Kapoor et al. 2020). As a result, drought generates oxidative stress, which impairs the photosynthetic mechanism and damages the protein structure, thereby leading to cell expansion limitation, increasing lipid peroxidation, and hence inhibiting plant growth (Ors et al. 2021; Razi and Muneer 2021). Carotenoids are crucial for the maintenance of photosynthesis by protecting membrane lipid photo-destruction, acting as an antioxidant agent, and reducing the light pressure on chlorophyll by absorbing excess energy (Maslova et al. 2021). Plants increase some osmoprotectants and protein soluble content in order to maintain cellular turgor under drought stress (Ahmad et al. 2022). In Leitão et al. (2021)'s proteomic study, it was found that sulfurtransferase and aquaporin proteins accumulated in lettuce leaves as a result of abiotic stress. It is predicted that these proteins will provide resistance to drought stress by protecting photosynthesis through their antioxidative properties of sulfurtransferase and increasing water transport efficiency through their water channel properties. To reduce the common detrimental effect of drought, the successful results have been obtained in lettuce by using following applications such as selenium, silicon, organic acid, and melatonin (Kiremit et al. 2024; Kleiber et al. 2024; Tufail et al. 2023; Villa e Vila et al. 2024). In parallel with the mentioned results, in this study, a significant increase in chlorophyll, carotenoid, and protein content of lettuce was detected in the 8 mM silicon application under dry conditions. In particular, melatonin application resulted in increases in the studied parameters of lettuce under full irrigation conditions, while silicon applications resulted in significant improvements in lettuce under drought conditions.

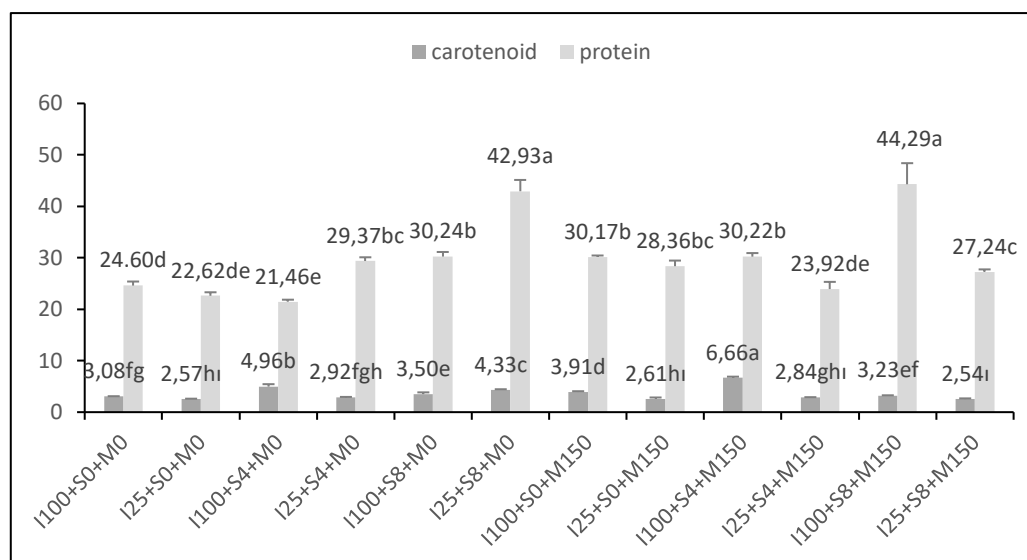


Figure 5. The carotenoid and protein content in lettuce, different letters represent statistical significance (carotenoid content expressed as mg g⁻¹, protein content expressed as µg g⁻¹) (p<0.05). I100: full irrigation, I25: drought, S0: non-silicon, S4: 4 mM silicon, S8: 8 mM silicon, M0: non-melatonin, M150: 150 mM melatonin.

Figure 6 summarizes the status of antioxidative enzymes in silicon- and melatonin-treated lettuces under drought conditions. Based on these data, SOD enzyme increases were recorded in the I25+S8+M150, I25+S4+M150, and I25+S0+M150 groups compared to the I100+S0+M0 group. According to the findings of the study, the highest activity of SOD and POD was observed in the I25+S4+M150 lettuce group. Regarding these findings, in the I25+S8+M150 group, silicon and melatonin treatments enhanced SOD activity and decreased POD activity compared to I25+S0+M0 group. One interesting detail was observed in POD enzyme activity, and while melatonin only slightly increased POD activity in drought-treated groups, silicon and melatonin co-treatment caused a significant increase in POD activity. It is known that the activity of antioxidant enzymes such as SOD, POD, and CAT increases under drought stress in different plant species, including lettuce (Ekinci et al. 2020; El-Bauome et al. 2024; Erol 2024).

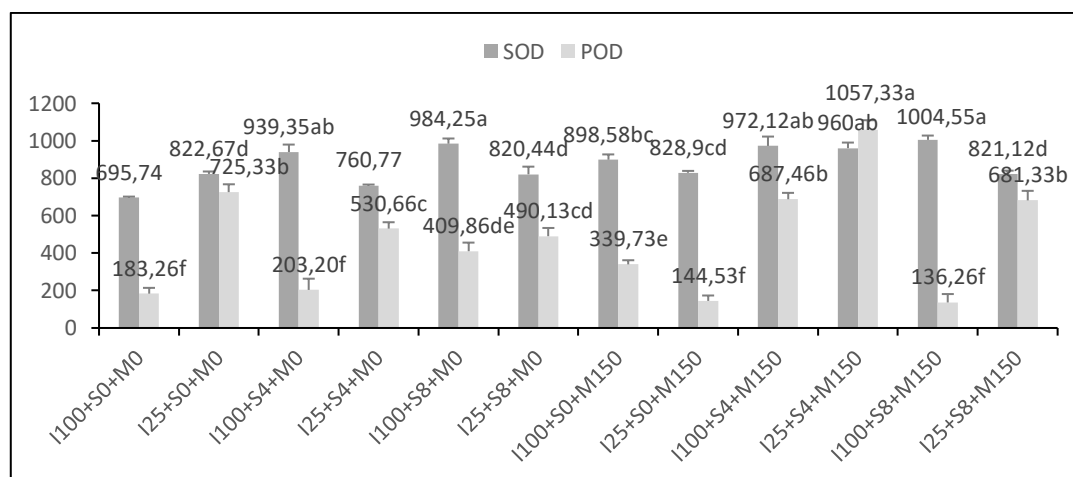


Figure 6. The SOD (µmol min⁻¹ mg⁻¹ FW) and POD (µmol min⁻¹ mg⁻¹ FW) content in lettuce, different letters represent statistical significance (p<0.05). I100: full irrigation, I25: drought, S0: non-silicon, S4: 4 mM silicon, S8: 8 mM silicon, M0: non-melatonin, M150: 150 mM melatonin

Silicon treatments have been reported to increase POD activity in drought, salinity, and heavy metal stress treatments in different plants (Akhtar et al. 2021; Basilio-Apolinar et al. 2021; Bhardwaj et al. 2024). Bhardwaj et al. (2024) reported that nitric oxide application together with Si significantly increased POD content in *Raphanus sativus* and also stated that Si+NO treatment improved the plant defense system during abiotic stress conditions by triggering antioxidant enzymes. Thus, while POD individually targets extracellular H₂O₂, SOD

contributes to plant abiotic stress tolerance rate by targeting superoxide radical. In summary, silicon and melatonin decreased the pressure on energy production and photosynthetic mechanisms with the assistance of the antioxidant enzyme defense system in lettuce under drought stress, while silicon treatments had a positive effect on lettuce water balance.

Table 1 provides the parameters related to photosynthesis and chlorophyll fluorescence. There was a statistically significant difference between drought and whole irrigation groups of lettuce with respect to leaf temperature, stomatal conductance (GSW), and quantum productivity of photosynthesis (PhiPSII). In melatonin and silicon treatments, there was a statistical difference between drought and whole irrigation groups with respect to leaf temperature, stomatal conductance, and PhiPSII. Leaf temperature, stomatal conductance, and PhiPSII have a crucial role in the optimal functioning of the photosynthetic machinery. The higher chlorophyll a, carotenoid, and total chlorophyll content also led to better performance of PhiPSII in the drought-treated lettuce group (I25+S8+M0). The higher content of chlorophyll a, and carotenoid, and better functioning of PhiPSII were also confirmed in the study by Lemos Neto et al. (2021). There is another parameter that ensures the maintenance of photosynthesis: stomatal conductance, which ensures the supply of gas exchange. In the present study, silicon treatment under drought conditions contributed to photosynthesis and subsequently to the dry matter content of lettuce by increasing stomatal conductance and gas exchange (continuity). The present findings are also supported by the results of the study conducted by Hidalgo-Santiago et al. (2021). The stomatal conductance also resulted in a decrease in canopy temperature as a natural consequence of gas exchange through the leaf in the silicon-treated I25+S8+M0 group. The low canopy temperature studies with the aid of silicon treatment have been recorded in many species (Kiremit et al. 2024; Seymen et al. 2024b; Villa e Vila et al. 2024), and this study is in parallel with these studies.

Table 1. Measurement of some photosynthetic parameters in lettuce under water deficit stress

Treatments		Photosynthesis		
		Tleaf (°C)	GSW (mol m ⁻² s ⁻¹)	PhiPSII
Irrigation	I100	25.43 ^b	0.521 ^a	0.671 ^a
	I25	26.11 ^a	0.391 ^b	0.593 ^b
Silicon	S0	25.80 ^{ns}	0.426 ^b	0.593 ^b
	S4	25.79 ^{ns}	0.443 ^b	0.630 ^b
	S8	25.71 ^{ns}	0.500 ^a	0.674 ^a
Melatonin	M0	25.77 ^{ns}	0.469 ^a	0.656 ^a
	M150	25.50 ^{ns}	0.443 ^b	0.608 ^b
Irrigation x Silicon x Melatonin Interactions				
	I100+S0+M0	25.16 ^d	0.508 ^a	0.617 ^{ab}
	I100+S4+M0	25.10 ^d	0.520 ^a	0.631 ^{ab}
	I100+S8+M0	25.10 ^d	0.514 ^a	0.733 ^a
	I100+S0+M150	25.64 ^{cd}	0.510 ^a	0.683 ^{ab}
	I100+S4+M150	25.54 ^{cd}	0.510 ^a	0.702 ^{ab}
	I100+S8+M150	26.02 ^{bc}	0.552 ^a	0.672 ^{ab}
	I25+S0+M0	27.02 ^a	0.318 ^b	0.413 ^c
	I25+S4+M0	26.95 ^a	0.378 ^b	0.586 ^b
	I25+S8+M0	25.26 ^d	0.578 ^a	0.672 ^{ab}
	I25+S0+M150	25.38 ^{cd}	0.356 ^b	0.658 ^{ab}
	I25+S4+M150	25.56 ^{cd}	0.364 ^b	0.631 ^{ab}
	I25+S8+M150	26.95 ^{ab}	0.356 ^b	0.631 ^{ab}

ns: non-significant, a,b,c Values within a row with different superscripts differ significantly at P<0.05, PhiPSII- quantum productivity of photosynthesis, GSW: Stomatal Conductance, Tleaf: leaf temperature.

The correlation matrix (Pearson) was generated using the features included in the study (Figure 7). In the current study, performed with silicon and melatonin treatments in limited irrigated lettuce, a negative moderate statistically significant relationship was found between Tleaf-PhiPSII, Tleaf-GSW, Tleaf-LFW, POD-PSII, and POD-GSW. The study also revealed a moderate positive statistically significant relationship between chl b-PhiPSII, chl b-GSW, chl b-LFW/LDW, Car-PhiPSII, Car-GSW, car-LFW, chl a-PhiPSII, chl a-LFW/LDW, chl a-GSW, t chl-PtiPSII, t chl-GSW, t chl-LFW/LDW, PhiPSII-LFW, GSW-protein, GSW-RFW, GSW-LFW/LDW, protein-RFW. A statistically significant and a very strong positive correlation was found between chl b-car,

chl b-chl a, chl b-t chl, car-t chl and chl a-t chl. The final crucial finding extracted from Figure 7 is that there is a statistically significant and strong positive correlation between PhiPSII-GSW. According to the data, there is a positive correlation between stomatal conductance and protein content, root fresh weight, leaf fresh and dry weights of lettuce treated with silicon+melatonin under drought stress and stomatal opening-fresh/dry increase is confirmed by some other studies (Akhtar et al. 2022; Alotaibi et al. 2023; Ramadan et al. 2024). In the present study, it is clearly found that silicon treatment has a significant positive effect on stomatal conductance in lettuce. Arif et al. (2021) explain that silicon has a positive effect on stomatal conductance and gas exchange by stimulating genes related to ABA biosynthesis, and these positive effects are reflected in the photosynthetic properties of the plant. Evidence supporting this study from a distinct perspective comes from the study of Markovich et al. (2022), and they state that drought application in combination with low silicon fertilization reduces the stomatal conductance. However, the positive correlation between PSII of chlorophyll and carotenoid pigments, stomatal conductance, and leaf fresh-dry weights also indicates that the photosynthetic mechanism remained unaffected for a certain period of time under drought stress in lettuce treated with silicon (Bukhari et al. 2021; Fatemi et al. 2020; Hassan et al. 2021; Seymen et al. 2024a). Moreover, as a natural consequence of the strong correlation between PSII and GSW, an increase in fresh and dry weight was observed in silicon-treated lettuce under drought stress in the present study.

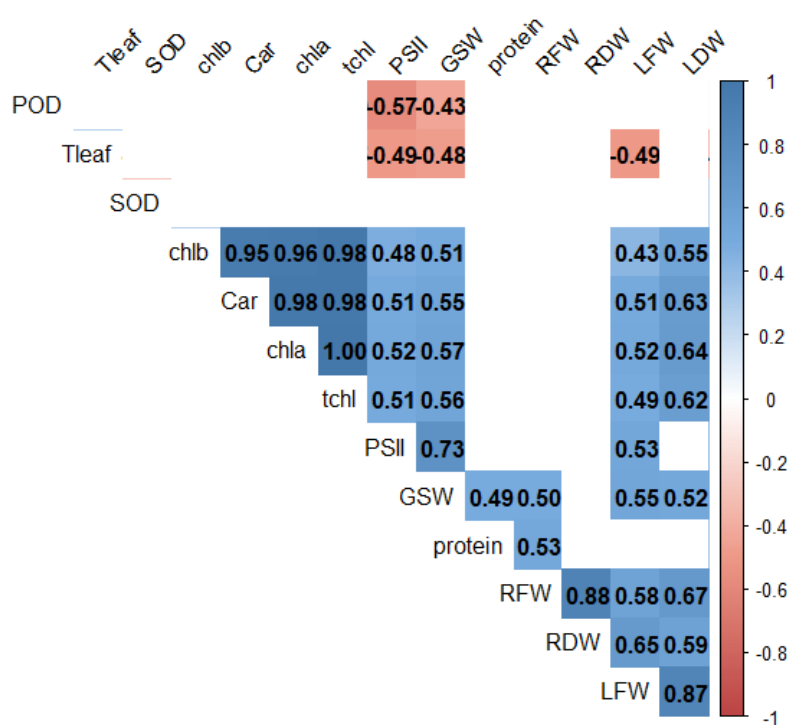


Figure 7. Pearson correlation matrix between the variables (blank boxes represent statistically insignificant data; the remaining-colored boxes are all statistically $p < 0.001$)

The principal components graph provided in Figure 8 and Table 2 explains 63.57% (the first two components) of the total variation. 83% of the total variation is explained by 4 components. The first component explained 48% of the variance and was the most significant contributor. Except for the Tleaf and POD parameters, the other parameters contributed significantly to explain 48% of the variance of PC1 (Figure 8 and Table 2). On the other hand, the second component explained 14.8% of the variance, with Tleaf and POD contributing the highest to the variance. Explaining 60% or more variation in the first two components has been used in many studies as an acceptable threshold and has been used in data classification (Zhang et al. 2018; Martinez et al. 2020).

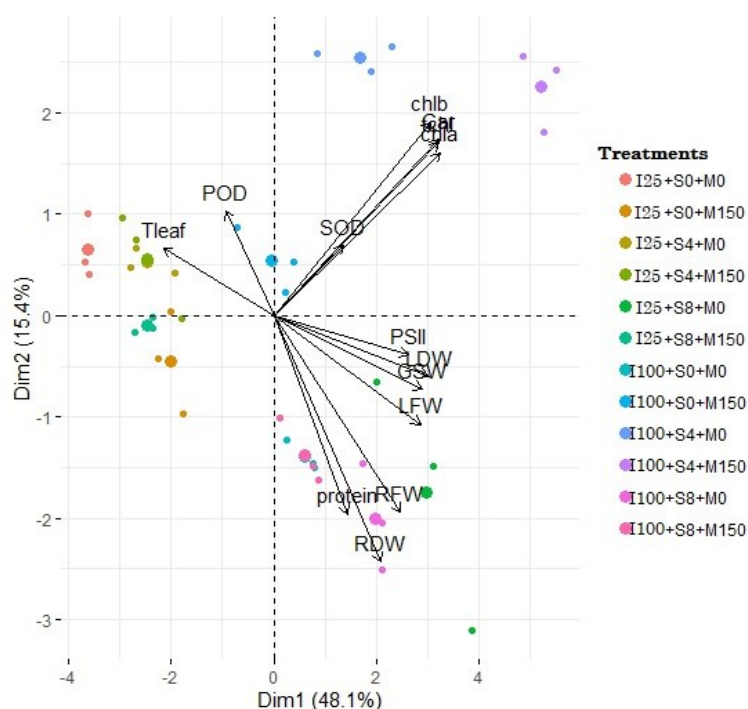


Figure 8. Principle Component analyses, Biplot graph visualized from PC1 and PC2 including variables

Table 2. Principle Component analyses results extracted from included traits

Items	PC1	PC2	PC3	PC4
Eigen value	6.738	2.162	1.596	1.065
Percentage of variance	48.12	15.45	11.40	7.60
Cumulative variance	48.12	63.57	74.97	82.57
Eigen vectors				
LFW	-0.296	0.196	-0.107	0.167
LDW	-0.313	0.109	-0.261	0.010
RFW	-0.256	0.354	-0.330	-0.020
RDW	-0.215	0.445	-0.282	0.179
Chl a	-0.336	-0.294	-0.046	0.079
Chl b	-0.316	-0.349	-0.019	0.117
Tchl	-0.333	-0.313	-0.039	0.091
Car	-0.333	-0.318	-0.066	-0.014
Protein	-0.149	0.358	0.097	-0.448
SOD	-0.140	-0.126	0.029	-0.781
POD	0.095	-0.188	-0.645	-0.273
Tleaf	0.222	-0.121	-0.144	-0.091
PSII	-0.272	0.070	0.446	-0.039
GSW	-0.300	0.133	0.275	-0.117

In the graph, all the points placed in rectangles indicate drought-treated lettuce with silicon and melatonin, while the points placed in the circle belong to the I25+S8+M0 group. The biplot plot indicates that the means of all treatments were placed at a different location from the origin and were grouped into three different treatments whose means differed from each other in general. In the study conducted by Sattar et al. (2023) similar to the present study, the treatments were grouped into 4 distinct categories: individual silicon-melatonin under drought, individual silicon-melatonin to control, combined silicon-melatonin drought and combined silicon-melatonin under drought. Except for I25+S8+M0, in the present study, the silicon, melatonin, and silicon+melatonin treated groups formed one cluster under drought conditions, while the silicon, melatonin, and silicon+melatonin treated groups formed two clusters under full irrigation conditions (first

group: I100+S4+M0, I100+S8+M150, second group: I100+S0+M0, I100+S8+M0, I100+S8+M150 and I25+S8+M0). The I25+S8+M0 group was located in the area where the non-drought-treated groups were located, which is another indicator that silicon treatment significantly mitigated adverse effects of drought. It has been reported by Kal et al. (2023) that the principal component analysis method provides significant insights in stress studies. As evidenced in Figure 8, the LFW, LDW, RFW, RDW, GSW, protein, and PSII are the variables used in the non-drought-treated group allocation, and it validated with correlation analysis (Figure 7) that have a critical impact on biomass production. On the other hand, the variables Tleaf, POD, and partly SOD were also used as indicators for the allocation of drought stress-related groups. Faisal et al. (2024) used some of these variables effectively in the allocation of treatments to alleviate heavy metal stress in PCA analysis, and these results generated consistent results with this study.

4. Conclusions

In this study, drought stress in lettuce and melatonin/silicon as a stress mitigation agent were tested in greenhouse conditions. Out of all treatments, 8 mM silicon treatment reduced the severe effect of drought by improving various parameters such as RFW, RDW, LFW, LDR, PSII, GSW, and protein in lettuce. Based on the results of the present study, it was observed that silicon fertilization improves lettuce cultivation under limited irrigation conditions, which can be applied in practice. The study also revealed two more key points: (1) melatonin treatment of well-watered lettuce resulted an increase in biomass and some related parameters, and (2) co-treatment of silicon and melatonin resulted in an increase in POD values. Consequently, the physiological investigation of these two points will be a priority in the following periods, and silicon fertilization and melatonin treatments will contribute to lettuce cultivation at varying rates.

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References

- Ahmad N, Virk AL, Hussain S, Hafeez MB, Haider FU, Rehmani MIA, Yasir TA, Asif A (2022). Integrated application of plant bioregulator and micronutrients improves crop physiology, productivity and grain biofortification of delayed sown wheat. *Environmental Science and Pollution Research* 29, 52534-52543. <https://doi.org/10.1007/s11356-022-19476-5>.
- Ahmad Z, Waraich EA, Akhtar S, Anjum S, Ahmad T, Mahboob W, Abdul-Hafeez O, Tapera T, Labuschagne M, Rizwan M (2018). Physiological responses of wheat to drought stress and its mitigation approaches. *Acta Physiologiae Plantarum* 40, 1-13. <https://doi.org/10.1007/s11738-018-2651-6>.
- Akhtar G, Faried HN, Razzaq K, Ullah S, Wattoo FM, Shehzad MA, Sajjad Y, Ahsan M, Javed T, Dessoky ES, Abdelsalam NR, Chattha MS (2022). Chitosan-induced physiological and biochemical regulations confer drought tolerance in pot marigold (*Calendula officinalis* L.). *Agronomy* 12(2), 474. <https://doi.org/10.3390/agronomy12020474>.
- Akhtar N, Ilyas N, Hayat R, Yasmin H, Noureldeen A, Ahmad P (2021). Synergistic effects of plant growth promoting rhizobacteria and silicon dioxide nano-particles for amelioration of drought stress in wheat. *Plant Physiology and Biochemistry* 166, 160-176. <https://doi.org/10.1016/j.plaphy.2021.05.039>.
- Alotaibi MO, Ikram M, Alotaibi NM, Hussain GS, Ghoneim AM, Younis U, Naz N, Danish S (2023). Examining the role of AMF-Biochar in the regulation of spinach growth attributes, nutrients concentrations, and antioxidant enzymes in mitigating drought stress. *Plant Stress* 10, 100205. <https://doi.org/10.1016/j.stress.2023.100205>.
- Altaf MA, Shahid R, Ren MX, Naz S, Altaf MM, Khan LU, Tiwari RK, Lal MK, Shahid MA, Kumar R, Nawaz MA, Jahan MS, Jan BL, Ahmad P (2022). Melatonin improves drought stress tolerance of tomato by

- modulating plant growth, root architecture, photosynthesis, and antioxidant defense system. *Antioxidants* 11(2), 309. <https://doi.org/10.3390/antiox11020309>.
- Arif Y, Singh P, Bajguz A, Alam P, Hayat S (2021). Silicon mediated abiotic stress tolerance in plants using physio-biochemical, omic approach and cross-talk with phytohormones. *Plant Physiology and Biochemistry* 166, 278-289. <https://doi.org/10.1016/j.plaphy.2021.06.002>.
- Basilio-Apolinar A, Vara LEG, Ramírez-Pimentel JG, Aguirre-Mancilla CL, Iturriaga G, Covarrubias-Prieto J, Raya-Pérez JC (2021). Silicon induces changes in the antioxidant system of millet cultivated in drought and salinity. *Chilean Journal of Agricultural Research* 81, 655-663. <http://dx.doi.org/10.4067/S0718-58392021000400655>.
- Bergmeyer HU (1965). *Methods of enzymatic analysis*. Academic Press, New York 1965.
- Beyer Jr WF, Fridovich I (1987). Assaying for superoxide dismutase activity: some large consequences of minor changes in conditions. *Analytical Biochemistry* 161(2), 559-566. [https://doi.org/10.1016/0003-2697\(87\)90489-1](https://doi.org/10.1016/0003-2697(87)90489-1)
- Bhardwaj S, Verma T, Kour J, Singh AD, Bhardwaj R, Sharma NR, Ansari S, Raza A, Prasad PVV, Thakur U, Kapoor D (2024). Silicon and nitric oxide modulate growth attributes, antioxidant defense system and osmolytes accumulation in radish (*Raphanus sativus* L.) under arsenic toxicity. *Plant Stress* 12, 100473. <https://doi.org/10.1016/j.stress.2024.100473>.
- Bradford MM (1976). A rapid and sensitive method for the quantitation of microgram quantities of protein utilizing the principle of protein-dye binding. *Analytical Biochemistry* 72, 248-254. [https://doi.org/10.1016/0003-2697\(76\)90527-3](https://doi.org/10.1016/0003-2697(76)90527-3).
- Bukhari MA, Ahmad Z, Ashraf MY, Afzal M, Nawaz F, Nafees M, Jatoi WN, Malghani NA, Shah AN, Manan A (2021). Silicon mitigates drought stress in wheat (*Triticum aestivum* L.) through improving photosynthetic pigments, biochemical and yield characters. *Silicon* 13, 4757-4772. <https://doi.org/10.1007/s12633-020-00797-4>.
- Can H (2023). Melatonin application at different doses changes the physiological responses in favor of cabbage seedlings (*Brassica oleracea* var. *capitata*) against flooding stress. *Gesunde Pflanzen* 75, 2733-2745. <https://doi.org/10.1007/s10343-023-00873-w>.
- Casey L, Freeman B, Francis K, Brychkova G, McKeown P, Spillane C, Bezrukov A, Zaworotko M, Styles D (2022). Comparative environmental footprints of lettuce supplied by hydroponic controlled-environment agriculture and field-based supply chains. *Journal of Cleaner Production* 369, 133214. <https://doi.org/10.1016/j.jclepro.2022.133214>.
- Chakhchar A, Lamaoui M, Aissam S, Ferradous A, Wahbi S, El Mousadik A, Ibnsouda-Koraichi S, Filali-Maltouf A, El Modafar C (2018). Using chlorophyll fluorescence, photosynthetic enzymes and pigment composition to discriminate drought-tolerant ecotypes of *Argania spinosa*. *Plant Biosystems-An International Journal Dealing with all Aspects of Plant Biology* 152, 356-367. <https://doi.org/10.1080/11263504.2017.1297334>.
- Chance B, Maehly AC (1955). Assay of catalases and peroxidases. *Methods in Enzymology* [https://doi.org/10.1016/S0076-6879\(55\)02300-8](https://doi.org/10.1016/S0076-6879(55)02300-8).
- Ekinci M, Ors S, Yildirim E, Turan M, Sahin U, Dursun A, Kul R (2020). Determination of physiological indices and some antioxidant enzymes of chard exposed to nitric oxide under drought stress. *Russian journal of plant physiology* 67, 740-749. <https://doi.org/10.1134/S1021443720040056>.
- El-Bauome HA, Doklega SM, Saleh SA, Mohamed AS, Suliman AA, Abd El-Hady MAM (2024). Effects of melatonin on lettuce plant growth, antioxidant enzymes and photosynthetic pigments under salinity stress conditions. *Folia Horticulturae* 36, 1-17. <https://doi.org/10.2478/fhort-2024-0001>.
- Erol UH (2024). Comparison of morphological, biochemical and enzymatic responses of some capsicum species to drought stress during developmental stages. *Russian Journal of Plant Physiology* 71, 106. <https://doi.org/10.1134/S1021443724605895>.
- Faisal M, Faizan M, Soysal S, Alatar AA (2024). Synergistic application of melatonin and silicon oxide nanoparticles modulates reactive oxygen species generation and the antioxidant defense system: a strategy

- for cadmium tolerance in rice. *Frontiers in Plant Science* 15, 1484600. <https://doi.org/10.3389/fpls.2024.1484600>.
- Fatemi H, Pour BE, Rizwan M (2020). Isolation and characterization of lead (Pb) resistant microbes and their combined use with silicon nanoparticles improved the growth, photosynthesis and antioxidant capacity of coriander (*Coriandrum sativum* L.) under Pb stress. *Environmental Pollution* 266, 114982. <https://doi.org/10.1016/j.envpol.2020.114982>.
- Haghighi M, Pessarakli M (2013). Influence of silicon and nano-silicon on salinity tolerance of cherry tomatoes (*Solanum lycopersicum* L.) at early growth stage. *Scientia Horticulturae* 161, 111-117. <https://doi.org/10.1016/j.scienta.2013.06.034>
- Hameed A, Farooq T, Hameed A, Sheikh MA (2021). Sodium nitroprusside mediated priming memory invokes water-deficit stress acclimation in wheat plants through physio-biochemical alterations. *Plant Physiology and Biochemistry* 160, 329-340. <https://doi.org/10.1016/j.plaphy.2021.01.037>.
- Hassan H, Alatawi A, Abdulmajeed A, Emam M, Khattab H (2021). Roles of Si and SiNPs in improving thermotolerance of wheat photosynthetic machinery via upregulation of PsbH, PsbB and PsbD genes encoding PSII core proteins. *Horticulturae* 7(2), 16. <https://doi.org/10.3390/horticulturae7020016>.
- Hidalgo-Santiago L, Navarro-León E, López-Moreno FJ, Arjó G, González LM, Ruiz JM, Blasco B (2021). The application of the silicon-based biostimulant Codasil® offset water deficit of lettuce plants. *Scientia Horticulturae* 285, 110177. <https://doi.org/10.1016/j.scienta.2021.110177>.
- Kal Ü, Dal Y, Kayak N, Yavuz D, Türkmen Ö, Seymen M (2023). Application of nitrogen for mitigating the adverse effects of flooding stress in lettuce. *Journal of Plant Nutrition* 46, 4664-4678. <https://doi.org/10.1080/01904167.2023.2240831>.
- Kapoor D, Bhardwaj S, Landi M, Sharma A, Ramakrishnan M, Sharma A (2020). The impact of drought in plant metabolism: How to exploit tolerance mechanisms to increase crop production. *Applied Sciences* 10(16), 5692. <https://doi.org/10.3390/app10165692>.
- Khalid MF, Huda S, Yong M, Li L, Li L, Chen ZH, Ahmed T (2023). Alleviation of drought and salt stress in vegetables: crop responses and mitigation strategies. *Plant Growth Regulation* 99(2), 177-194. <https://doi.org/10.1007/s10725-022-00905-x>.
- Khan S, Basit A, Hafeez MB, Irshad S, Bashir S, Bashir S, Maqbool MM, Saddiq MS, Hasnain Z, Aljuaid BS, El-Shehawi AM, Li Y (2021). Moringa leaf extract improves biochemical attributes, yield and grain quality of rice (*Oryza sativa* L.) under drought stress. *Plos one* 16(7), e0254452. <https://doi.org/10.1371/journal.pone.0254452>.
- Kiremit MS, Akinoğlu G, Mitrovica B, Rakıçoğlu S (2024). Enhancing drought-salinity stress tolerance in lettuce: Synergistic effects of salicylic acid and melatonin. *South African Journal of Botany* 172, 212-226. <https://doi.org/10.1016/j.sajb.2024.07.021>.
- Kleiber T, Chadzinikolau T, Formela-Luboińska M, Lartey JL, Kosiada T (2024). Enhancing lettuce drought tolerance: The role of organic acids in photosynthesis and oxidative defense. *Applied Sciences* 14(12), 5119. <https://doi.org/10.3390/app14125119>.
- Korkmaz N, Aşkın MA, Altunlu H, Polat M, Okatan V, Kahramanoğlu İ (2022). The effects of melatonin application on the drought stress of different citrus rootstocks. *Turkish Journal of Agriculture and Forestry* 46(4), 585-600. <https://doi.org/10.55730/1300-011X.3027>
- Leitão I, Leclercq CC, Ribeiro DM, Renaut J, Almeida AM, Martins LL, Mourato MP (2021). Stress response of lettuce (*Lactuca sativa*) to environmental contamination with selected pharmaceuticals: A proteomic study. *Journal of Proteomics* 245, 104291. <https://doi.org/10.1016/j.jprot.2021.104291>.
- Lemos Neto HdS, de Almeida Guimarães M, Mesquita RO, Sousa Freitas WE, de Oliveira AB, da Silva Dias N, Gomes-Filho E (2021). Silicon supplementation induces physiological and biochemical changes that assist lettuce salinity tolerance. *Silicon* 13, 4075-4089. <https://doi.org/10.1007/s12633-020-00715-8>.

- Li J, Abbas K, Wang L, Gong B, Hou S, Wang W, Dai B, Xia H, Wu X, Lü G, Gao H (2023). Drought resistance index screening and evaluation of lettuce under water deficit conditions on the basis of morphological and physiological differences. *Frontiers in Plant Science* 14. <https://doi.org/10.3389/fpls.2023.1228084>.
- Liang D, Ni Z, Xia H, Xie Y, Lv X, Wang J, Lin L, Deng Q, Luo X (2019). Exogenous melatonin promotes biomass accumulation and photosynthesis of kiwifruit seedlings under drought stress. *Scientia Horticulturae* 246, 34-43. <https://doi.org/10.1016/j.scienta.2018.10.058>.
- Lichtenthaler HK, Buschmann C (2001). Chlorophylls and carotenoids: Measurement and characterization by UV-VIS spectroscopy. *Current Protocols in Food Analytical Chemistry* 1(1), F4-3. <https://doi.org/10.1002/0471142913.faf0403s01>.
- Mampholo BM, Maboko MM, Soundy P, Sivakumar D (2016). Phytochemicals and overall quality of leafy lettuce (*Lactuca sativa* L.) varieties grown in closed hydroponic system. *Journal of Food Quality* 39(6), 805-815. <https://doi.org/10.1111/jfq.12234>.
- Markovich O, Zexer N, Negin B, Zait Y, Blum S, Ben-Gal A, RivkaElbaum R (2022). Low Si combined with drought causes reduced transpiration in sorghum Lsi1 mutant. *Plant and Soil* 477, 57-67. <https://doi.org/10.1007/s11104-022-05298-4>.
- Martínez MG, Floquet P, Dupont C, da Silva Perez D, Meyer X M (2020). Assessing the impact of woody and agricultural biomass variability on its behaviour in torrefaction through Principal Component Analysis. *Biomass and Bioenergy* 134, 105474. <https://doi.org/10.1016/j.biombioe.2020.105474>.
- Maslova TG, Markovskaya EF, Slemnev NN (2021). Functions of carotenoids in leaves of higher plants (Review). *Biology Bulletin Reviews* 11, 476-487. <https://doi.org/10.1134/S2079086421050078>.
- Mathews PG (2004). Design of experiments with MINITAB. Quality press.
- Mavrič Čermelj A, Golob A, Vogel-Mikuš K, Germ M (2021). Silicon mitigates negative impacts of drought and UV-b radiation in plants. *Plants* 11(1): 91. <https://doi.org/10.3390/plants11010091>.
- Michelon N, Pennisi G, Myint NO, Dall'Olio G, Batista LP, Salviano AAC, Gruda NS, Orsini F, Gianquinto G (2020). Strategies for improved yield and water use efficiency of lettuce (*Lactuca sativa* L.) through simplified soilless cultivation under semi-arid climate. *Agronomy* 10(9), 1379. <https://doi.org/10.3390/agronomy10091379>.
- Niu S, Luo Y, Li D, Cao S, Xia J, Li J, Smith MD (2014). Plant growth and mortality under climatic extremes: an overview. *Environmental and Experimental Botany* 98, 13-19. <https://doi.org/10.1016/j.envexpbot.2013.10.004>.
- Ors S, Ekinci M, Yildirim E, Sahin U, Turan M, Dursun A (2021). Interactive effects of salinity and drought stress on photosynthetic characteristics and physiology of tomato (*Lycopersicon esculentum* L.) seedlings. *South African Journal of Botany* 137, 335-339. <https://doi.org/10.1016/j.sajb.2020.10.031>.
- Pei ZF, Ming DF, Liu D, Wan GL, Geng XX, Gong HJ, Zhou WJ (2010). Silicon improves the tolerance to water-deficit stress induced by polyethylene glycol in wheat (*Triticum aestivum* L.) seedlings. *Journal of Plant Growth Regulation* 29, 106–115 (2010). <https://link.springer.com/article/10.1007/s00344-009-9120-9>.
- Ramadan KM, El-Beltagi HS, Makhoulouf BSI, Khalil SRAE, Al-Daej MI, Shalaby TA, Bendary ES, Saudy HS (2024). Carboxymethyl chitosan improves sugar beet tolerance to drought by controlling enzyme activity and stomatal conductance. *Polish Journal of Environmental Studies* 34(1), 791-800.
- Razi K, Muneer S (2021). Drought stress-induced physiological mechanisms, signaling pathways and molecular response of chloroplasts in common vegetable crops. *Critical Reviews in Biotechnology* 41, 669-691. <https://doi.org/10.1080/07388551.2021.1874280>.
- Ren J, Yang X, Ma C, Wang Y, Zhao J (2021). Melatonin enhances drought stress tolerance in maize through coordinated regulation of carbon and nitrogen assimilation. *Plant Physiology and Biochemistry* 167, 958-969. <https://doi.org/10.1016/j.plaphy.2021.09.007>.
- Şalk A, Arın L, Deveci M, Polat S (2008). Özel sebzeçilik. Namık Kemal Üniversitesi Ziraat Fakültesi pp 448.

- Sattar A, Sher A, Ijaz M, Ul-Allah S, Hussain S, Rasheed U, Hussain J, Al-Qahtani SM, Al-Harbi NA, Mahmoud SF, Ibrahim MFM (2023). Modulation of antioxidant defense mechanisms and morpho-physiological attributes of wheat through exogenous application of silicon and melatonin under water deficit conditions. *Sustainability* 15(9), 7426. <https://doi.org/10.3390/su15097426>.
- Seymen M, Alkhateb R, Mutlu A, Yavuz D (2024a). Do exogenous melatonin and nitric oxide mitigate the adverse effects of flooding stress in spinach? *Scientia Horticulturae* 330, 113081. <https://doi.org/10.1016/j.scienta.2024.113081>.
- Seymen M, Erçetin M, Yavuz D, Kıymacı G, Kayak N, Mutlu A, Kurtar ES (2024b). Agronomic and physio-biochemical responses to exogenous nitric oxide (NO) application in cauliflower under water stress conditions. *Scientia Horticulturae* 331, 113116. <https://doi.org/10.1016/j.scienta.2024.113116>.
- Seymen M, Yavuz D, Can H, Kıymacı G, Türkmen Ö, Paksoy M, Yavuz N, Kayak N, Kurtar ES (2024). Molecular and physiological responses to exogenously applied melatonin in spinach under deficit irrigation conditions. *Journal of Plant Growth Regulation* 43(6), 1858-1874. <https://doi.org/10.1007/s00344-023-11226-2>.
- Shaffique S, Khan MA, Imran M, Kang SM, Park YS, Wani SH, Lee IJ (2022). Research progress in the field of microbial mitigation of drought stress in plants. *Frontiers in Plant Science* 13, 870626. <https://doi.org/10.3389/fpls.2022.870626>.
- Shaffique S, Shah AA, Kang SM, Injamum-Ul-Hoque M, Shahzad R, Azzawi TNIA, Yun BW, Lee IJ (2024). Melatonin: dual players mitigating drought-induced stress in tomatoes via modulation of phytohormones and antioxidant signaling cascades. *BMC Plant Biology* 24, 1101. <https://doi.org/10.1186/s12870-024-05752-8>.
- Shin YK, Bhandari SR, Jo JS, Song JW, Lee JG (2021). Effect of drought stress on chlorophyll fluorescence parameters, phytochemical contents, and antioxidant activities in lettuce seedlings. *Horticulturae* 7(8), 238. <https://doi.org/10.3390/horticulturae7080238>.
- Sun H, Jia M, Wang Y, Lu H, Wang X (2023). The complexity of melatonin and other phytohormones crosstalk with other signaling molecules for drought tolerance in horticultural crops. *Scientia Horticulturae* 321, 112348. <https://doi.org/10.1016/j.scienta.2023.112348>.
- Tiwari RK, Lal MK, Kumar R, Chourasia KN, Naga KC, Kumar D, Das SK, Zinta G (2021). Mechanistic insights on melatonin-mediated drought stress mitigation in plants. *Physiologia Plantarum* 172(2), 1212-1226. <https://doi.org/10.1111/ppl.13307>.
- Tufail B, Ashraf K, Abbasi A, Ali HM, Sultan K, Munir T, Khan MT, uz Zaman Q (2023). Effect of selenium on growth, physio-biochemical and yield traits of lettuce under limited water regimes. *Sustainability* 15(8), 6804. <https://doi.org/10.3390/su15086804>.
- TÜİK (2023). Bitkisel Üretim İstatistikleri. <https://www.tuik.gov.tr/> (access date:01.06.2024).
- Ünlükara A, Cemek B, Karaman S, Erşahin S (2008). Response of lettuce (*Lactuca sativa* var. *crispa*) to salinity of irrigation water. *New Zealand Journal of Crop and Horticultural Science* 36(4), 265-273. <https://doi.org/10.1080/01140670809510243>.
- Urbutis M, Laužikė K, Samuolienė G (2023). Exogenous phytohormones: effects on lettuce photosynthesis, antioxidant response and growth. *Horticulturae* 9(7), 792. <https://doi.org/10.3390/horticulturae9070792>.
- Velikova V, Yordanov I, Edreva A (2000). Oxidative stress and some antioxidant systems in acid rain-treated bean plants: protective role of exogenous polyamines. *Plant Science* 151, 59-66. [https://doi.org/10.1016/S0168-9452\(99\)00197-1](https://doi.org/10.1016/S0168-9452(99)00197-1).
- Villa e Vila V, Marques PAA, Gomes TM, Nunes AF, Montenegro VG, Wenneck GS, Franco LB (2024). Deficit irrigation with silicon application as strategy to increase yield, photosynthesis and water productivity in lettuce crops. *Plants* 13(7), 1029. <https://doi.org/10.3390/plants13071029>.
- Wahab A, Abdi G, Saleem MH, Ali B, Ullah S, Shah W, Mumtaz S, Yasin G, Muresan CC, Marc RA (2022). Plants' physio-biochemical and phyto-hormonal responses to alleviate the adverse effects of drought stress: A comprehensive review. *Plants* 11(13), 1620. <https://doi.org/10.3390/plants11131620>.

- Witham FH, Blaydes DF, Devlin RM (1971). Experiments in plant physiology. Wageningen University and Research Library catalog.
- Zhang H, Zhu J, Gong Z, Zhu JK (2022). Abiotic stress responses in plants. *Nature Reviews Genetics* 23(2), 104-119. <https://doi.org/10.1038/s41576-021-00413-0>.
- Zhang X, Wei S, Sun Q, Wadood SA, Guo B (2018). Source identification and spatial distribution of arsenic and heavy metals in agricultural soil around Hunan industrial estate by positive matrix factorization model, principle components analysis and geo statistical analysis. *Ecotoxicology and Environmental Safety* 159, 354-362. <https://doi.org/10.1016/j.ecoenv.2018.04.072>.
- Zhang Y, Yu SHI, Gong HJ, Zhao HL, Li HL, Hu YH, Wang YC (2018). Beneficial effects of silicon on photosynthesis of tomato seedlings under water stress. *Journal of Integrative Agriculture* 17(10), 2151-2159. [https://doi.org/10.1016/S2095-3119\(18\)62038-6](https://doi.org/10.1016/S2095-3119(18)62038-6).



The Determination of Agronomic Characteristics of Pea Lines in F₄ Generation

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HIGHLIGHTS

- Peas are vital for sustainable agriculture, offering high protein content, forage potential, and adaptability, addressing food and forage needs globally and in Türkiye.
- This study evaluated 24 F₄ pea lines for seed yield and disease tolerance, aiming to identify superior genotypes for breeding programs.
- Eight genotypes, including G1 (10-1) and G12 (10-1 Ozel), exhibited high yields and disease tolerance, highlighting their potential for developing resilient pea varieties.

Abstract

Peas, the fourth most produced legume globally, suffer from yield losses due to diseases. Developing disease-tolerant varieties can contribute to sustainable agriculture by meeting protein needs through pea cultivation. For this reason, 24 pea lines, advanced to the F₄ generation through hybridization and single-seed descent selection, along with 6 control varieties, were evaluated in 2016 under field conditions in Konya using an Augmented Experimental Design with three replications. Among the genotypes, the highest number of pods per plant (11.35 pods) was observed in the line coded as G1 (10-1). The line coded as G11 (12-1) demonstrated the highest seed yield (229.93 kg da⁻¹). Additionally, plants exhibiting natural symptoms of viral infection and powdery mildew under field conditions were scored as 1 (diseased), while those without symptoms were scored as 3 (healthy). To evaluate the tolerance of genotypes under these biotic stress conditions, a path analysis was conducted. The path model revealed that plant height, pod width, and pod height were associated with the presence of viral and powdery mildew pathogens. Furthermore, a cluster analysis based on these five traits grouped the 24 lines and 6 control varieties into four clusters. In the first group, comprising susceptible genotypes, G11 (12-1) and G9 (4) emerged as the most tolerant lines. The second group included genotypes tolerant to both pathogens, with G10 (208) standing out. The third group consisted of genotypes tolerant to powdery mildew, with G1 (10-1), G2 (15), and G18 (10-1 Ozel S) being prominent. The fourth and final group, composed of the most tolerant genotypes, identified G12 (10-1 Ozel) as the most productive type. Based on the findings, we conclude that these eight genotypes, characterized by high tolerance to diseases and superior seed yield, hold potential as genetic resources for developing high-yielding, disease-resistant pea varieties.

Keywords: Augmented trial design; plant breeding; *Pisum sativum* ssp. *Arvense*; selection; yield

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1. Introduction

Pea cultivation today focuses on two main subspecies, *Pisum sativum* ssp. *sativum* (edible peas) and *Pisum sativum* ssp. *arvense* (forage peas), both globally and in Türkiye (Bilgili 2009). Peas, which have diverse uses such as grain, forage, and vegetable production, rank as the fourth most-produced legume worldwide, following soybean, peanut, and common bean (Heuze et al. 2015). According to TUIK data for 2014, forage pea cultivation in Türkiye covered approximately 3,740 hectares, yielding 70,422 tons of production (TUIK 2024). While edible pea cultivation historically covered a larger area compared to forage peas, in recent years, the increasing emphasis on addressing the forage deficit has led to significant growth in the cultivation area and production of forage peas. According to TUIK statistics, forage peas were cultivated over 23,840 hectares in 2023, producing 457,281 tons of green fodder (TUIK 2024). Globally, the average yield of grain peas is approximately 2,000 kg ha⁻¹, whereas forage pea yields are generally higher but highly variable, depending on environmental conditions, ranging from 4.9 tons DM ha⁻¹ to as much as 35.9 tons DM ha⁻¹ (FAO 2011; Bilgili et al. 2010; FAOSTAT 2024).

Peas exhibit high adaptability, enabling cultivation across a wide range of regions in Türkiye, where their planting area has increased over the years. This growth can be attributed to the plant's high crude protein and mineral content, palatability, suitability for early spring grazing, and the nutritional value of pea silage, which is comparable to that of alfalfa silage. Additionally, forage peas play a significant role in agricultural production due to their contributions to soil organic matter preservation and their use as green manure (Bilgili 2009; Heuze et al. 2015). Biotic and abiotic stress factors, particularly diseases, are major contributors to yield losses in pea cultivation, with powdery mildew being among the most critical factors, causing yield reductions of 25% to 50% (Kora and Teshome 2016; Al-Rubaye 2023). Therefore, breeding efforts have increasingly focused on developing disease-tolerant pea varieties. These efforts are expected to make significant contributions to meeting Turkey's protein needs, both by using forage peas for animal protein production and edible peas for plant-based protein consumption (Endes and Tamkoç 2006).

Scientific research in pea breeding has achieved significant progress in developing new varieties with higher nutritional value, improved environmental adaptability, and enhanced stability. Despite these substantial advancements, the ever-changing cultivation conditions and the lack of varieties adapted to these conditions highlight the ongoing need and opportunities for further improvements and the development of new pea varieties. In genetic selection studies, various criteria and analyses, such as correlation coefficients, multiple regression, and path analysis, are employed to examine causal relationships within interconnected systems of traits. Path analysis stands out as an effective tool for evaluating interdependencies between yield and its components, offering more reliable results compared to other methods (Georgieva et al. 2015). However, Kingsolver and Schemske (1991) utilized path models to address topics such as pollination biology, phenotypic integration, and selection on morphometric and ontogenetic traits.

In this study, the morphological traits of pea lines/varieties advanced to the F4 generation through hybridization and single-seed descent selection were examined using an Augmented experimental design, as the available seed quantities were insufficient. Additionally, the study aimed to identify and select genotypes tolerant to naturally occurring viral and powdery mildew symptoms under field conditions by employing a path model. The main hypothesis proposed is that there is significant genetic variation among pea genotypes grown under field conditions in terms of agronomic traits and disease tolerance (viral infection and powdery mildew tolerance). This study seeks to answer the question: Which pea genotypes exhibit both high yield and tolerance to powdery mildew, making them suitable candidate lines for future breeding programs?

2. Materials and Methods

2.1. Establishment of the Experiment

A total of 30 genotypes were used as the material for the study. Among these, 24 pea lines were advanced to the F4 generation through single-seed descent following hybridization. Additionally, three pure lines (Sultan-1, Sultan-2, 8th line) and three registered cultivars (Ozkaynak, Taskent, Furkan) were included as control varieties (Tables 1-2).

Table 1. The codes for the control varieties used in the study

Check Variety Code	Name
C1	Ozkaynak
C2	Taskent
C3	Furkan
C4	Sultan-2
C5	Sultan-1
C6	8 th line

Table 2. The codes for the genotypes used in the study

Genotype Code	Name	Genotype Code	Name	Genotype Code	Name	Genotype Code	Name
G1	10-1	G7	1084222	G13	602-1	G19	10-2
G2	15	G8	ALRAQI	G14	12-2	G20	3
G3	17	G9	4	G15	8.38.Row	G21	2
G4	10-1(Ozel-S)	G10	208	G16	602-2	G22	5
G5	B6-Duz	G11	12-1	G17	B6-Renkli	G23	13
G6	16	G12	10-1 Ozel	G18	10-1 Ozel S	G24	7

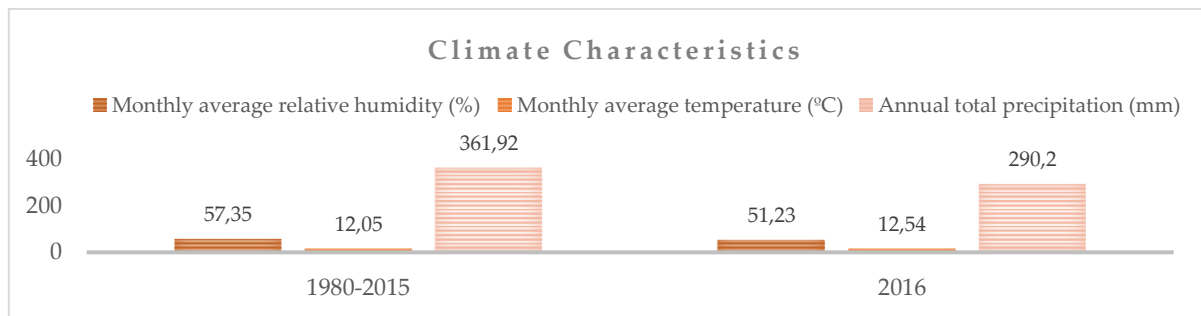


Figure 1. Climate characteristics of the experimental field (Climate data were taken from the Konya Meteorology Regional Directorate)

The research was conducted under irrigated conditions in the Experimental Field of Field Crops at Selçuk University in 2016. According to the analysis of the soil at a depth of 30 cm, the soil was characterized as clay-loam with 2.40% organic matter, an alkaline reaction (pH 8.12), and no salinity problem (EC1:5 0.88 dS m⁻¹ NaCl). The soil exhibited high levels of lime (20%) and potassium (0.03%) but was deficient in P₂O₅ (18.30 kg ha⁻¹) and ferritin content (1.19 mg kg⁻¹). The climatic characteristics of the experimental area are presented in Figure 1.

Due to the limited availability of experimental material, this study was designed using the Augmented Experimental Design with three replications, including six check (control) varieties in each replication. The number of replications was calculated according to Petersen (1994) (Equation 1).

$$r \geq \left(\frac{10}{c-1} \right) + 1, \quad (1)$$

r: replication, c: number of Check

This study was sown on April 10, 2016, with block dimensions of 15 m in length and 2 m in width. The planting was conducted with 50 cm row spacing and 20 cm plant spacing within the rows. Along with sowing, 150 kg ha⁻¹ of diammonium phosphate (DAP) fertilizer was applied. Seedlings emerged between April 26 and April 29, 2016, and weed control was performed by hoeing when the plants reached the four-to-five leaf stage. The plants were irrigated using sprinkler irrigation for initial establishment, followed by three applications of drip irrigation during the flowering, pod formation, and grain filling stages (Figure 2A).

2.2. Data collection and Statistical Analysis

2.2.1. Determination of Differences in Morphological Traits Among Genotypes Using Augmented Experimental Design

All genotypes flowered between June 10 and June 14, 2016, and the plants began pod setting between June 12 and June 17, 2016. Observations and measurements were taken during this period (Figures 2B and 2C). This research was organized into two stages. The first phase involved the cultivation of lines according to the Augmented Experimental Design, as well as the collection and evaluation of observations and measurements. In this phase, the following traits were measured: plant height (PH) (cm), number of pods per plant (NPPP) (pods/plant), pod length (PL) (mm), pod width (PW) (mm), pod height (PoH) (mm), seeds per pod (SPP), thousand-seed weight (TSW) (g), and seed yield (SY). Measurements were taken at the harvest stage.



Figure 2. (A) The general view of the experiment (May 29, 2016), (B) observation of flowering (June 13, 2016), and (C) measurements taken from pods are presented, where X represents pod width, Y represents pod length, and Z represents pod height (June 17, 2016).

Plant height was measured in centimeters as the natural height of the plant. Pod-related measurements, including pod length, were recorded in millimeters from three pods per plant, as schematized in Figure 2C. The number of pods per plant was determined by counting all pods on each plant within a line and calculating the average reported as the number of pods. The number of seeds per pod was obtained by counting seeds in three pods and calculating the average (Al-Rubaye 2023).

The number of seeds per plant was calculated by multiplying the number of pods per plant by the average number of seeds per pod. Thousand-seed weight (TSW) was determined by weighing 50 seeds and multiplying the result by 20, with the final value reported in grams (Özköse 2012).

Additionally, in the field experiment, symptoms of viral damage and powdery mildew began to appear on the plants 30 days after emergence under natural conditions. Due to the differing responses of the cultivars/lines to these two pathogens, scoring was conducted based on observations: a score of 1 was assigned if virus (VP) or powdery mildew (PMP) damage was observed, and a score of 3 was assigned if the plant was healthy (Figure 3).

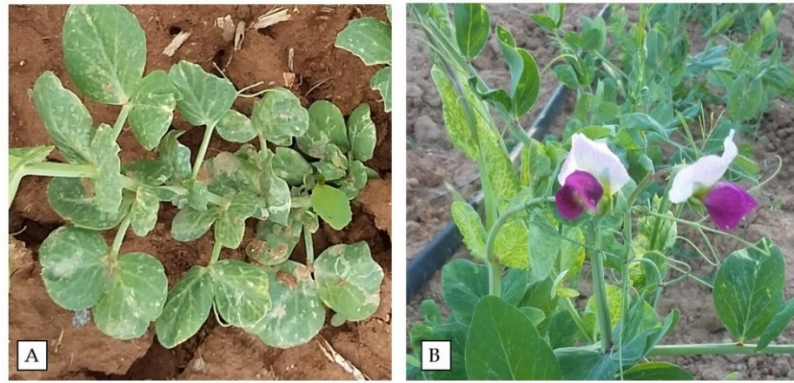


Figure 3. Powdery mildew observed on the plants (A; May 29, 2016) and the presence of the virus (B; June 13, 2016).

In this section, which constitutes the first phase of the study, the data obtained were subjected to statistical analyses using the JMP 7 software package based on the Augmented Experimental Design (Sall et al., 2017). For each trait found to be significant, a Student's *t*-test was performed (Petersen 1994).

2.2.2. Selection of Genotypes Tolerant to Naturally Occurring Virus and Powdery Mildew Pathogens Under Field Conditions

In this section of the study, path analysis was performed using multiple regression analysis (Forward MRA) in SPSS 15 software, with the purpose of determining the relationship between the presence of naturally occurring virus and powdery mildew pathogens under field conditions and the examined botanical traits (Ho, 2013). In the multiple regression analysis, the presence of virus and powdery mildew were set as the dependent variables, while botanical traits (plant height, number of pods, pod length, pod width, pod height, number of seeds per pod, thousand-seed weight, and seed yield) were defined as independent variables. To better explain the relationships between the traits, a path model was constructed based on the results of the multiple regression analysis (Forward MRA). In the model, the standardized beta coefficient (β) obtained from the multiple regression analysis was used as the path coefficient, or direct effect (Anonymous 2021). For a specific residual variable (*U*), the path coefficient is calculated using the following formula (Equation 2) (Kingsolver and Schemske 1991). Additionally, the correlation between the traits used in the path model was determined using Pearson correlation analysis.

$$U = \sqrt{(1 - R^2)}, \quad (2)$$

In this section of the study, cluster analysis was performed using the JMP 7 software package based on the results of path analysis, with virus and powdery mildew presence and the associated traits (Sall et al. 2017). Using the SRplot online platform, principal coordinate analysis was performed to identify 30 genotypes in the F4 generation that are both high yielding and tolerant to virus and powdery mildew (Tang et al. 2023).

3. Results

3.1. Determining the Differences in Morphological Traits Among Genotypes

Analysis of variance was performed based on the Augmented Experimental Design provided in Table 3. For the check, the number of pods per plant, pod length, and pod width were found to be statistically significant at the 5% level, while pod height, seed yield, thousand-seed weight, and virus presence were found to be statistically significant at the 1% level. For the genotypes, only the number of pods per plant, pod height, and virus presence were statistically significant at the 5% level, while the other traits were determined to be non-significant.

Table 3. The table of variation analysis's summary (F value)

Source of Variation	Degree of Freedom	PH	NPPP	SPP	SY	TSW
Block	2	3,754	3,958	0,574	0,862	0,786
Check	6	1,196	5,266*	0,265	6,583**	32,083**
Genotype [Check]	23	0,927	3,555*	1,686	1,954	2,419
Error	10					
Total	41					
CV%		21,83	17,87	15,75	40,49	14,25

Source of Variation	Degree of Freedom	PL	PW	PoH	VP	PMP
Block	2	2,083	1,061	1,893	1,000	0,294
Check	6	3,750*	4,926*	18,125**	12,339**	0,982
Genotype [Check]	23	1,130	2,436	3,444*	4,228*	0,805
Error	10					
Total	41					
CV%		11,90	11,73	7,46	22,50	60,85

*P<0.05, **P<0.01, PH: Plant Height, NPPP: Number of Pod per Plant, SPP: Seed per Pod, SY: Seed Yield, TSW: Thousand Seed Weight, PL: Pod Length, PW: Pod Width, PoH: Pod Height, VP: Virus Presence, PMP: Powdery Mildew Presence

Table 4. Mean values and standard deviations of the control varieties

Check variety	PH (cm)	NPPP	SPP	SY (kg da ⁻¹)	TSW(g)
C1	43,6±11,79	7,7±2,52	4,7±0,67	68,62±23,29	95,6±15,31
C2	44,0±8,19	10,3±1,80	4,4±0,79	87,28±40,02	93,4±19,92
C3	39,3±3,51	7,7±0,88	4,6±0,69	65,78±13,04	92,2±11,50
C4	36,7±5,84	8,9±0,69	4,8±0,19	211,71±33,60	243,3±15,19
C5	46,3±13,07	7,7±1,76	4,4±0,98	137,53±67,17	190,9±24,92
C6	38,1±13,77	8,2±1,17	5,0±0,67	106,86±22,88	129,9±17,88
Mean	41,3±6,62	8,4±1,06	4,6±0,23	112,97±14,41	140,9±6,62

Check variety	PL(mm)	PW(mm)	PoH(mm)	VP(Scor.)	PMP(Scor.)
C1	43,4±2,40	7,3±0,43	4,0±0,22	1,0±0,00	1,0±0,00
C2	43,0±0,49	6,8±0,29	4,1±0,48	1,0±0,00	1,0±0,00
C3	43,2±1,97	7,5±0,14	4,3±0,26	1,0±0,00	1,0±0,00
C4	59,3±4,33	10,3±1,38	6,4±0,36	3,0±0,00	2,3±1,15
C5	54,5±12,19	9,5±0,47	5,5±0,69	2,3±1,15	1,7±1,15
C6	54,4±8,45	8,8±1,91	5,9±0,17	3,0±0,00	1,7±1,15
Mean	49,6±3,49	8,4±0,42	5,0±0,21	1,9±0,19	1,4±0,19

PH: Plant Height, NPPP: Number of Pod per Plant, SPP: Seed per Pod, SY: Seed Yield, TSW: Thousand Seed Weight, PL: Pod Length, PW: Pod Width, PoH: Pod Height, VP: Virus Presence (1: diseased, 3: healthy), PMP: Powdery Mildew Presence (1: diseased, 3: healthy)

When examining the mean values of the control varieties presented in Table 4, it can be stated that the Sult-1 variety with code C5, having a natural plant height of 46.3 cm, is the tallest genotype among the controls.

In terms of the number of pods per plant (10.3 pods), the highest yield was obtained from the Taskent variety with code C2. When examining the number of seeds per pod, the highest value of 5 seeds was recorded for the 8th line with code C6. In our study, the Sult-2 variety with code C4 stands out in terms of pod length (59.3 mm), pod width (10.3 mm), pod height (6.4 mm), seed yield (211.71 kg da⁻¹), and thousand-seed weight (243 g). Additionally, this variety can be considered the healthiest genotype in terms of virus and powdery mildew presence compared to the other controls. Furthermore, the 8th line with code C6 was also determined to be the healthiest control variety in terms of virus presence.

The plant characteristics of the 24 pea lines advanced to the F4 generation are presented in Table 5. The highest natural plant height, 50.15 cm, was recorded for the G22 code, from the 5th line. The highest number of pods per plant, 11.35 pods, was obtained from the G1 code, 10-1 line. The highest number of seeds per pod, 6.41 seeds, was determined for the 10-1(OZEL-S) line. In our study, the G13 code, 602-1 line, stood out for pod length (64.87 mm), the G16 code, 602-2 line, for pod width (11.91 mm), and the G6 code, 16 line, for pod height (6.39 mm).

When examining the yield components, thousand-seed weight and seed yield, the G10 code, 208 line, had the highest thousand-seed weight (192.56 g), and the G1 code, 10-1 line, had the highest seed yield (229.93 kg da⁻¹). The seed yield of the genotypes used in this study ranged from 15 kg da⁻¹ to 229 kg da⁻¹, indicating a large variation among the genotypes.

Among the pea lines advanced to the F4 generation, the G7 (1084222) and G8 (ALRAQI) genotypes, which exhibited the least presence of the virus pathogen under field conditions (score 3.11), can be considered the healthiest lines. Additionally, these genotypes were recorded as the healthiest in terms of powdery mildew presence, with a score of 3.22. Furthermore, the G1 (10-1) and G2 (15) genotypes were also among the healthiest in terms of powdery mildew presence.

3.2. Selection of Genotypes Tolerant to Virus and Powdery Mildew Pathogens

The results of the Multiple Regression analysis conducted to identify genotypes that continue to grow and develop under natural field conditions with virus and powdery mildew pathogens are presented in Table 6. Based on the information provided in Table 5, the resulting path model is shown in Figure 5.

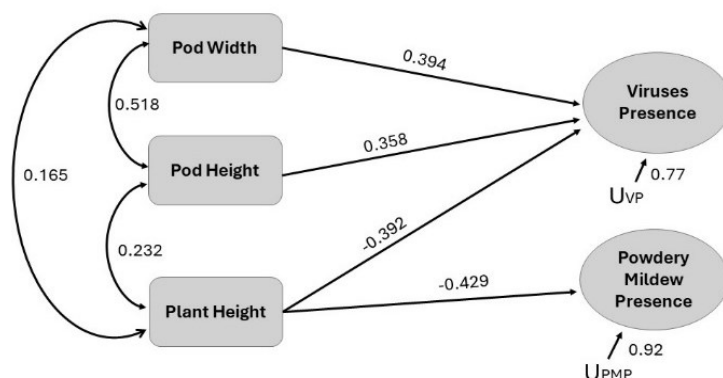


Figure 5. Path model

In the path model presented in Figure 5, the direct effects (β) of plant traits on the presence of virus and powdery mildew are represented by unidirectional arrows, while correlations between traits are depicted with bidirectional arrows. Plant height has a negative effect on virus presence ($\beta = -0.392$), whereas other traits exhibit positive effects. Additionally, pod width has the highest direct effect on virus presence, accounting for 23.9% of the variation in virus presence alone. Similarly, plant height negatively affects powdery mildew presence ($\beta = -0.429$) and explains 15.5% ($R^2 = 0.155$) of the variation in powdery mildew presence (Table 5).

Table 5. Adjusted means and LSD values of the examined traits according to the augmented experimental design

Code	PH (cm)	NPPP	SPP	SY (kg da ⁻¹)	TSW (g)	PL (mm)	PW (mm)	PoH (mm)	VP (Scor.)	PMP (Scor.)
G1	29,43	11,35	5,74	229,93	175,08	55,44	8,29	6,05	1,11	3,22
G2	37,76	9,68	4,74	107,22	113,75	53,01	8,60	6,24	1,11	3,22
G3	37,60	8,18	4,74	85,77	108,41	46,33	8,56	4,06	1,11	1,22
G4	31,43	4,35	6,41	53,39	106,41	54,22	6,15	4,74	1,11	1,22
G5	33,76	8,01	4,41	71,60	102,08	41,93	6,48	4,29	1,11	1,22
G6	48,43	5,01	5,74	84,85	155,75	59,55	9,45	6,39	1,11	1,22
G7	28,10	5,68	3,24	35,27	85,91	48,94	9,33	5,02	3,11	3,22
G8	18,10	4,68	2,74	28,68	106,41	44,80	8,59	4,15	3,11	3,22
G9	37,42	7,11	5,44	101,24	127,73	51,38	8,19	5,45	0,78	0,89
G10	42,25	9,78	5,10	189,89	192,56	52,87	10,89	5,71	0,78	2,89
G11	46,08	11,11	5,77	160,45	118,40	48,26	7,78	4,94	0,78	0,89
G12	21,42	4,78	5,44	71,14	129,06	47,22	7,13	4,70	2,78	2,89
G13	46,75	3,78	5,44	41,24	96,40	64,87	11,77	5,27	0,78	2,89
G14	41,75	7,28	5,10	85,64	114,06	44,21	9,24	5,31	2,78	2,89
G15	23,08	3,78	3,44	15,44	86,09	53,50	11,19	5,54	0,78	2,89
G16	38,42	1,78	3,44	15,42	140,06	45,76	11,91	5,13	2,78	2,89
G17	33,65	5,54	3,66	45,84	98,77	36,08	6,29	4,33	1,11	0,89
G18	36,82	9,54	4,82	134,91	151,52	54,88	7,29	4,93	1,11	2,89
G19	32,15	5,21	4,82	53,65	114,52	56,71	9,47	5,13	1,11	2,89
G20	34,15	4,04	3,16	25,59	67,52	45,85	8,64	3,66	1,11	0,89
G21	35,65	6,04	5,16	64,23	99,02	49,09	7,38	5,45	1,11	0,89
G22	50,15	6,21	4,16	77,95	139,19	54,99	10,43	6,06	1,11	2,89
G23	40,15	7,21	4,49	71,36	110,52	44,60	7,25	4,73	1,11	2,89
G24	40,82	5,54	4,49	61,39	112,74	43,86	7,19	4,74	1,11	2,89
SE	8,817	1,377	0,771	40,089	19,27	6,246	1,053	0,397	0,497	0,92
LSD ₁	-	2,376	-	-	-	-	-	0,686	1,220	-
LSD ₂	-	3,497	-	-	-	-	-	1,010	1,796	-
LSD ₃	-	4,115	-	-	-	-	-	1,188	2,113	-
LSD ₄	-	4,445	-	-	-	-	-	1,283	2,282	-
1 st BCT	5,903	-0,681	0,259	-2,521	2,588	1,930	0,467	0,129	-0,222	-0,111
2 nd BCT	1,250	1,222	-0,102	15,509	4,936	2,101	-0,349	0,115	0,111	0,222
3 rd BCT	-7,153	-0,542	-0,157	-12,988	-7,523	-4,031	-0,118	-0,244	0,111	-0,111

BCT: Block Correction Term, SE: Standard Error, LSD₁: Comparison among the controls, LSD₂: Comparison between the controls and genotypes, LSD₃: Comparison among genotypes within the same block, LSD₄: Comparison among genotypes across different blocks, Scoring 1: disease, 3: healthy

Based on the path model results, the standout plant traits—plant height, pod width, and pod height—were identified as the key features to be used in the selection process of our study concerning virus and powdery mildew presence. The clustering analysis conducted using these traits is presented in Figure 6. As a result of the clustering analysis, 24 pea lines and 6 control varieties were divided into four groups.

Table 6. Multiple regression analysis of morphological traits in pea in relation to virus and powdery mildew presence (Forward MRA)

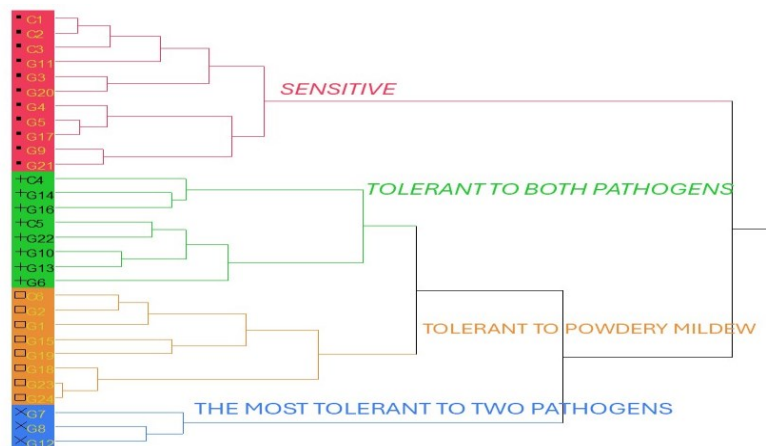
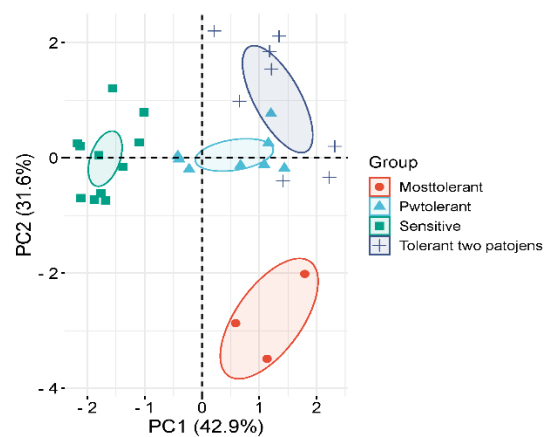
Dependent variable	Predictors	Coefficients			Model Summary	
		Standardized Beta Coefficients (β)	<i>t</i>	<i>P</i>	<i>R</i>	<i>R</i> ²
Viruses Presence	Pod Width	0,394	2,351	0,027*	0,515(a)	0,239
	Plant Height	-0,392	-2,662	0,013*	0,614(b)	0,330
	Pod Height	0,358	2,110	0,045*	0,684(c)	0,406
Powdery Mildew Presence	Plant Height	-0,429	-2,512	0,018*	0,429(a)	0,155

Viruses Presence

- Predictors: (Constant), Pod Width
- Predictors: (Constant), Pod Width, Plant Height
- Predictors: (Constant), Pod Width, Plant Height, Pod Height

Powdery Mildew Presence

- Predictors: (Constant), Plant Height

**Figure 6.** Results of the cluster analysis**Figure 7.** Results of the PCoA analysis using SRplot online platform

The first group consists of sensitive genotypes, including C1, C2, C3, G3, G4, G5, G9, G11, G17, G20, and G21. The second group comprises genotypes tolerant to both pathogens (Tolerant to Two Pathogens), including C4, C5, G6, G10, G13, G14, G16, and G22. The third group includes genotypes tolerant only to powdery mildew (PM-tolerant), comprising eight genotypes: C6, G1, G2, G15, G18, G19, G23, and G24. The fourth and final group, identified as the most tolerant (Most Tolerant), consists of three genotypes: G7, G8, and G12. The clusters obtained from the Principal Coordinate Analysis (PCoA) corroborate the results of the Cluster Analysis, indicating that the fourth group, the most tolerant, forms a distinctly separate cluster from the other three groups (Figure 7).

4. Discussion

In genotype selection for plant breeding, lines that are less affected or unaffected by disease pathogens are significant (Al-Rubaye, 2023). In studies related to disease pathogen presence, Al-Rubaye (2023) found that 164 out of 242 lines were unaffected by any disease, and in their scale evaluation, where 1 = diseased and 5 = healthy, the average value was determined to be 3.69.

Singh and Srivastava (2015), in their study on peas with different leaf morphologies, reported that plant height ranged from 110 cm to 140 cm, and thousand-seed weight ranged from 24 g to 38 g. The semi-leafless plant type (LeLe AfAf TITl StSt) exhibited the highest thousand-seed weight compared to normal plant types. On the other hand, the "pleiofila" type with reduced stipule leaves (afaf tltl stst) had the smallest thousand-seed weight. They also found that seed yield per plant was highest in semi-leafless plant types in both tall and dwarf groups. Furthermore, they stated that the most suitable plant height for effectively suppressing weeds and preventing lodging was between 60 cm and 100 cm (Olle, 2015; Olle, 2017).

Avcı and Ceyhan (2006), using the Line x Tester method to determine general and specific combining abilities in peas, investigated the pod characteristics of 12 hybrids created from 4 lines and 3 testers. In their study, they found that the number of pods per plant ranged from 45 to 91, the number of seeds per pod ranged from 4 to 6, pod length ranged from 51 mm to 84 mm, pod width ranged from 8 mm to 12 mm, and thousand-seed weight ranged from 110 g to 190 g. If we calculate the seed yield per plant by multiplying the number of pods per plant and the number of seeds per pod, the range was between 200 and 360 seeds per plant. Furthermore, the path coefficient analysis conducted in the study showed that the highest direct effect was recorded for the number of pods per plant.

Ouafi et al. (2016) cultivated pea genotypes obtained from ICARDA in Algeria from 2013 to 2016 and studied the agro-morphological characteristics of the plants based on UPOV criteria. In their study, they reported that the average pod length of the plants was 5 cm, and the pod width was 0.5 cm.

Özdemir and Tamkoç (2019) conducted a study in Konya under irrigated conditions during the 2017 summer growing season to determine which lines could be used as second crop cultivars. The study involved 22 different F₆ generation pure forage pea lines and 4 registered forage varieties (Ozkaynak, Taskent, Furkan, Bilgehan). According to the results, plant height ranged from 43.3 to 105.0 cm, and the study concluded that the lines 4/3 and 5/1 could be grown as second crops under irrigated conditions in the Konya region.

Kadioğlu et al. (2020) examined some morphological characteristics of 18 pea genotypes under Erzurum conditions in 2011, 2012, and 2013. The study reported that plant height varied between genotypes, ranging from 76 cm to 110 cm, with the number of pods per plant ranging from 5 to 10, and the thousand seed weight varying between 159 g and 303 g. In this study, as well as in our research, the Ozkaynak and Taskent varieties were used, with plant heights recorded as 90 cm and 93 cm, respectively, the number of pods per plant as 10, and the thousand seed weight as 199 g and 198 g.

Al-Rubaye (2023) studied the winter hardiness of 242 F₂ generation lines obtained from the hybridization of wild pea genotypes collected from nature with improved varieties and lines. As a result of the study, winter damage was not observed in 174 lines, with plant height varying between 35 and 150 cm, the number of pods per plant ranging from 4 to 81, and the number of seeds per pod varying between 2 and 9.3. The differences

between the findings of this study and those of other researchers may primarily be attributed to ecological variations and differences in the varieties or lines used.

Selvi et al. (2016) conducted a path coefficient analysis using morphological data from 24 pea varieties. Their study revealed that plant height during vegetative and flowering stages, the number of days to 50% flowering, pod circumference, single pod weight, single seed weight, leaf area, the number of pods per plant, and shelling percentage had a positive direct effect on pod yield.

Powdery mildew in peas leads to significant yield losses by reducing total biomass, the number of pods per plant, seeds per pod, plant height, and the number of nodes (Fondevilla and Rubiales 2012). In our study, a negative relationship was observed between plant height and the appearance of virus and powdery mildew symptoms. This could be attributed to the increased surface area of taller plants, which provides more space for pathogen adherence. However, Singh et al. (2015) reported that dwarf varieties were more susceptible to powdery mildew compared to medium or tall varieties. Contrary to this, Hammarlund (1925), in the earliest studies on the genetics and physiology of powdery mildew resistance in peas, identified a single resistant plant in the dwarf William Hurst variety, which was exposed to various races of the powdery mildew fungus (Sharma, 2015). The findings indicated that resistance to powdery mildew is governed by a recessive gene, *er-1* (Timmerman et al. 1994; Vaid and Tyagi 1997; Janila and Sharma 2004; Katoch et al. 2010). Different studies have localized genes conferring resistance to powdery mildew on LG I, LG III, LG V, or LG VI. Additionally, a clear genetic linkage between resistance to powdery mildew (designated as *er-1*) and the morphological marker “Gritty” (*Gty*) has been demonstrated within linkage group 6 (Timmerman et al. 1994). Therefore, the relationships observed among these traits in the F₄ generation hybrids examined in our study could be influenced by linkage effects.

5. Conclusions

Due to the insufficient quantity of seeds obtained from the 24 pea lines advanced to the F₄ generation through hybridization and single plant selection, this study was established and evaluated using an Augmented experimental design. Among the genotypes, G1 (10-1) and G11 (12-1) emerged as the most productive in terms of seed count per plant. However, based on path analysis conducted to determine the tolerance of genotypes to naturally occurring virus and powdery mildew symptoms under field conditions, it was observed that plant height, pod width, and pod height were significantly associated with the presence of these pathogens. Using these five traits, a cluster analysis categorized the 24 lines and six control varieties into four distinct groups. In the first group (sensitive genotypes), G11 (12-1) and G9 (4) stood out as the most tolerant genotypes. In the second group, tolerant to both pathogens, G10 (208) was identified as a promising genotype. In the third group, characterized as productive and tolerant to powdery mildew, G1 (10-1), G2 (15), and G18 (10-1 Ozel S) were notable genotypes. The fourth and final group, comprising the most tolerant genotypes, identified G12 (10-1 Ozel) as the most productive type. Based on the findings of our study, these eight genotypes demonstrate strong potential as genetic resources for the development of cultivars with high disease tolerance and grain yield.

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Data Availability Statement: The data will be made available upon reasonable request from the corresponding authors.

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References

- Al-Rubaye BMA (2023). Selection of winter-resistant genotypes and determination of some agricultural characteristics in hybrid field pea lines (F2). Master's Thesis, Selcuk University (Unpublished), Türkiye.
- Anonymous (2021). Example of very simple path analysis via regression (with correlation matrix input). <https://psych.unl.edu/psycrs/971/pathanalysis/path1ex.pdf> (26.10.2021)
- Avci MA, Ceyhan E (2006). Correlations and genetic analysis of pod characteristics in pea (*Pisum sativum* L.). *Asian Journal of Plant Sciences* 1(2), 1-4.
- Bilgili U (2009). Forage Crops, Vol. II. (Ed: *Avcioglu R., Hatipoğlu R., Karadağ Y.*), Ministry of Agriculture and Rural Affairs Publications, İzmir, s. 440-448 (In Turkish).
- Bilgili U, Uzun A, Sincik M, Yavuz M, Aydinolu B, Cakmakci S, Geren H, Avciolu R, Nizam I, Tekel S, Gül S, Anlarsal E, Yücel C, Avci M, Acar Z, Ayan I, Ustün A, Acikgoz E (2010). Forage yield and lodging traits in peas (*Pisum sativum* L.) with different leaf types. *Turkish Journal of Field Crops* 15 (1), 50-53
- Endes T, Tamkoç A (2006). Comparative karyotype analyses in some F7 generation pea (*Pisum sativum* L.) lines and their parents. *Selcuk Journal of Agriculture and Food Sciences* 20(38), 150-158 (In Turkish).
- FAOSTAT (2024). FAO statistical databases. <http://www.fao.org/faostat/en/#data/QCL> (25.12.2024)
- FAO (2011). Grassland Index. A searchable catalogue of grass and forage legumes. FAO, Rome, Italy
- Fondevilla S, Rubiales D (2012). Powdery mildew control in pea. A review. *Agronomy for Sustainable Development* 32, 401-409.
- Georgieva N, Nikolova I, Kosev V (2015). Association study of yield and its components pea (*Pisum Sativum* L.). *International Journal of Pharmacognosy* 2(11), 536-542
- Hammarlund C. von. (1925). Zur genetik, biologie und physiologie einiger Erysiphaceen (The genetics, biology and physiology of some Erysiphes). *Hereditas* 6, 11–26.
- Heuze V, Tran G, Giger-Reverdin S, Noblet J, Renaudeau D, Lessire M, Lebas F (2015). Pea seeds. Feedipedia, a programme by INRA, CIRAD, AFZ and FAO. Retrieved August 8, 2015, from <http://www.feedipedia.org/node/264>.
- Ho R (2013). Handbook of univariate and multivariate data analysis with IBM SPSS. CRC press
- Janila P, Sharma B (2004). RAPD and SCAR markers for powdery mildew resistance gene er in pea. *Plant Breeding* 123, 271–274.
- Kadioğlu S, Tan M, Kadioğlu B, Taşğın G (2020). Determination of yield and some characteristics of forage pea genotypes (*Pisum sativum* ssp. *arvense* L.) under Erzurum conditions. *Atatürk Üniversitesi Ziraat Fakültesi Dergisi*, 51(2), 151-158.
- Kingsolver JG, Schemske DW (1991). Path analyses of selection. *Trends in Ecology & Evolution* 6(9), 276-280.
- Kora D, Teshome E (2016). Field evaluation of some botanical extracts against the pea aphid *Acyrthosiphon pisum* (Homoptera: Aphididae) on Field pea *Pisum sativum* L.. *Journal of Entomology and Zoology Studies* 4(4), 336-339.
- Katoch V, Sharma S, Pathania S, Banayal DK, Sharma SK, Rathour R (2010). Molecular mapping of pea powdery mildew resistance gene er2 to pea linkage group III. *Molecular Breeding* 25, 229-237.
- Olle M (2015). Which varieties of field peas to grow? (Milliseid hernesorte kasvatada?) *Maamajandus* 10(40), 4–4.
- Olle M (2017). The yield, height and content of protein of field peas (*Pisum sativum* L.) in Estonian agro-climatic conditions. *Agronomy Research* 15(4), 1725–1732, <https://doi.org/10.15159/AR.17.026>

- Ouafi L, Alane F, Rahal-Bouziane H, Abdelguerfi A (2016). Agro-morphological diversity within field pea (*Pisum sativum* L.) genotypes. *African Journal of Agricultural Research* 11(40), 4039-4047.
- Özdemir B, Tamkoç A (2019). The determination of field pea lines suitable for the second crop production. *Journal of Bahri Dagdas Crop Research* 8(2), 299-305.
- Özköse A (2012). Determination of some morphological and agronomic characteristics of perennial ryegrass (*Lolium perenne* L.) genotypes collected from the natural flora of Ankara, PhD's Thesis, *The Graduate School of Natural and Applied Science of Selçuk University*, (Unpublished) Konya (In Turkish)
- Petersen RG (1994). *Agricultural field experiments: design and analysis*. Crc Press.
- Sall J, Stephens ML, Lehman A, Loring S (2017). JMP Start Statistics: A Guide to Statistics and Data Analysis Using JMP; SAS Institute: Cary, NC, USA.
- Sharma B (2015). Powdery mildew resistance in pea: Historical perspective. *Pulses: Challenges & Opportunities*, 37.
- Selvi BS, Rajangam J, Suresh J, Muthuselvi R (2016). Character association and path analysis studies for yield and its components in pea (*Pisum sativum* L.). *Electronic Journal of Plant Breeding* 7(3), 750-757.
- Singh AK, Srivastava CP (2015). Effect of plant types on grain yield and lodging resistance in pea (*Pisum sativum* L.). *Indian Journal of Genetics and Plant Breeding* 75(01), 69-74.
- Singh J, Dhall RK, Aujla IS (2015). Characterization of resistance response of garden pea (*Pisum sativum* L.) against powdery mildew (*Erysiphe pisi* DC) in sub-tropical plains of India.
- Tang D, Chen M, Huang X, Zhang G, Zeng L, Zhang G, Wu S (2023). Wang Y. SRplot: A free online platform for data visualization and graphing. *PLoS One* 18(11), e0294236. <https://doi.org/10.1371/journal.pone.0294236>
- Timmerman GM, Frew TJ, Weeden NF, Miller AL, Goulden DS. (1994). Linkage analysis of er-1, a recessive *Pisum sativum* gene for resistance to powdery mildew fungus (*Erysiphe pisi* DC). *Theoretical and Applied Genetics* 88, 1050-1055.
- TUIK (2024). Turkish Statistical Institute Crop Production Statistics. <http://www.tuik.gov.tr/> (25.12.2024)
- Vaid A, Tyagi PD (1997). Genetics of powdery mildew resistance in pea. *Euphytica* 96, 203–206.



Agriculture and Sustainability in Somalia: Challenges and Pathways to Sustainable Development

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HIGHLIGHTS

- Somalia's agricultural sector faces challenges hindering sustainable development.
- Opportunities exist for infrastructure investment and technology adoption.
- Threats include climate change, unsustainable practices, insecurity, and terrorism.
- Successful implementation can lead to economic growth and poverty reduction.

Abstract

The agricultural sector in Somalia is crucial to the country's economy, food security, and rural development; however, it faces challenges in adopting sustainable practices. To address these challenges, a mixed-method approach was employed, using data from the Ministry of Agriculture, FAO, World Bank, and scholarly sources to identify indicators of sustainable agriculture. A literature-based review and SWOT analysis revealed strengths, including agro-ecological zones, a traditional farming system, and international support. In contrast, weaknesses included inadequate infrastructure, low productivity, and dependence on rainfed agriculture. Opportunities included investment in infrastructure and technology adoption, while threats comprised climate change and limited financial resources. To enhance agricultural inputs, proposed recommendations included environmental protection policies, education on sustainable practices, and increased funding for research and development. Revitalizing Somalia's agricultural sector can promote economic growth, enhance food security, and contribute to poverty reduction. By addressing challenges and leveraging opportunities, sustainable development can be achieved, resulting in positive socio-economic outcomes for the country.

Keywords: Agriculture; Sustainability; Somalia; Challenges; Pathways; Development

1. Introduction

Agriculture plays a vital role in human survival and societal advancement. Sustainable farming encompasses three key aspects: sustainable agricultural production, sustainability in rural economy and society, and sustainability in environmental and ecological agricultural systems (Brodthorn et al. 2011). Sustainability is defined as an economic state that does not reduce the capacity of the environment because of the demand put on it by people. Hawken (1994) also proposed an economic golden rule: "Leave the world better than you found it, take no more than you need, try not to harm life or the environment, make amends if you do" (Hawken 1994). Sustainable farming embodies a farming approach that closely aligns with natural

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processes, aiming to reduce waste, minimize environmental harm, and maintain profitability. In a sustainable farm system, the resulting agricultural products are not only nutritious but also free from substances that may pose a risk to human consumption. These farming systems are designed to optimize the utilization of soil nutrients, soil organisms, energy flow, and water cycles (Eap 1989). The idea of agricultural sustainability development originated in the early 1980s and attracted more academic attention after the publication of the Brundtland Report by the World Commission on Environment and Development in 1987 (Millennium Ecosystem Assessment 2005; Harwood 2020). However, as sustainable agriculture is a vague and ambiguous concept, its use and implementation are extremely difficult. Velten et al. (2015) conducted a structured literature review of sustainable agriculture and divided its goals into the categories of “ecological soundness,” “social responsibility,” and “economic viability.” Zhao et al. (2018) further emphasized that the essence of agricultural sustainability development was to develop agriculture without compromising the ecosystem, social development, resources, or environment. Sarkar et al. (2021) pointed out that the indicator of sustainable agriculture might vary by region and utilized partial least squares structural equation modeling (PLS-SEM) tactics to build an evaluation system for sustainable agriculture.

In Europe and North America, the adoption of sustainable farming practices has been rapidly increasing, particularly in the western world. Interest in sustainable farming extends beyond farmers who are interested in sustainable farming; political leaders, consumers, and conservationists also show a keen interest in promoting sustainable agricultural practices. Farmers in these developed regions are witnessing and reaping the benefits of embracing sustainability. Farming methods that are not sustainable are subjected to thorough scientific investigation, enabling farmers to produce safe and healthy food (Benbrook 1991). This progress is facilitated by government legislations and programs aimed at supporting sustainable farming. Many farmers in these regions have embraced this change and are actively engaging in research and training related to sustainable farming.

Although some improvements have been observed in key sustainable agriculture indicators in Africa, such as agricultural productivity and cereal yield, the region still lags behind the rest of the world on these performance indicators. African agricultural systems are marked by low productivity, land degradation, reliance on manual labor, and fragmented small-scale farms (Abdullahi and Arisoy 2022). Climate change is now a growing concern, while environmental pollution and over-dependence on fossil-fuel-powered machinery are not given top priority. Small-scale farmers, particularly women, perceive agroecological practices as adding pressure due to the requirement of producing organic farm additives like composts, biochar, and biopesticides themselves (Mestmacher and Braun 2021). Smallholder farmers, operating on plots averaging 2 hectares, reportedly feed approximately one-third of the 238 million urban dwellers and the majority of the 712 million hungry individuals in rural and remote areas worldwide (Altieri et al. 2012). This indicates that small-scale farming supports roughly half of the global population and produces over 70% of the world's food (Kihara et al. 2020; Sheppard et al. 2020).

Somalia, a country situated in the Horn of Africa, faces significant difficulties in implementing sustainable agriculture practices. Despite the potential benefits that sustainable agriculture offers in terms of food security, environmental conservation, and rural development, the country encounters obstacles that hinder its broad adoption. The purpose of this analysis is to explore these challenges and provide potential solutions to foster a conducive environment for sustainable agricultural practices in Somalia. This study aims to investigate the connection between agriculture and sustainability, identify the challenges involved, and propose viable pathways to achieve sustainable development.

2. Materials and Methods

This study employs a mixed-methods approach to analyze sustainable agriculture indicators in Somalia. Primary data sources include official statistics from Somalia's Ministry of Agriculture and Irrigation, supplemented by reputable international datasets (e.g., FAO, World Bank). Secondary sources consist of peer-reviewed articles, policy documents, and theses to establish a robust theoretical framework. To assess barriers and opportunities for sustainable agriculture, the study applies SWOT analysis, incorporating insights from

local studies (Zencirkiran and Gürbüz 2009; Baris and Uslu 2009), policy reviews, and expert consultations. Following Weihrich's (1982) methodology, the SWOT framework helps identify key factors influencing sustainability, offering a comprehensive evaluation of Somalia's agricultural sector and potential development pathways. By integrating empirical data with literature-based analysis, this study ensures methodological rigor, enhancing the reliability of its findings. The results aim to inform policy decisions and promote scalable solutions for sustainable agriculture in Somalia.

3. Results

3.1. *An Overview of Agricultural Sector in Somalia*

Agriculture remains the sector with the most significant potential for driving broad-based and inclusive economic growth. This is because most of its people live in rural areas, where the mainstay is agricultural production. It also plays a pivotal role in the economic growth and development of Somalia, consistently remaining the largest platform for economic activities. Also holds significant economic importance in the country, serving as a vital activity that fulfills the population's food needs, generates income through crop sales, and offers employment opportunities within the agricultural sector (Abdullahi 2023). Over 70% of the land area of Somalia is arable land, with a total of 8.9 million hectares. Its two main rivers have a total length of 2,300 km (Anonymous 2022). With an annual average temperature of 28 degrees Celsius, south-central Somalia has a tropical climate. The mountainous terrain leads to great agro-climatic variability that is favorable for numerous crop varieties. Somalia is strategically located in the Horn of Africa along the southern approaches to the Bab el-Mandeb and routes through the Red Sea and Suez Canal. Its proximity to critical Middle East markets and its maritime connection to EU markets confer an advantage in terms of freight costs and rapid transport access to markets. Improved governance and security over the past decade have contributed to an expanding economy, with GDP growth averaging 3.4% per annum during 2017 to 2020 (AFDB 2020). The role of the agricultural sector in the Somali economy can be evaluated based on its contribution to the GDP (Gross Domestic Product) and employment, as well as its significance for sustainable economic development. In addition, more than two-thirds of the country's labor force is employed in the agriculture sector, and it accounts for more than sixty percent of the country's productivity (Pyrtel 2018). Also, in testing the correlation between GDP and the agriculture sector, the test showed that there is a strong positive correlation between them (Sheikdon 2019). According to the World Bank's 2018 report, agriculture holds a substantial share of Somalia's gross domestic product (GDP), accounting for nearly 60.18%. Furthermore, the agricultural sector contributes approximately 93% to the country's total exports, with a significant focus on thriving livestock exports, particularly in the years preceding the recent drought period. By examining the below table, we can observe the changes in Somalia's economic performance over the years. For example: In 2022, Somalia's GDP grew by 4.8%, and the GDP per capita reached \$476. The agriculture sector contributed about 60.17% to the overall GDP its evident that agricultural is backbone of economy in Somalia. In 1990, the country experienced a negative GDP growth of -1.5%, and the GDP per capita decreased by 15.6%. In 1985, Somalia's GDP had a substantial growth rate of 8.2%, and the GDP per capita increased by 6.8%. Overall, this table gives us insight into the fluctuations in Somalia's economic indicators over the specified years, providing a glimpse into the country's economic trends and performance.

Analyzing this data, we observe that Somalia's economy has experienced various periods of growth and contraction over the years. For instance, in 2022, the country's GDP increased to \$8,126 million, with a growth rate of 4.8%. The GDP per capita reached \$476, indicating an improvement in individual economic output. On the other hand, in 1990, there was a negative GDP growth of -1.5%, and the GDP per capita experienced a significant decline, dropping to \$131. The table highlights the fluctuations in Somalia's economic performance, which can be influenced by multiple factors such as global economic conditions, policy decisions, and the performance of key sectors like agriculture, forestry, and fishing.

While the existing production system suffers from traditional farming practices, unimproved seed, lack of fertilizer use, etc. (Abdi-Soojeede 2018). The production area, production amount, yield of the cereal group, and the number of livestock, which have an important place in terms of nutritive properties in Somalia, are

shown in the table below. The number of livestock in Somalia has decreased between 1980 and 2021. Possible reasons for this decline include recurrent droughts and the impact of climate change, conflicts and insecurity disrupting traditional herding practices, disease outbreaks, overgrazing and land degradation, economic challenges, population growth and urbanization, and limited access to resources and services. The situation is complex and influenced by multiple factors.

Table 1. Economic Data for Somalia Over Various Years: Annual GDP and Agriculture Sector Contribution

Date	Annual GDP	GDP Growth (%)	GDP per capita	GDP P.C. Annual Growth	Agriculture, forestry, and fishing, value added (% of GDP) - Somalia
1980	\$604M	-3.9%	\$102	-6.2%	64.4
1985	\$876M	8.2%	\$132	6.8%	63.6
1990	\$917M	-1.5%	\$131	-15.6%	69.34
1995	\$1,122M	0%	\$156	-3.8%	60.09
2000	\$2,052M	3.0%	\$235	-2.2%	60.16
2005	\$2,316M	3.0%	\$221	12.8%	60.09
2010	\$1,093M	2.6%	\$91	-14.5%	60.18
2015	\$5,335M	4.6%	\$310	-0.7%	60.18
2016	\$5,534M	4.7%	\$313	0.8%	60.18
2017	\$5,609M	2.2%	\$327	4.4%	60.18
2018	\$5,856M	3.7%	\$332	1.8%	60.18
2019	\$6,485M	2.7%	\$338	1.8%	60.18
2020	\$6,883M	-0.3%	\$416	23.1%	60.17
2021	\$7,628M	2.9%	\$447	7.4%	60.18
2022	\$8,126M	4.8%	\$476	6.5%	60.17

Source: Anonymous; 2023

As seen in the table, when we look at the years 1980-2021 in Somalia, there have been fluctuations in grain production over the years. Although there is a decrease in the number of areas harvested in 2021 compared to 1980, there is a significant decrease in production. On the other hand, there is an increase in yield. Among the most important reasons for this are the technological developments in agriculture, the farmers becoming more conscious, the increase in labor productivity, the better irrigation opportunities, and the use of fertilizers.

Table 2. The Cereal Crop Cultivation Area, Production, and Yield Status, and Number of Livestock in Somalia (1980-2021)

Date	Cultivation Area, Production and Yield Status of Cereal Crops			Number of Livestock in Somalia by Type (Heads) (Million)				
	Area harvested (1000 Hectares)	Production (1000 tons)	Yield (Kg/tons)	Date	Camels	Cattle	Goats	Sheep
1980	575200	266100	4626	1980	5.8	4.3	17.0	10.3
1985	687500	513500	7469	1985	6.4	4.4	19.0	11.8
1990	732500	580925	7931	1990	6.7	4.0	18.5	13.0
1995	576080	284919,9	4946	1995	6.1	5.2	12.5	13.5
2000	535373	392408	7330	2000	7.0	5.1	12.3	13.8
2005	546473	355708,7	6509	2005	7.2	5.5	14.6	14.7
2010	618634	355814,9	5752	2010	7.0	4.8	11.5	12.0
2015	447104	265481,4	5938	2015	7.2	4.8	11.6	12.0
2018	330636	234812,8	7102	2018	7.3	4.7	11.6	10.3
2019	353489	184581,7	5222	2019	7.3	4.8	11.7	11.0
2020	353531	177639,8	5025	2020	7.4	4.8	11.6	11.3
2021	353551	177683,2	5026	2021	7.4	4.4	11.6	11.4

(FAOSTAT 2023)

However, over time, Somalia's agricultural sector has faced challenges that have led to a shift towards unsustainable farming practices. Factors such as recurring conflicts, climate change, and economic instability have negatively impacted agricultural productivity and sustainability (FAO 2021). As a result, traditional and sustainable farming practices have been disrupted, leading to an increased dependence on chemical inputs, unsustainable land use practices, and the overexploitation of natural resources.

This transition from sustainable to unsustainable farming practices poses significant threats to the environment and ecosystem. Soil degradation, deforestation, loss of biodiversity, and water pollution are among the adverse consequences of the shift towards unsustainable practices in Somalia's agriculture.

Efforts to address these challenges are essential to promote sustainable agriculture in Somalia. Implementing practices that protect the environment, conserve natural resources, and promote resilience to climate change will be crucial to ensure the long-term viability of the agricultural sector and food security for the population. Moreover, investment in research, training, and capacity-building for farmers can enable them to adopt sustainable farming techniques that are both environmentally friendly and economically viable.

3.2. SWOT analysis of sustainable Agriculture in Somalia

To achieve sustainable agricultural development in Somalia, it is essential to address the identified challenges and leverage the opportunities. Implementing strategic pathways is crucial in promoting resilience, productivity, and long-term sustainability in the sector. In order to develop an effective plan to make the agriculture in Somalia competitive and back to its best, a SWOT analysis was carried out. Therefore, this part of thesis will be discussing the strengths, weaknesses, opportunities and threats of the agriculture in Somalia. The table below shows the elements used in this analysis.

Table 3. SWOT Analysis of Agriculture in Somalia

STRENGTHS	WEAKNESSES
✓ Great Agro and Ecological Zones	✓ Insufficient Infrastructure
✓ Native Farming system	✓ Low Productivity
✓ Low cost of labor	✓ Dependency on Rainfed Agriculture
✓ Large numbers of farmer	✓ Unstable economic
✓ Nomadic Livestock Herding	✓ Lack of support
✓ International organizational support e.g., World bank, FAO	✓ Large numbers of small farmers (Low skilled)
	✓ Poor marketing
	✓ Lack of current information
OPPORTUNITIES	THREATS
✓ Investment in Infrastructure	✓ Climate Change
✓ Good telecommunication system	✓ Unsustainable agricultural practices
✓ Modernization and Technology Adoption	✓ Pest and disease
✓ Export Potential	✓ Terrorists
✓ Foreign Aid and Investment	✓ Limited Access to Finance
	✓ Unstable government

3.2.1. Strengths for Agriculture in Somalia

Somalia benefits from a diverse range of Agro-ecological zones, including fertile farmlands, pastoral areas, and coastal regions. These zones offer favorable conditions for growing a variety of crops and support diverse livestock production. The potential to cultivate different crops and rear various livestock species contributes to the resilience and adaptability of Somalia's agriculture sector. Somalia's agriculture relies on traditional and native farming practices that have been adapted over generations to suit local conditions. The native farming system incorporates age-old knowledge and practices that align with the region's climate and natural resources. This system not only preserves cultural heritage but also offers sustainable solutions that are well-suited to the local environment. One of the strengths of Somalia's agriculture is the availability of a low-cost labor force. The country's predominantly agrarian economy ensures a large workforce engaged in farming activities. The availability of affordable labor helps reduce production costs and provides opportunities for labor-intensive agricultural activities. Somalia has a significant number of farmers engaged in various agricultural activities. The agriculture sector is a primary source of livelihood for a considerable portion of the population, especially in rural areas. The large numbers of farmers contribute to the sector's productivity and potential for growth. Nomadic livestock herding is a traditional practice deeply ingrained in Somalia's culture and history. This unique system allows herders to move their livestock to different grazing areas based on seasonal changes and available resources. The mobility of nomadic herding helps optimize resource utilization and supports the livelihoods of pastoral communities. Somalia receives support from international organizations like the World Bank and the Food and Agriculture Organization (FAO). These organizations provide financial assistance, technical expertise, and knowledge sharing to bolster the country's agriculture sector. Their contributions play a crucial role in developing sustainable agricultural practices, building capacity, and implementing projects aimed at improving food security and rural livelihoods.

3.2.2 Weaknesses for Agriculture in Somalia

Somalia's agriculture sector suffers from inadequate infrastructure, including poorly maintained roads, limited irrigation systems, and insufficient storage facilities. The lack of proper transportation and storage infrastructure hinders the efficient movement of agricultural products from farms to markets, leading to post-harvest losses and reduced market access for farmers. Low agricultural productivity is a significant challenge in Somalia. Farmers often lack access to modern farming techniques, improved seeds, and fertilizers. Traditional and outdated practices contribute to low yields and limit the sector's potential for growth and increased food production. Somalia's reliance on rainfed agriculture makes it vulnerable to climate variability and periodic droughts. Inconsistent and unpredictable rainfall patterns can negatively impact crop yields and food production, leading to food insecurity in affected regions. Somalia's economy is susceptible to fluctuations and instability, which can have adverse effects on the agriculture sector. Uncertain economic conditions may lead to reduced investments in agriculture, making it challenging for farmers to access credit and resources needed for agricultural development. The agriculture sector in Somalia faces a lack of adequate support from the government and other stakeholders. Limited financial and technical assistance hinders the adoption of modern agricultural practices and inhibits the sector's overall growth and productivity. A significant portion of Somali farmers consists of small-scale farmers with limited access to training and resources. Many of these farmers lack the necessary skills and knowledge to implement modern agricultural practices effectively, which further contributes to low productivity. The lack of an efficient and organized marketing system presents a challenge for Somali farmers. Inadequate market linkages and price fluctuations make it difficult for farmers to obtain fair prices for their produce, discouraging further investments in agriculture. Access to up-to-date agricultural information and data is limited in Somalia. The absence of timely and accurate information on market trends, weather forecasts, and best agricultural practices hampers farmers' ability to make informed decisions and adapt to changing conditions.

3.2.3. Opportunities for Agriculture in Somalia

Investing in agricultural infrastructure presents a significant opportunity for Somalia's agriculture sector. Improving roads, bridges, irrigation systems, and storage facilities can enhance the efficiency of the agricultural supply chain. Better infrastructure will facilitate the transportation of agricultural produce from farms to markets, reducing post-harvest losses and improving access to both domestic and international markets. Somalia's relatively good telecommunication system can play a crucial role in transforming the agriculture sector. Access to mobile phones and the internet enables farmers to access timely information on weather forecasts, market prices, and agricultural best practices. Improved communication also facilitates the exchange of knowledge and expertise between farmers and agricultural extension services. Modernizing agriculture through the adoption of advanced technologies presents a significant opportunity for growth. Implementing practices like precision farming, greenhouse cultivation, and drip irrigation can increase productivity and resource efficiency. The use of modern agricultural machinery and equipment can further enhance farm productivity, reducing manual labor and operational costs. Somalia's agriculture has considerable export potential, especially for products like livestock, fruits, and fish. The country's geographical location and proximity to international markets create opportunities for increased export volumes. With proper quality control and compliance with international standards, Somali agricultural products can access a broader customer base and generate foreign exchange earnings for the country. Foreign aid and investment from international organizations, donor countries, and development partners offer valuable opportunities for the growth and development of Somalia's agriculture sector. Such investments can be channeled into projects that focus on improving agricultural practices, enhancing value chains, and building capacity within the sector.

3.2.4. Threats to Agriculture in Somalia

Somalia is particularly vulnerable to the impacts of climate change, including erratic weather patterns, prolonged droughts, and increased frequency of extreme weather events. These changes can disrupt agricultural activities, reduce crop yields, and affect livestock productivity. Climate change poses a significant threat to food security and livelihoods for farmers and pastoral communities. Unsustainable agricultural

practices, such as overuse of chemical fertilizers and pesticides, improper land management, and deforestation, can lead to soil degradation and loss of biodiversity. These practices jeopardize the long-term productivity of farmland and contribute to environmental degradation. Outbreaks of pests and diseases can devastate crops and livestock, leading to significant economic losses for farmers and agribusinesses. Inadequate pest and disease management can further exacerbate food insecurity and disrupt agricultural production. The presence of terrorist groups and ongoing conflicts in certain regions of Somalia pose serious threats to agricultural activities. Insecurity and violence can disrupt farming operations, hinder market access, and displace farmers, resulting in a negative impact on food production and distribution. The lack of access to affordable credit and financial services is a major challenge for Somali farmers. Limited access to finance hampers investments in modern agricultural technologies, inputs, and equipment, hindering the sector's growth and potential. Political instability and governance challenges in Somalia can create an uncertain environment for agricultural development. Frequent changes in government policies and weak institutions can affect agricultural planning and investment decisions, leading to a lack of long-term vision for the sector.

4. Discussion

The SWOT analysis of Somalia's agriculture reveals a complex landscape with both favorable attributes and significant challenges. The strengths of diverse agro-ecological zones, traditional farming systems, low-cost labor, a high proportion of smallholder farmers, nomadic pastoralism, and international institutional support establish a strong foundation for sectoral growth. However, significant threats remain. However, several weaknesses, such as insufficient infrastructure, low productivity, dependency on rainfed agriculture, unstable economic conditions, lack of support, large numbers of low-skilled small farmers, poor marketing, and limited access to current information, pose obstacles to its development.

Despite these challenges, there are significant opportunities to enhance the resilience and productivity of Somalia's agriculture. Investing in infrastructure, such as irrigation systems and storage facilities, can improve market access and reduce post-harvest losses. The country's relatively good telecommunication system enables the dissemination of crucial information to farmers, empowering them to make informed decisions and adopt modern agricultural practices. Moreover, modernizing agriculture through the adoption of advanced technologies like precision farming and drip irrigation holds promise for increasing productivity and resource efficiency.

Yet, threats loom large on the horizon, threatening to undermine agricultural development efforts. Climate change exacerbates agricultural vulnerabilities through erratic weather, prolonged droughts, and declining yields. Unsustainable agricultural practices, such as overuse of chemicals and improper land management, degrade soil quality and threaten long-term productivity. Moreover, ongoing conflicts and insecurity in certain regions of Somalia disrupt farming operations, exacerbating food insecurity, and hindering economic development.

Addressing these challenges and opportunities, a concerted effort is needed to build resilience and sustainability in Somalia's agricultural sector. Strengthening governance structures, enhancing access to finance, and promoting peace and stability are essential for creating an enabling environment for agricultural development. Furthermore, investing in research and extension services, promoting climate-smart agricultural practices, and improving market linkages can empower farmers and enhance the sector's productivity and resilience.

Overall, achieving sustainable agricultural development in Somalia requires a multifaceted approach that addresses the sector's complex challenges while harnessing its inherent strengths and opportunities. By investing in infrastructure, technology, and human capital, Somalia can unlock its agricultural potential, improve food security, and promote economic growth and resilience across the country.

Somalia benefits from its diverse agro-ecological zones, which include fertile farmlands, pastoral areas, and coastal regions. These zones offer favorable conditions for cultivating various crops and supporting diverse livestock production. The inherent resilience and adaptability of Somalia's agriculture sector are

bolstered by the potential to cultivate different crops and rear various livestock species, ensuring food security and livelihoods for a considerable portion of the population. However, their effective utilization in the agricultural sector has been hindered by misplaced priorities, loss of focus, and insufficient support for key players. Nevertheless, there are ample opportunities for Somalia to revitalize its agricultural sector and make it a driving force in the economy. Addressing issues such as land degradation, conflicts, unstable policies, and attracting investors are critical steps in achieving this goal. Successful implementation of the mentioned recommendations can lead to significant achievements, including increased investment and contribution to the country's GDP. This, in turn, can bring about income growth, diversified revenue sources, job creation, and ultimately a reduction in poverty.

5. Conclusion

In conclusion, Somalia's agricultural sector has the potential to contribute significantly to the country's economic development. By fostering overall progress, especially in rural areas, Somalia can achieve food security and agricultural sustainability. The country benefits from diverse agro-ecological zones, traditional farming practices, a large labor force, and international support. However, inadequate infrastructure, low productivity, dependency on rainfed agriculture, economic instability, inadequate support, and limited access to resources and information pose significant challenges. Despite these hurdles, investing in agricultural infrastructure, modernizing farming practices, accessing international markets, and leveraging foreign aid represent key opportunities for advancement. Nevertheless, threats such as impacts of climate change, unsustainable practices, insecurity, and limited access to finance require careful management. Addressing these challenges and seizing opportunities can unlock Somalia's agricultural potential, fostering economic growth, food security, and rural development. Achieving sustainable agriculture in Somalia demands coordinated efforts from government, stakeholders, and international partners to overcome barriers and realize the sector's transformative potential for the country's future prosperity. To enhance the contribution of agriculture to the Somali economy, several recommendations have been proposed. These include establishing and enforcing environmental protection policies, educating farmers on modern and sustainable practices, conducting surveys to identify areas prone to climate change and environmental degradation, and increasing government investment in research and development for sustainable agriculture.

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Reference

- Abdi-Soojeede MI (2018). Crop production challenges faced by farmers in Somalia: A case study of Afgoye District. *Agricultural Sciences* 9(8), 1032-1046. <https://doi.org/10.4236/as.2018.98071>
- Abdullahi AA, Arisoy H (2022). Agricultural structure in Somalia. *Eurasian Journal of Agricultural Economics* 2(1), 1-14.
- Abdullahi AA (2023). Improvements of sesame production: Marketing and its export trends in Somalia. *Conference: 8th International Student Symposium. At: İstanbul*. Volume: 978-625-7480-21-5.
- African Development Bank Group (2020). AFDB Group, Somalia Country Brief 2017-2020; https://www.afdb.org/fileadmin/uploads/afdb/Documents/Project-and-Operations/Somalia-Country-Brief_-2017-2020.pdf. (access date: 15.12.2024).

- Altieri MA, Nicholls CI (2017). The adaptation and mitigation potential of traditional agriculture in a changing climate. *Climatic Change* 140, 33–45. <https://doi.org/10.1007/s10584-013-0909-y>
- Anonymous (2022). Overview of country profile, Somalia <https://data.worldbank.org/country/somalia>. (access date: 01.01.2025).
- Anonymous (2023). Gross Domestic Product by Country, Somalia GDP - Gross Domestic Product <https://countryeconomy.com/gdp/Somalia> (access date: 10.11.2024).
- Baris ME, Uslu A (2009). Cut flower production and marketing in Türkiye. *African Journal of Agricultural Research* 4(9): 765-771.
- Benbrook C (1991). Sustainable agriculture research and education in the field. 1st ed. Washington: *National Academy Press*.
- Brodt S, Six J, Feenstra G, Ingels C, Campbell D (2011). Sustainable Agriculture. *Nature Education Knowledge* 3(10):1.
- Eap MC (1989). An Introduction to Sustainable Agriculture. [online] Available at: <http://eap.mcgill.ca/publications/EAP16.htm> (access date: 05.04.2017).
- FAO (2021). The impact of disasters and crises on agriculture and food security: 2021. Rome. <https://doi.org/10.4060/cb3673en> (access date: 18.06.2022).
- FAOSTAT (2023). Somalia Crops and livestock products <https://www.fao.org/faostat/en/#data/OCL> (access date: 15.11.2024).
- Harwood RR (2020). A History of Sustainable agriculture. Sustainable agricultural systems. Boca Raton, FL: CRC Press, 3–19. <https://doi.org/10.1201/9781003070474-2>
- Kihara J, Bolo P, Kinyua M, Nyawira SS, Sommer R (2020). Soil health and ecosystem services: lessons from sub-Saharan Africa (SSA). *Geoderma* 370, 114342. <https://doi.org/10.1016/j.geoderma.2020.114342>
- Mestmacher J and Braun A (2021). Women, agroecology and the state: new perspectives on scaling-up agroecology based on a field research in Chile. *Agroecology and Sustainable Food Systems* 45, 981–1006. <https://doi.org/10.1080/21683565.2020.1837330>
- Millennium Ecosystem Assessment (2005). *Mea. Ecosystems and Human Well-Being*. Washington, DC: Island Press.
- Paul H (1994). *The ecology of commerce: A declaration of sustainability*. New York: Harper Business.
- Pyrtel M (2018) Sustainable agriculture in Somalia. *Somalia Strat Rev* 2012, 1-5
- Sarkar A, Azim JA, Asif AA, Qian L and Peau AK (2021). Structural equation modeling for indicators of sustainable agriculture: Prospective of a developing country's agriculture. *Land Use Policy* 109, 105638. <https://doi.org/10.1016/j.landusepol.2021.105638>
- Sheikdon AA (2019). An analysis of the contribution of the agriculture sector to the Somali. *International Journal of Economics & Management Sciences* 8, 2.
- Sheppard JP, Bohn Reckziegel R, Borrass L, Chirwa PW, Cuaranhua C J, Hassler SK (2020). Agroforestry: an appropriate and sustainable response to a changing climate in southern Africa? *Sustainability* 12, 6796. <https://doi.org/10.3390/su12176796>
- Velten S, Leventon J, Jager N, and Newig J (2015). What is sustainable agriculture? A systematic review. *Sustainability* 7, 7833–7865. <https://doi.org/10.3390/su7067833>
- Wehrich H (1982). The TOWS Matrix—A tool for situational analysis. *Long Range Plan* 15(2): 54-66.
- Zencirkiran M, Gürbüz IB (2009). Turkish ornamental plants sector in the European Union screening process. *Journal of Fruit and Ornamental Plant Research* 17(2), 235-250.

Zhao D, Liu C, and Bao B (2018). Agricultural sustainable development ability evaluation and subsystem coordination degree analysis: Take the major grain-producing areas of China as an example. *Economic Geography* 38, 157–163.



Interactive Effects of Water Salinity and Water-Deficit on Biochemical Content and Photosynthetic Activity of Melon (*Cucumis melo* L.) Seedlings

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HIGHLIGHTS

- Salinity and water deficit are important stress factors during the melon seedling period.
- During the growth period of melon, high salinity of 4000 µmhos negatively affects.
- 25% water restriction can be applied in regions where irrigation water is limited.

Abstract

The deleterious effects of abiotic stress factors, which have emerged in the context of global climate change, have a detrimental impact on agricultural production. Irregularity in seasonal rainfall and high temperatures make it difficult to meet the water needs of the plant. In addition, intensive fertilization, monoculture and use of poor-quality water in irrigation in vegetable fields cause salinity problems. It has been observed that both stress factors cause yield and quality losses in vegetable farming. For this purpose, in the present study, five different salt (NaCl-S) levels {control S₁ (main water=500 µmhos), S₂ (2000 µmhos), S₃ (4000 µmhos), S₄ (6000 µmhos) and S₅ (8000 µmhos)} and three different irrigation water levels (full irrigation-I₁₀₀, 75% irrigation-I₇₅ and 50% irrigation-I₅₀) were applied to melon seedlings in the study and their effects on photosynthetic activity and biochemical changes were tried to be determined. The study revealed that elevated levels of both stress factors resulted in a reduction in the growth of melon seedlings. Conversely, the findings indicated that superoxide dismutase (SOD) enzyme activity served as a significant indicator under both stress factor conditions. Furthermore, an increase in SOD activity was observed as stress levels escalated. In addition, it was observed that saline waters with a conductivity higher than 4000 µmhos would have a toxic effect on melon seedlings. It is important for the sustainability of melon farming that 25% water restriction can be applied in regions where irrigation water is limited.

Keywords: Abiotic stress; chlorophyll; *Cucumis melo* L.; leaf pigments; photosynthesis.

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1. Introduction

Climate change resulting from global warming negatively affects many sectors. The agricultural sector is among the sectors most affected. Climate change causes greenhouse gases: changes in temperatures, irregular precipitation regime, an increase or decrease in sea level, and many environmental events. The agricultural sector alone accounts for 20% of annual greenhouse gas production. A significant portion of this rate is attributed to the use of animal manure and excessive fertilizers. The negative effects resulting from this situation can be listed as geographical displacement, decreasing water resources for irrigation, and land loss due to rising sea levels. In addition, there is a serious increase in temperatures, and precipitation regimes are seen to become more irregular. The results of climate change vary across different regions of the world. Especially in tropical regions, climate change significantly affects agricultural productivity (Cumhur and Malcolm 2008).

Abiotic stress factors are increasing their effects due to the effects of climate change. Examples of abiotic stress factors are excessive light, exposure to UV rays, high and low temperatures, freezing, drought, salinity, presence of heavy metals in the soil, oxygen deficiency, air pollution, radiation, deficiency or excess of nutrients, flooding, and waterlogging (Hirayama and Shinozaki 2010). When we consider agricultural lands in the world, the areas affected by drought have a share of 26% among abiotic stress conditions (Blum 1985). Drought is the inadequacy of water needed by the plant due to transpiration and evaporation. Drought is a serious problem that increases its effect day by day and spreads to large areas, causing yield and quality losses (Çelik et al. 2024).

Drought stress is responded to by plants in two different ways: reversible and irreversible. Drought is divided into two groups: physical and physiological. Physical drought occurs when a negative water potential occurs in the protoplasm due to water scarcity in the plant's environment. The other is physiological drought, which is the situation where the plant cannot get the water it needs from the soil, even though there is enough water in the soil. Stomatal closure caused by drought conditions reduces gas exchange and increases leaf temperature, which in turn increases water loss through transpiration (Kuşvuran 2012; Ansari et al. 2019). Water deficiency and desiccation are two different terms related to drought that need to be distinguished. Water deficiency is a moderate water deficiency that causes stomata to close and gas exchange to be restricted. As a result of stomata closure, carbon dioxide uptake is restricted. Desiccation is defined as excessive water loss that causes complete disruption of metabolism and cell functions and failure to secrete enzyme activities (Smirnov 1993; Kalefetoğlu and Ekmekçi 2005). As plants begin to dry, signs of wilting begin to appear on the leaves. After desiccation occurs, the damage caused by dehydration to the plant cannot be recovered, even if the necessary water is given, and death occurs (Kaçar 2015). When the plant cannot provide the water it needs for photosynthesis from the root area, stress begins to appear in the plant, and when stress begins to show its effect, plants either reduce water consumption or try to take more water from the soil (Bray 1997). This causes a decrease in the photosynthesis rate in plants and, accordingly, a slowdown in vegetative growth (Sağlam 2004). Restriction of photosynthesis, reduction in stem diameter and length, cessation of stem and root development, also reduces leaf area, leaf number, and leaf life, causing the leaf to yellow and wither (Anjum et al. 2011; Öztürk 2015).

Similar to drought conditions, salinity stress represents a critical abiotic stressor that constrains vegetative development within agricultural environments. Salinity is characterized as the concentration of salts present in soil or aqueous mediums and is observed to exert a considerable influence on plant development (Fileccia et al. 2017; Ibrahim et al. 2019; Omid et al. 2022). It is seen that high salinity levels cause osmotic stress, and the available water that the plant will consume in respiration will decrease, and physiological drought will begin (Ibrahim et al. 2019). Similar to drought, salinity inhibits photosynthesis in plants and negatively affects nutrient uptake. It manifests itself in morphological changes, including the decrease in leaf number and leaf area, which are directly related to the decrease in photosynthesis. (Abdel-Farid et al. 2020; Omid et al. 2022). It has been noted that elevated salinity levels perturb ion homeostasis, resulting in the accumulation of deleterious ions, including sodium (Na^+) and chloride (Cl^-), within plant tissues. (Fileccia et al. 2017; Ibrahim et al. 2019; Ali et al. 2022). This ionic imbalance damages cellular structures, impairs enzyme functions and

inhibits metabolic processes. In a study, it was reported that salinity stress leads to a decrease in chlorophyll content and gas exchange, which are indispensable for photosynthesis (Alam et al. 2020; Hameed et al. 2021). It has been revealed that the presence of salinity in the environment increases the production of reactive oxygen species (ROS) and causes more damage to plant cells (Akram et al. 2019; Hameed et al. 2021).

Salinity and drought are well-documented stress factors that have been shown to have a detrimental effect on the growth, development and yield of melons, a vegetable species that is widely cultivated around the world. Different varieties of melons are tolerant to different levels of salt. In general, it is reported that the salinity tolerance threshold in melons is approximately 2.2 dS m⁻¹, beyond which yield can decrease significantly (Sobhani and Mohammadzadeh 2017). Melons exposed to drought stress exhibit low germination rates, impaired seedling growth and changes in biochemical pathways, including the accumulation of osmoprotectants such as proline and citrulline, which help alleviate stress effects (Kuşvuran et al. 2013; Ansari et al. 2019).

Melon (*Cucumis melo* L.) is a vegetable species that is eaten with pleasure by people and has a high production and consumption potential. Although previously believed to be native to Africa, recent research suggests that melon may be of Asian origin. There is a world production of melon of 29 541 294 tons. Turkey, in particular, is an important producer, ranking third after China and India with a production of 1 403 214 tons (FAO 2023). The regions where melon production is highest in Türkiye are the Mediterranean region, the Aegean region, and the Southeastern Anatolia region, respectively. The cities where production is highest are Adana, Denizli, Antalya, Mardin, Manisa, and Konya. (TÜİK 2023). Melon has a low protein and fat content in terms of nutritional content, while it contains plenty of carbohydrates and sugar. In addition, it is a vegetable species rich in vitamins A, B, C, calcium, potassium, iron and magnesium (Salunkhe and Kadam 1998). It is an economically important vegetable and is used in making fruit juice in addition to fresh consumption. In addition, some varieties are used as ornamental plants (Wien 1997).

The combination of salinity and drought stress causes more damage to yield, growth and development (Kuşvuran 2012; Chevilly et al. 2021). This interaction is especially important in semi-arid regions where both salinity and drought are common due to irregular rainfall patterns and inadequate irrigation practices (Pereira et al. 2017; Sousa et al. 2018). In such environments, effective irrigation management is mandatory to minimize salinity accumulation and ensure adequate water supply for melon cultivation. In studies on melon, salinity and drought stress have generally been evaluated separately. In our study, we tried to determine the separate and interactive effects of two important stress factors, such as drought and salinity, on photosynthetic activity and biochemical contents in melon seedlings.

2. Materials and Methods

2.1. Experimental area

The investigation was conducted in controlled pot environments within the greenhouses of the Faculty of Agriculture at Konya Selçuk University from September 26 to November 12, 2024. The geographical coordinates of the research site are situated at 38°02' north latitude and 32°30' east longitude, with an average elevation of 1 105 meters above sea level. Throughout the duration of the experimental period, climatic data within the greenhouse were systematically recorded, revealing an average temperature of 18.3°C and an average relative humidity of 45.7% (refer to Figure 1). Comprehensive physical and chemical analyses of the soil sample utilized in the experiment were conducted, indicating an organic matter content of 4.8% alongside a clayey-loamy texture. It was noted that the experimental soil exhibited favorable attributes concerning its nutrient composition, with a pH of 8.05, an electrical conductivity of 1 050 µS cm⁻¹, and a calcium carbonate content of 13%. The field capacity and wilting point of the soil were ascertained to be 25.12% and 12.4%, respectively. Upon the evaluation of the collected results, it was determined that the climatic and soil characteristics did not induce any stressors in the cultivation of melons.

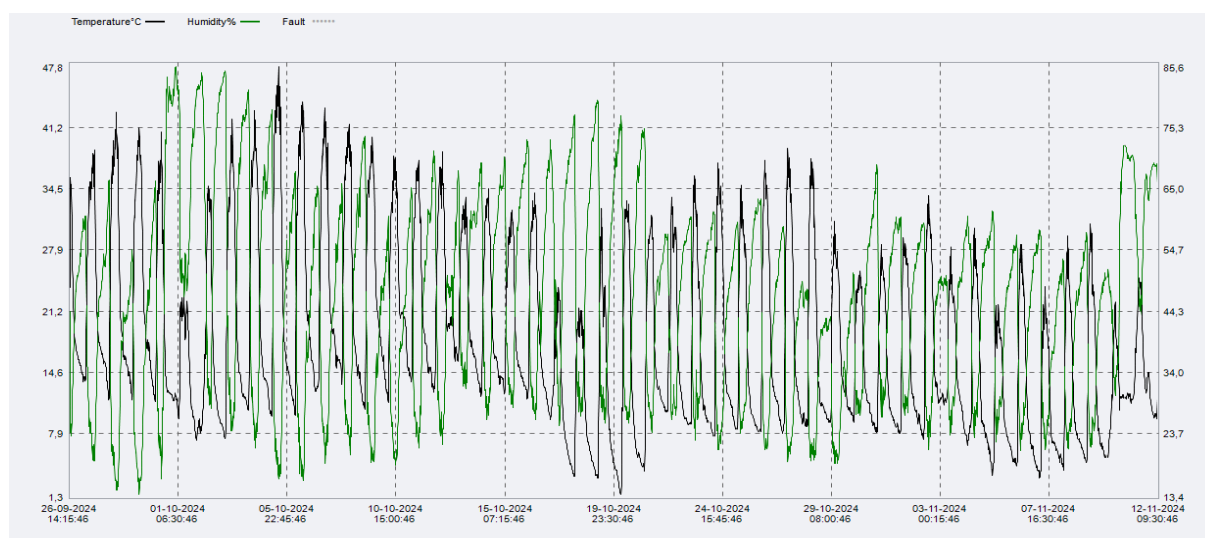


Figure 1. The distribution of temperature and relative humidity inside the greenhouse was measured and recorded throughout the study

2.2. Plant Materials, Planting, Irrigation and Salinity Procedures

The material used in the study was a standard melon variety, Kırkağaç 631. In the experiment, plastic pots with a height of 24 cm, a base diameter of 19 cm and an upper diameter of 29 cm were used. Each pot to be used in the experiment was filled with dry soil and weighed to 10 kg. The study was set up with three replications and 6 to 9 seeds were planted in the pots to form a triangle. After the seeds germinated, thinning was done so that three plants remained in each pot. In this study, five different salt (NaCl) levels {control S₁ (main water = 500 µmhos), S₂ (2000 µmhos), S₃ (4000 µmhos), S₄ (6000 µmhos) and S₅ (8000 µmhos)} were used. At the same time, three different irrigation water levels (full irrigation-I₁₀₀, 75% irrigation-I₇₅ and 50% irrigation-I₅₀) were used. After the seedlings reached two or three true leaves, the soil was brought to field capacity. The pots in S₁I₁₀₀ subjects were weighed regularly and the decreasing water was applied to the pots. As of October 16, 2024, the calculated salt and irrigation amounts were started to be applied to the pots. A total of 6 water and salt stress applications were made and the seedlings were harvested on November 12, 2024. Cultural procedures were carried out regularly in the study.

2.3. Physiological and Biochemical Analyses

Following the demonstration of the impact of stress, measurements of g_s (stomatal conductance), PSII (actual photosynthetic efficiency), and T Leaf (leaf temperature) were conducted on melon foliage. Illuminance assessments were executed utilizing a portable LI-600 fluorimeter device (LI-COR Inc. USA) during the time frame of 9:00 a.m. to 11:00 a.m. (Liang et al. 2019).

Spectrophotometric analyses (Shimadzu-UV-6300PC) were performed on samples procured from melon foliage. The protocol delineated by Lichtenthaler (1987) was employed to quantify total chlorophyll and carotenoid concentrations within the leaves of melon specimens. In order to ascertain the levels of malondialdehyde (MDA) and H₂O₂ in the leaf tissues, the spectrophotometric technique articulated by Esterbauer and Cheeseman (1990) was taken into account. The Bradford method was utilized for the quantification of proline and protein concentrations within the leaf (Bradford, 1976). The activities of catalase (CAT), superoxide dismutase (SOD), and peroxidase (POD) were evaluated according to the methodologies established by Havir and McHale (1987), Beyer and Fridovich (1987), and Bergmeyer et al. (1983), respectively.

2.4. Data Analysis

Data obtained from melons tested under all applied stress conditions were analyzed using JMP-17 Pro software at 5% and 1% significance levels. All data were then subjected to principal component analysis (PCA) using the same software to determine significant parameters and their relationships.

3. Results and Discussion

3.1. Effects of Salinity and Irrigation Deficit on the Stomatal Conductance, Actual Photosynthetic Efficiency, and Leaf Temperature in Melon

An analysis of the data revealed that the application of different irrigation levels and salt applications to melon seedlings exhibited statistically significant effects on g_s , PSII and T leaf (Table 1). Upon examination of the table, it was observed that irrigation water salinity and varying irrigation water levels did not demonstrate any statistically significant change in g_s . When the measured PSII values were analyzed, salt applications and irrigation water amounts did not generate a significant difference; however, when both stress factors were combined, significant changes were observed. The study observed that under control conditions, melon seedlings exhibited a leaf temperature of 19.97°C, which decreased significantly with increasing salinity stress. When water stress applications are examined, the highest leaf temperature was observed to be 19.21 °C in the I 100 application. According to the findings of the study, leaf temperature decreases compared to the control with increasing water stress.

Table 1. The effects of salinity and irrigation deficit on the g_s , PSII, T leaf, and pigment contents in melon

Treatments		g_s (mol m ⁻² s ⁻¹)	PSII	Tleaf (C°)	Chl a (mg g ⁻¹)	Chl b (mg g ⁻¹)	CT (mg g ⁻¹)
<u>Salinity (S)</u>							
S ₁ (control)		0.03	0.71	19.97 ^A	17.94 ^B	5.13 ^B	4.42 ^C
S ₂		0.03	0.73	19.17 ^B	19.84 ^A	5.69 ^A	4.89 ^B
S ₃		0.03	0.72	18.93 ^B	19.98 ^A	5.61 ^A	5.42 ^A
S ₄		0.03	0.73	18.37 ^C	15.67 ^C	4.43 ^C	4.23 ^D
S ₅		0.05	0.71	18.19 ^C	14.83 ^D	4.27 ^C	4.06 ^E
<u>Irrigation (I)</u>							
I ₁₀₀		0.03	0.72	19.21 ^a	19.42 ^a	5.72 ^a	5.04 ^a
I ₇₅		0.03	0.72	18.69 ^b	17.22 ^b	4.87 ^b	4.51 ^b
I ₅₀		0.04	0.73	18.89 ^b	16.32 ^c	4.49 ^c	4.26 ^c
<u>S X I (Interactions)</u>							
S ₁	I ₁₀₀	0.04	0.69 ^{bc}	21.11 ^a	19.44 ^c	5.47 ^{de}	5.09 ^{cde}
	I ₇₅	0.03	0.70 ^{abc}	19.52 ^b	20.99 ^b	6.37 ^b	4.54 ^g
	I ₅₀	0.02	0.74 ^a	19.29 ^{bc}	13.39 ^f	3.56 ^h	3.63 ^j
S ₂	I ₁₀₀	0.03	0.73 ^{ab}	19.20 ^{bcd}	16.77 ^d	4.88 ^f	4.31 ^h
	I ₇₅	0.03	0.72 ^{abc}	19.04 ^{bcd}	21.00 ^b	5.79 ^{cd}	5.15 ^{cd}
	I ₅₀	0.02	0.75 ^a	19.28 ^{bc}	21.76 ^b	6.39 ^{ab}	5.21 ^c
S ₃	I ₁₀₀	0.02	0.71 ^{abc}	18.72 ^{bef}	23.15 ^a	6.75 ^a	5.88 ^a
	I ₇₅	0.03	0.72 ^{ab}	18.84 ^{cde}	17.37 ^d	4.82 ^f	4.85 ^f
	I ₅₀	0.03	0.74 ^{ab}	19.24 ^{bcd}	19.43 ^c	5.26 ^e	5.54 ^b
S ₄	I ₁₀₀	0.02	0.71 ^{abc}	18.80 ^{cde}	18.85 ^c	5.39 ^e	5.00 ^{def}
	I ₇₅	0.04	0.73 ^{ab}	17.89 ^g	12.96 ^f	3.69 ^h	4.12 ^h
	I ₅₀	0.02	0.74 ^{ab}	18.40 ^{efg}	15.20 ^e	4.21 ^g	3.56 ^{jk}
S ₅	I ₁₀₀	0.03	0.73 ^{ab}	18.19 ^{fg}	18.92 ^c	6.12 ^{bc}	4.91 ^{ef}
	I ₇₅	0.03	0.74 ^a	18.14 ^g	13.78 ^f	3.69 ^h	3.90 ⁱ
	I ₅₀	0.11	0.67 ^c	18.24 ^{fg}	11.80 ^g	3.01 ⁱ	3.37 ^k
<u>Significance</u>							
S		ns	ns	**	**	**	**
I		ns	ns	**	**	**	**
S X I		ns	*	**	**	**	**

*Statistically significant according to P<0.05 and 0.001. ns not significant. g_s (Stomatal conductance), PhiPSII (actual photosynthetic efficiency), T Leaf (Leaf temperature), Chl a (Chlorophyll a), Chl b (Chlorophyll b), CT (Carotenoid)

Plants try to prevent water loss from plant tissues by closing their stomata under water stress conditions or high temperature conditions. In this way, plants develop a defense mechanism against stress and photosynthesis is negatively affected. In a study conducted on lettuce, it was reported that g_s and PSII were

not affected in applications where water stress was mild, while significant decreases occurred in applications where stress was intense (Yavuz et al. 2023). In a similar vein, it has been documented that water stress on cabbage growth has been shown to result in a significant reduction in gs and PSII values. (Seymen et al. 2023). In the present study, while the findings obtained from salt stress and water stress did not cause significant changes in PSII and gs when examined separately, both stress factors decreased leaf temperature compared to the control.

3.2. Effects of Salinity and Irrigation Deficit on The Biochemical Contents in Melon

The findings of the study demonstrated that the application of different irrigation and salt treatments to melon seedlings exhibited statistically significant ($P < 0.01$) effects on pigment content (see Table 1). Upon examination of chlorophyll a content, it was observed that the S₂ and S₃ applications resulted in the highest levels of chlorophyll a, with concentrations of 19.84 and 19.98 mg g⁻¹, respectively. However, when the impact of varying water levels was analyzed, the maximum chlorophyll a content was observed in the I₁₀₀ application, reaching 19.42 mg g⁻¹. Conversely, as water stress levels increased, a decline in chlorophyll content was evident. When the interactive effect of both stress factors was examined, the maximum chlorophyll a content was attained by the S₃I₁₀₀ application, reaching 23.15 mg g⁻¹. The most significant decrease was observed in the S₅I₅₀ application, which had the highest level of both stresses, with a value of 11.80 mg g⁻¹. Chlorophyll b content was also found to be negatively impacted by salt stress. When water levels were analyzed, the maximum value for chlorophyll b content was obtained from the I₁₀₀ application, at 5.72 mg g⁻¹, while significant decreases in chlorophyll b content were observed as water stress increased. In the interaction of salinity and water limitation, S₃I₁₀₀ and S₂I₅₀ applications exhibited the highest chlorophyll b values. Conversely, S₅I₅₀ application, which had the maximum chlorophyll b content, had the lowest chlorophyll b content. In the examination of carotenoid content, it was observed that low-dose salt levels increased the carotenoid content compared to the control, while high-level salt applications caused significant decreases. The irrigation application of I₁₀₀ resulted in the highest carotenoid content of 5.04 mg g⁻¹, while significant decreases in carotenoid content were observed as water stress increased. The interaction of stress factors revealed that the application of S₃I₁₀₀ yielded the highest carotenoid content of 5.88 mg g⁻¹.

Pigments found in plant leaves play a pivotal role in the process of photosynthesis and the utilization of excess energy. A well-documented mechanism for mitigating ROS production under stress conditions involves enhanced tolerance through the dissipation of excess energy in chloroplasts via the xanthophyll cycle, facilitated by carotenoids (Latowski et al. 2011). Research findings have demonstrated significant alterations in pigment content under conditions of salinity and water stress (Seymen 2021; Yavuz et al. 2022; Kurtar et al. 2024). In a study conducted on spinach, it was reported that 50% water stress did not result in a statistically significant difference in chlorophyll a, b and carotenoid contents (Kayak et al. 2023). Conversely, a separate study revealed that salt and water stress significantly diminished chlorophyll a, chlorophyll b, and carotenoid contents in spinach (Yavuz et al. 2022). Conversely, a study on cabbage revealed significant alterations in pigment content under diverse irrigation water and salt stress conditions, accompanied by substantial declines in chlorophyll a, chlorophyll b, and carotenoid levels (Seymen et al. 2023). The findings of the present study are in alignment with these earlier research findings, underscoring the pivotal role of pigment content in mediating the impact of stress conditions.

It was observed that salt and water stress applied to melon had statistically significant effects on H₂O₂, MDA, protein and proline (Table 2). When we look at H₂O₂ content, control (S₁) application had the highest H₂O₂ content with 15.46 µmol g⁻¹. Other salt stress applications caused a decrease in H₂O₂ content. While the highest H₂O₂ content was obtained under full irrigation conditions, decreases in H₂O₂ content were observed as water stress increased. In the interaction, S₁I₇₅, S₁I₅₀ and S₄I₁₀₀ applications were the applications with the highest H₂O₂ contents and were statistically in the same group. When we look at MDA contents, S₅ (8000 µmhos) application, where the highest salt stress was applied, had the lowest MDA content with 0.55 nmol mL⁻¹, while other salt applications were statistically in the same group. When different water level applications were examined, it was seen that water levels did not have a significant effect on MDA contents. Similarly, the interaction of both stresses was not found to be statistically significant. When protein contents were examined,

S₂ and control (S₁) applications had the highest protein contents, while higher salt applications decreased the protein content. It was seen that different irrigation levels did not have a significant effect on protein content. When stress interactions were examined, the highest protein content was obtained from S₄I₅₀ application. When proline was examined, control (S₁) and S₃ applications gave the highest results with 17.30 and 15.43 µg g⁻¹ among different applications. At different irrigation levels, I₇₅ and I₅₀ applications had the highest proline contents with 15.06 and 16.38 µg g⁻¹.

Table 2. The effects of salinity and irrigation deficit on the levels of H₂O₂, MDA, PT, and PL, as well as on the antioxidant enzyme activities in cabbage

Treatments		H ₂ O ₂ (µmol g ⁻¹)	MDA (nmol mL ⁻¹)	Prot (µg g ⁻¹)	Prol (µg g ⁻¹)	SOD (EU/g ⁻¹)	POD (EU/g ⁻¹)	CAT (EU/g ⁻¹)
<u>Salinity (S)</u>								
S ₁ (control)		15,46 ^A	0,81 ^A	104,70 ^{AB}	17,30 ^A	4509,36 ^C	3060,98 ^D	1572,44 ^A
S ₂		9,87 ^B	0,76 ^A	105,76 ^A	14,21 ^{BC}	4523,99 ^C	3253,69 ^D	1631,11 ^A
S ₃		9,84 ^B	0,74 ^A	103,67 ^{BC}	15,43 ^{AB}	4725,73 ^{BC}	4214,22 ^C	1700,22 ^A
S ₄		10,14 ^B	0,77 ^A	103,21 ^{BC}	14,32 ^{BC}	5044,53 ^B	4637,51 ^B	1453,78 ^A
S ₅		6,66 ^C	0,55 ^B	102,34 ^C	13,04 ^C	5443,15 ^A	5776,00 ^A	803,78 ^B
<u>Irrigation (I)</u>								
I ₁₀₀		11,54 ^a	0,72	103,35	13,14 ^b	4687,24	5581,76 ^a	1401,20 ^b
I ₇₅		9,99 ^b	0,69	103,99	15,06 ^a	4844,97	3871,04 ^b	1213,47 ^b
I ₅₀		9,65 ^b	0,77	104,47	16,38 ^a	5015,85	3112,64 ^c	1682,13 ^a
<u>S X I (Interactions)</u>								
S ₁	I ₁₀₀	12,60 ^d	0,81	106,48 ^c	16,74	4724,82	3161,07 ^{hi}	1556,00 ^{b-e}
	I ₇₅	16,89 ^e	0,79	107,13 ^{bc}	15,48	4358,71	3698,67 ^{gh}	1440,00 ^{c-f}
	I ₅₀	16,90 ^e	0,83	100,50 ^{gh}	19,69	4444,56	2323,20 ^{jk}	1721,33 ^{bcd}
S ₂	I ₁₀₀	14,51 ^{bc}	0,77	102,50 ^{efg}	13,23	4499,44	4387,73 ^{ef}	1830,67 ^{abc}
	I ₇₅	8,49 ^{ef}	0,69	109,51 ^b	15,07	4514,06	3845,87 ^{fg}	830,67 ^{gh}
	I ₅₀	6,62 ^g	0,83	105,28 ^{cde}	14,32	4558,45	1527,47 ^l	2232,00 ^a
S ₃	I ₁₀₀	6,90 ^{fg}	0,77	105,84 ^{cb}	12,35	4291,10	5355,20 ^c	1846,00 ^{abc}
	I ₇₅	9,57 ^e	0,66	102,07 ^{gh}	16,62	4800,69	5462,93 ^c	1298,67 ^{def}
	I ₅₀	13,05 ^{cd}	0,80	103,09 ^{def}	17,31	5085,42	1824,53 ^{kl}	1956,00 ^{ab}
S ₄	I ₁₀₀	16,02 ^{ab}	0,78	102,27 ^{fg}	11,04	4910,80	6642,13 ^b	1245,33 ^{efg}
	I ₇₅	7,68 ^{fg}	0,67	93,08 ^c	15,77	4853,16	2643,73 ^{ij}	1457,33 ^{c-f}
	I ₅₀	6,73 ^g	0,86	114,29 ^a	16,13	5369,63	4626,67 ^{de}	1658,67 ^{b-e}
S ₅	I ₁₀₀	7,71 ^{fg}	0,48	99,66 ^{gh}	12,31	5010,06	8362,67 ^a	528,00 ^h
	I ₇₅	7,32 ^{fg}	0,64	108,14 ^{bc}	12,35	5698,24	3704,00 ^{gh}	1040,67 ^{fg}
	I ₅₀	4,96 ^h	0,53	99,20 ^h	14,44	5621,16	5261,33 ^{cd}	842,67 ^{gh}
<u>Significance</u>								
S		**	**	**	**	**	**	**
I		**	ns	ns	**	ns	**	**
S X I		**	ns	**	ns	ns	**	**

*Statistically significant according to P<0.05 and 0.001. ns not significant

H₂O₂ (Hydrogen peroxidase), MDA (Malondialdehyde), Prot (Protein), Prol (Proline), SOD (Superoxide dismutase), POX (Peroxidase), CAT (Catalase).

MDA, which has been observed to increase under stress conditions, is an indicator of lipid peroxidation (Riasat et al. 2019). MDA is the end product of lipid peroxidation and its increase indicates that ROS accumulation increases as a result (Savvides et al. 2016). It has been explained that H₂O₂ is a toxic substance that increases significantly in plant cells as a result of stress. Its high concentration has been observed to cause lipid peroxidation and membrane damage, with a consequent negative effect on the plant (Nayar and Kaushal 2002). MDA and H₂O₂ have been observed to increase underwater stress conditions in many studies (Seymen et al. 2023; Kayak et al. 2024; Yavuz et al. 2024). In contrast, our study observed no such increase in melon under both stress conditions. The reduction of oxidative damage is achieved by proline and proteins through their synergy with enzymatic and non-enzymatic antioxidant defence systems under stress conditions (Hanif et al. 2021). Proline, a non-enzymatic antioxidant, has been shown to enhance the production of osmoprotectants (Khedr et al. 2003). It has been documented that proline and protein contents increase under both stress conditions and interactions (Yavuz et al. 2022; Seymen et al. 2023). In the present study, although proline content decreased under salinity stress conditions, it increased under water stress conditions.

It was observed that the effects of salinity and water stress applications on antioxidant enzyme activities in melon were statistically significant (Table 2). When SOD enzyme activity was examined, it was seen that S₅ application had the highest SOD enzyme activity with 5443.15 EU/g⁻¹ and it was observed that SOD activity increased as stress increased. Different irrigation levels and both stress interactions did not have statistically significant effects on SOD enzyme activity. When POD activity was examined, the highest SOD value among different salinity applications was obtained from S₅ application with 5776 EU/g⁻¹. Similarly, it was observed that POD activity increased as salinity level increased. In different irrigation conditions, I₁₀₀ application was the application giving the highest value with 5581.76 EU/g⁻¹ and POD activity decreased as water restriction increased. When the interaction of these two was examined, S₅I₁₀₀ application had the highest POD value. When CAT enzyme activity was examined, S₅ application gave the lowest enzyme activity of 803.78 EU/g⁻¹ from different salt levels and other salt applications were statistically in the same group. When water restriction applications were examined, the highest CAT activity was obtained from I₅₀ application with 1682.13 EU/g⁻¹. When the interaction was examined, the highest activity was obtained from S₂I₅₀ and S₃I₅₀ applications.

Although reactive oxygen species (ROS) formed under stress conditions restrict the development of plants, antioxidant enzymes secreted by plants (such as CAT, SOD, POD, etc.) are important mechanisms in scavenging ROS. SOD, for example, attempts to reduce the negative effects of stress by converting the formed O₂ anion into less reactive species O₂ and H₂O₂ (Kireçci 2018). Numerous studies have documented the augmentation of SOD activity under abiotic stress conditions in diverse plant species (Gao et al. 2020; Seymen 2021; Yavuz et al. 2022). CAT, an enzyme that can directly modify H₂O₂, plays a pivotal role in the scavenging of ROS (Van Breusegem et al. 2001). POD has also been observed to increase stress conditions and contribute to the accumulation of secondary metabolites and osmolytes to scavenge ROS (Sattar et al. 2020). In many stress studies, it has been observed that CAT and POD enzyme activities increase (Yavuz et al. 2022; Seymen et al. 2023). In the present study, salinity stress in melon revealed significant increases in SOD and POD enzyme activities, like literature. A considerable increase in CAT enzyme activity was observed in the context of underwater stress conditions.

3.3. PCA

PCA was performed on photosynthetic activity and biochemical contents of different salt and irrigation water applications applied to melon (Table 3). The analysis revealed that four components explained 81.21% of the study. In the first component, with the highest explanation, Chl a, Chl b, Car, MDA, CAT and T Leaf were the most strongly explained parameters in the positive direction. Similarly, in the first component, SOD and gs were the most strongly explained parameters in the negative direction. The second component exhibited Chl a, Chl b, Car and POD as the most strongly explained parameters in the positive direction, whilst MDA, Prol and CAT were the most strongly explained parameters in the negative direction. The examination of the loading plot graph elucidated a strong positive correlation between the pigment contents. Numerous studies have demonstrated the presence of a strong correlation between the pigment contents under conditions of water and salinity stress (Yavuz et al., 2022; Kayak et al., 2023; Seymen et al., 2023). While a strong positive correlation was identified between T Leaf, H₂O₂, MDA, CAT, PSII and Prol, it was observed that these parameters exhibited a strong negative correlation with POD (Figure 2). In numerous studies, it was observed that the correlation relationship between biochemical and photosynthetic activities under water and salinity stress conditions was interpreted with a loading plot graph (Seymen 2021; Seymen et al. 2024; Yavuz et al. 2024). In order to interpret the significant differences between the applications, a scoria plot graph was drawn from the first two components (Figure 3). The examination of this graph revealed that the S₅I₅₀ application, which was subjected to the highest levels of water and salt stress, was associated with elevated SOD activity. This finding indicated that SOD was the predominant enzyme responsible for both stresses. Furthermore, it was observed that the S₃I₁₀₀, S₂I₇₅ and S₁I₇₅ applications, which exhibited high levels of pigment content, were the least impacted by stress. The S₁I₁₀₀ application was found to be high in terms of protein content, and it was revealed that the protein content was high in the absence of stress. Conversely, the first component is generally the component explaining salinity stress, while the second component is the component explaining water stress. According to these results, it has been observed that waters with salinity

higher than 4000 μmhos in melon irrigation water limit plant growth. Conversely, in regions where water resources are scarce, it has been demonstrated that imposing a 25% water restriction during the initial melon development stages can lead to substantial water savings.

Table 3. Results of the principal component analysis (PCA) performed for biochemical contents, and photosynthetic activity in melon under salinity and irrigation deficit conditions

Items	PC1	PC2	PC3	PC4
Eigenvalue	4.87	2.86	1.69	1.16
Percentage of variance	37.30	21.98	13.03	8.91
Cumulative variance	37.30	59.27	72.30	81.21
Eigenvectors				
Chl a	0.354	0.346	0.030	0.096
Chl b	0.329	0.385	0.011	0.008
Car	0.304	0.339	0.026	-0.090
H ₂ O ₂	0.216	-0.158	0.309	-0.313
MDA	0.353	-0.280	-0.052	0.183
Prot	0.172	0.035	-0.206	0.757
Prol	0.083	-0.450	0.194	-0.012
CAT	0.310	-0.280	-0.110	-0.011
SOD	-0.345	-0.060	-0.194	0.352
POD	-0.178	0.433	0.011	-0.080
T leaf	0.304	-0.095	0.442	0.225
gs	-0.328	-0.019	0.407	0.187
PSII	0.130	-0.168	-0.638	-0.245

*Statistically significant according to $P < 0.05$ and 0.001 . Chl a; Chlorophyll a, Chl b; Chlorophyll b, Car; Carotenoid, H₂O₂; Hydrogen peroxidase, MDA; Malondialdehyde, Prot; Protein, Prol; Proline, SOD; Superoxide dismutase, POX; Peroxidase, CAT; Catalase, gs; Stomatal conductance, PSII; actual photosynthetic efficiency, T Leaf; Leaf temperature

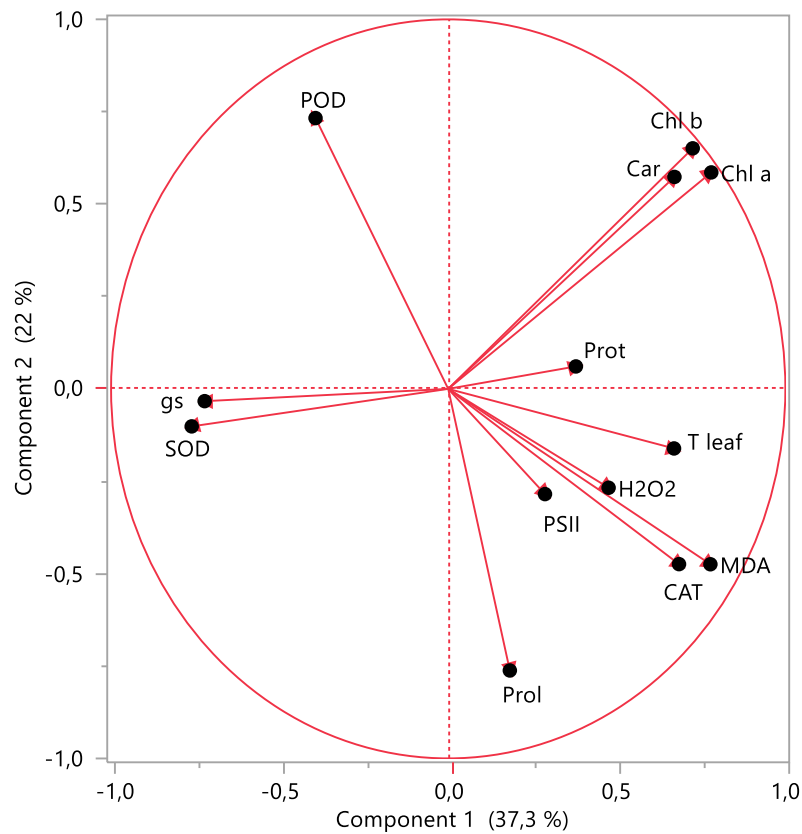


Figure 2. Loading plot for PC1 and PC2 as a result of PCA of the biochemical contents, and photosynthetic activity in melon under salinity and irrigation deficit conditions

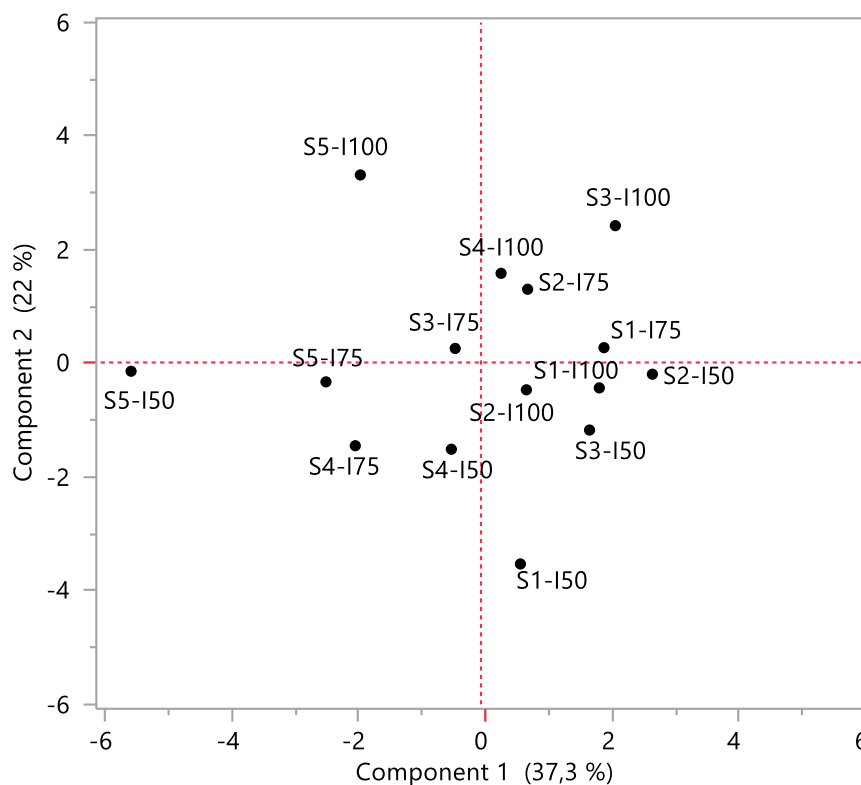


Figure 3. Score plot for PC1 and PC2 as a result of PCA of the biochemical contents, and photosynthetic activity in melon under salinity and irrigation deficit conditions

4. Conclusions

It was observed that saline irrigation water and water deficit applications applied to melon seedlings had significant effects on photosynthetic activity and biochemical contents. As a result of the research, it was revealed that there was a positive correlation between pigment contents in the plant and that they were important parameters in determining stress. It was observed that saline waters higher than 4000 μmhos would limit plant development in the seedling period of melon. SOD enzyme activity was an important indicator of both stress factors and significant increases were experienced in SOD activity as stress increased. It was observed that 25% water restriction could be applied in the seedling period of melon in agricultural areas where irrigation water was limited, and that water saving would be achieved.

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References

Abdel-Farid I, Marghany M, Rowezeck M, Sheded M (2020). Effect of salinity stress on growth and metabolomic profiling of *Cucumis sativus* and *Solanum lycopersicum*. *Plants* 9(11), 1626. <https://doi.org/10.3390/plants9111626>.

- Akram W, Aslam H, Ahmad S, Anjum T, Yasin N, Khan W, Ahmad A, Guo J, Wu T, Luo W, Li G (2019). *bacillus megaterium* strain a12 ameliorates salinity stress in tomato plants through multiple mechanisms. *Journal of Plant Interactions* 14(1), 506-518. <https://doi.org/10.1080/17429145-2019.1662497>.
- Alam H, Khattak J, Ksiksi T, Saleem M, Fahad S, Sohail H, Ali Q, Zamin M, El-Sawai M, Saud S, Jiang X, Alwahibi M, Alkahtani J (2020). Negative impact of long-term exposure of salinity and drought stress on native *tetraena mandavillei* L. *Physiologia Plantarum* 172(2), 1336-1351. <https://doi.org/10.1111/pp1.13273>.
- Ali B, Wang X, Saleem M, Hafeez A, Afridi M, Khan S, Un Nisa Z, Ullah I, Amaral Júnior ATD, Alatavi A, Ali S. (2022). Pgpr-mediated salt tolerance in maize by modulating plant physiology, antioxidant defense, compatible solutes accumulation and bio-surfactant producing genes. *Plants* 11(3), 345. <https://doi.org/10.3390/plants11030345>.
- Anjum SA, Xie X, Wang L, Saleem MF, Man C, Lei W (2011). Morphological, physiological and biochemical responses of plants to drought stress. *African Journal of Agricultural Research* 6, 2026-2032.
- Ansari W, Atri N, Ahmad J, Qureshi M, Singh B, Kumar R, Rai V, Pandey S (2019). Drought mediated physiological and molecular changes in muskmelon (*Cucumis melo* L.). *Plos One* 14(9), e0222647. <https://doi.org/10.1371/journal.pone.0222647>.
- Bergmayer H (1983). UV method of catalase assay. *Methods of Enzymatic Analysis* 3, 273.
- Beyer Jr WF, Fridovich I (1987). Assaying for superoxide dismutase activity: some large consequences of minor changes in conditions. *Analytical Biochemistry* 161(2), 559-566.
- Blum A (1985). Breeding crop varieties for stress environments. *Critical Reviews in Plant Sciences* 2, 199-238.
- Bradford MM (1976). A rapid and sensitive method for the quantitation of microgram quantities of protein utilizing the principle of protein-dye binding. *Analytical biochemistry* 72(1-2): 248-254.
- Bray EA (1997), Plant Responses to Water Deficit. *Trends Plant Science* 2, 48-54.
- Chevilly S, Dolz-Edo L, Martínez-Sánchez G, Morcillo L, Vilagrosa A, López-Nicolás J, Blanca J, Yenush L, Mulet, J. (2021). Distinctive traits for drought and salt stress tolerance in melon (*Cucumis melo* L.). *Frontiers in Plant Science* 12. <https://doi.org/10.3389/fpls.2021.777060>.
- Cumhur A, Malcolm SC (2008). The effects of global climate change on agriculture. *American-Eurasian Journal of Agricultural and Environmental Sciences* 3(5), 672-676.
- Çelik MÖ, Yakar M, (2024). Mersin'in farklı kuraklık indeksleri aracılığıyla kuraklık tehdidinin araştırılması. *Afyon Kocatepe University Journal of Sciences and Engineering* 24(1), 71-84. <https://doi.org/10.35414/-akufemubid.1331753>.
- Esterbauer H, Cheeseman KH (1990). Determination of aldehydic lipid peroxidation products: malonaldehyde and 4-hydroxynonenal. In *Methods in enzymology* Academic Press 186: 407-421.
- FAO (2023). [Crops and livestock products](https://www.fao.org/faostat/en/#data/QCL) <https://www.fao.org/faostat/en/#data/QCL> (access date: 25.09.2024).
- Fileccia V, Ruisi P, Ingrassia R, Giambalvo D, Frenda A, Martinelli F (2017). Arbuscular mycorrhizal symbiosis mitigates the negative effects of salinity on durum wheat. *Plos One* 12(9), e0184158. <https://doi.org/10.1371/journal.pone.0184158>.
- Gao S, Wang Y, Yu S, Huang Y, Liu H, Chen W, He X. (2020). Effects of drought stress on growth, physiology and secondary metabolites of Two Adonis species in Northeast China. *Scientia Horticulturae* 259, 108795.
- Hameed A, Ahmed M, Hussain T, Aziz I, Ahmad N, Gul B, Nielsen B (2021). Effects of salinity stress on chloroplast structure and function. *Cells* 10(8), 2023. <https://doi.org/10.3390/cells10082023>

- Hanif S, Saleem MF, Sarwar M, Irshad M, Shakoor A, Wahid MA, Khan HZ (2021). Biochemically triggered heat and drought stress tolerance in rice by proline application. *Journal of Plant Growth Regulation* 40(1), 305-312.
- Havir EA, McHale NA (1987). Biochemical and developmental characterization of multiple forms of catalase in tobacco leaves. *Plant Physiology* 84(2), 450-455.
- Hirayama T, Shinozaki K (2010). Research on plant abiotic stress responses in the post-genome era: past, present and future. *The Plant Journal* 61(6), 1041-1052.
- Ibrahim M, Zhu X, Zhou G, Ali A, Ahmad I, Elsiddig, Zhu G, A, Nimir, N. (2019). Promoting salt tolerance in wheat seedlings by application of nitrogen fertilizer. *Pakistan Journal of Botany* 51(6), [https://doi.org/10.30848/pjb2019-6\(29\)](https://doi.org/10.30848/pjb2019-6(29)).
- Kaçar B (2015). Genel Bitki Fizyolojisi. Nobel Akademik Yayıncılık: Yayın No: 1243, Ankara.
- Kalefetoğlu T, Ekmekçi Y (2005). The Effect of Drought on Plants and Tolerance Mechanisms. *G. U. Journal of Science* 18(4), 723- 740.
- Kayak N, Kal Ü, Dal Y, Yavuz D, Seymen M (2023). Do proline and glycine betaine mitigate the adverse effects of water stress in spinach? *Gesunde Pflanzen* 75(1), 97-113.
- Kayak N (2024). The effect on morpho-physiological and biochemical characteristics of cauliflower and cabbage harvested at different times under flooding stress conditions. *Journal of Crop Health* 76(1), 145-159.
- Khedr AHA, Abbas MA, Wahid AAA, Quick WP, Abogadallah GM (2003). Proline induces the expression of salt-stress-responsive proteins and may improve the adaptation of *Pancreaticum maritimum* L. to salt-stress. *Journal of Experimental Botany* 54(392), 2553-2562.
- Kireççi OA (2018). Enzymatic and non-enzymatic antioxidants in plants. *Bitlis Eren Üniversitesi Fen Bilimleri Dergisi* 7(2), 473-483.
- Kurtar ES, Seymen M, Yavuz D, Acar B, Metin D, Atakul Z, Kal Ü. (2024). Morphophysiological and biochemical investigation of the potential of citron watermelon (*Citrullus lanatus* var. *citroides*) rootstock under different irrigation regimes. *Horticulture, Environment, and Biotechnology* 1-15.
- Kuşvuran Ş (2012). Effects of drought and salt stresses on growth, stomatal conductance, leaf water and osmotic potentials of melon genotypes (*Cucumis melo* L.). *African Journal of Agricultural Research* 7(5). <https://doi.org/10.5897/ajar11.1783>
- Kuşvuran Ş, Daşgan H, Abak K (2013). Citrulline is an important biochemical indicator in tolerance to saline and drought stresses in melon. *The Scientific World Journal* 2013(1) <https://doi.org/10.1155/2013/253414>
- Latowski D, Kuczyńska P, Strzałka K (2011). Xanthophyll cycle—a mechanism protecting plants against oxidative stress. *Redox Report* 16(2), 78-90.
- Liang D, Ni Z, Xia H, Xie Y, Lv X, Wang J, Lin L, Deng Q, Luo X (2019). Exogenous melatonin promotes biomass accumulation and photosynthesis of kiwifruit seedlings under drought stress. *Scientia Horticulturae* 246, 34-43. <https://doi.org/10.1016/j.scienta.2018.10.058>.
- Lichtenthaler HK (1987). Chlorophylls and carotenoids: pigments of photosynthetic biomembranes. In *Methods in enzymology* 148: pp. 350-382). *Academic Press* 6879(87), 48036-1.
- Nayar H, Kaushal SK (2002). Chilling induced oxidative stress in germinating wheat grains as affected by water stress and calcium. *Biology Plant* 45, 601-604.
- Omidi M, Khandan-Mirkohi A, Kafi M, Zamani Z, Ajdanian L, Babaei M (2022). Biochemical and molecular responses of *rosa damascena* mill. cv. kashan to salicylic acid under salinity stress. *BMC Plant Biology* 22(1). <https://doi.org/10.1186/s12870-022-03754->

- Öztürk N Z (2015). Bitkilerin kuraklık stresine tepkilerinde bilinenler ve yeni yaklaşımlar. *Turkish Journal Of Agriculture-Food Science And Technology* 3(5), 307-315.
- Pereira F, Medeiros J, Gheyi H, Dias N, Preston W, Vasconcelos C (2017). Tolerance of melon cultivars to irrigation water salinity. *Revista Brasileira De Engenharia Agrícola E Ambiental* 21(12), 846-851. <https://doi.org/10.1590/1807-1929/agriambi.v21n12p846-851>.
- Riasat M, Kiani S, Saed-Mouches A, Pessarakli M (2019). Oxidant related biochemical traits are significant indices in triticale grain yield under drought stress condition. *Journal of Plant Nutrition* 42(2), 111-126.
- Sağlam A (2004). Ağır kuraklık stresi geçirmiş *Ctenanthe setosa* bitkisinin yeni kuraklık koşullarına adaptasyon yeteneğinin araştırılması. Yüksek Lisans Tezi, Karadeniz Teknik Üniversitesi, Trabzon.
- Salunkhe DK, Kadam S (1998). Handbook of vegetable science and technology: Production, Composition, Storage and Processing, CRC press.
- Sattar A, Sher A, Ijaz M, Ul-Allah S, Rizwan MS, Hussain M, Jabrab K, Cheema, M. A. (2020). Terminal drought and heat stress alter physiological and biochemical attributes in flag leaf of bread wheat. *PLoS One* 15(5), e0232974.
- Savvides A, Ali S, Tester M, Fotopoulos V (2016). Chemical priming of plants against multiple abiotic stresses: mission possible? *Trends in plant science* 21(4), 329-340.
- Seymen M (2021). Comparative analysis of the relationship between morphological, physiological, and biochemical properties in spinach (*Spinacea oleracea* L.) under deficit irrigation conditions. *Turkish Journal of Agriculture and Forestry* 45(1), 55-67.
- Seymen M, Erçetin M, Yavuz D, Kıymacı G, Kayak N, Mutlu A, Kurtar E S (2024). Agronomic and physio-biochemical responses to exogenous nitric oxide (NO) application in cauliflower under water stress conditions. *Scientia Horticulturae* 331, 113116.
- Seymen M, Yavuz D, Eroğlu S, Arı BÇ, Tanrıverdi ÖB, Atakul Z, Issı N (2023). Effects of different levels of water salinity on plant growth, biochemical content, and photosynthetic activity in cabbage seedling under water-deficit conditions. *Gesunde Pflanzen* 75(4), 871-884.
- Sminroff N (1993). The role of active oxygen in the response of plants to water deficit and desiccation. *New Phytology* 125, 27-58.
- Sobhani A, Mohammadzadeh A (2017). The effect of saline water on quantitative and qualitative characteristics of melon genotypes. *Journal of BioScience and Biotechnology* 6(2), 83-90.
- Sousa V, Costa C, Diniz G, Santos J, Bomfim M (2018). Physiological behavior of melon cultivars submitted to soil salinity1. *Pesquisa Agropecuária Tropical* 48(3), 271-279. <https://doi.org/10.1590/1983-40632018v4852495>.
- TÜİK (2023). <https://biruni.tuik.gov.tr/medas/?locale=tr>. (access date: 25.09.20024).
- Van Breusegem F, Vranová E, Dat JF, Inzé D (2001). The role of active oxygen species in plant signal transduction. *Plant science* 161(3), 405-414.
- Wien H (1997) The cucurbits: Cucumber, melon, squash and pumpkin. Health-promoting properties of fruitand vegetables, 118-134
- Yavuz D, Gökmen Yılmaz F, Seymen M, Korkmaz A, Baştaş KK (2024). Effects of newly isolated rhizobacteria on the physiological characteristics and nutrient uptake of watermelon plants grafted onto different rootstocks under water stress. *Journal of Crop Health* 76(4), 865-881.
- Yavuz D, Kılıç E, Seymen M, Dal Y, Kayak N, Kal Ü, Yavuz N (2022). The effect of irrigation water salinity on the morph-physiological and biochemical properties of spinach under deficit irrigation conditions. *Scientia Horticulturae* 304, 111272.

Yavuz D, Seymen M, Kal Ü, Atakul Z, Tanrıverdi ÖB, Türkmen Ö, Yavuz N (2023). Agronomic and physio-biochemical responses of lettuce to exogenous sodium nitroprusside (SNP) applied under different irrigation regimes. *Agricultural Water Management* 277, 108127.



Investigating The Expectation Meeting Ratio of Partners: The Case of Edirne Province Agricultural Development / Irrigation Cooperatives

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HIGHLIGHTS

- Highest expectation in administrative issues was management being composed of competent people.
- Highest expectation in economic issues was the level of product sale price.
- The issue that met the expectation the most was the management's behavior towards members.
- The issue that met the expectation the least was the level of product sale price.

Abstract

The aim of this study is to analyze the expectations and current status of the members of the Agricultural Development Cooperative and Irrigation Cooperatives in Edirne province. The Expectation Meeting Ratio (EMR), which is calculated by evaluating the expectations and current status, is used as a performance indicator for cooperatives. The main material of the study consists of 165 survey data points based on face-to-face interviews with cooperative members. While the highest expectation in administrative issues is about "The management being composed of competent people" (4.81 points), the subject where the expectation is met the most is "The management's behaviour towards members" (93.15%). It has been determined that the subject with the highest expectation in economic and social issues is "Increase in the income of the members" (4.85 points), and the position where the expectation is met the most is "Provision of input supply" (87.63%). When the current status of administrative, economic and social issues is examined according to the cooperative of which the member is; It was determined that the average values of the subjects of "Defining the job descriptions, authorities and responsibilities of the employees" and "Providing training to the partners" were statistically significantly higher in Agricultural Credit Cooperatives than in Irrigation Cooperatives ($p < 0.05$). This study suggests several strategies to enhance the effectiveness and sustainability of cooperatives. Key recommendations include strengthening managerial capacity through targeted training programs, improving members' technical knowledge via collaborations with agricultural advisory services and academic institutions, and developing transparent pricing mechanisms alongside collective marketing practices to increase member income. Additionally, implementing regular performance evaluations and feedback systems is essential for continuous improvement. Active support from public institutions and local authorities through financial incentives, technical assistance, and appropriate regulatory frameworks is also critical for long-term success.

Keywords: Agricultural development cooperative; Irrigation cooperative; Expectation meeting rate; Edirne

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1. Introduction

Agricultural cooperatives are structures formed by farmers' organizations that serve many important goals such as supporting rural development, improving the economic and social situation of farmers, and increasing productivity in agricultural production. Especially in societies where organization is strong, farmers become more resistant to market conditions and have the opportunity to market their products at more competitive prices. The mental basis of the cooperative movement in Türkiye is the input and cash demands of the villagers and the product marketing needs. Meeting the input demands of agricultural producers and product marketing are still among the most serious problems of the agricultural sector. The most effective and easy solution to these problems is to conduct partnership-based trade and strengthen solidarity relations. Cooperatives are meeting places with legal personality where partnership-based relations are carried out.

Cooperatives have great importance in the sector in agriculturally developed countries. The European Union has highlighted cooperatives with various supports. However, it is widely believed that cooperatives are not successful in Türkiye. For this reason, organization or corporatization comes to the fore in all problems related to farmer welfare (Şahin et al. 2014). In Edirne province, where animal and plant production are intensive in Türkiye, especially dairy farmers market their milk mainly through cooperatives. Cooperatives contribute to the development of agriculture and local economies as they diversify and grow their activities. The strengthening of cooperatives in the milk market is important in terms of the profitability and sustainability of agricultural enterprises.

In recent years, it has been observed that competition has intensified in terms of both raw material supply and maintaining market share with the entry of domestic and foreign investments into the milk and dairy products sector. It has been stated that investments in the dairy sector have increased rapidly; an oligopoly market structure and a perfect competition market have formed (Ömerci Kart and Demircan 2014). This situation reveals the necessity of cooperatives operating in the dairy sector to increase their market shares by operating effectively in the market (Yercan 2018). Cooperatives are structures established to respond to the needs of farmers and support agricultural development in both administrative and economic terms. However, the effectiveness of these structures and the extent to which they meet farmers' expectations have not been sufficiently researched. The main purpose of the study is to determine the expectations of the Agricultural Development Cooperatives (ADC) and Irrigation Cooperative (IC) partners in Edirne province from cooperatives, their current status and the Expectation Meeting Rate (EMR). In addition, the differences between the two cooperatives will be revealed. The calculated EMR will provide an idea about the performance of the cooperatives in the eyes of the partners in terms of management, economic and social issues. The results obtained in the study are presented for the improvement of the functioning of cooperatives and policy recommendations.

2. Materials and Methods

2.1 Research Area

The economy of Edirne province is mainly based on agriculture. It is estimated that 73% of the active population is engaged in agriculture, fishing, hunting, and forestry. It is estimated that agriculture contributes approximately 42% of the gross income. The total surface area of Edirne Province is 609,791 hectares. Approximately 370,948 hectares of this area are agricultural land, 106,939 hectares are forest land, and 57,388 hectares are meadow-pasture land. The non-agricultural area is 74,516 hectares. (Anonymous 2018). Edirne province was chosen as the research area because animal and plant production is intense, and especially milk producers market their milk mainly through cooperatives. Edirne province holds a significant position in Türkiye's agricultural production and organization.

2.2 Research Material

Agricultural Development Cooperatives and Irrigation Cooperatives were selected in this research because they play an important role in the marketing of milk in Edirne province. The main material of the research is

a survey conducted in 2024 with the partners of the Agricultural Development Cooperative and Irrigation Cooperative in Edirne province, based on face-to-face interviews. Secondary data consists of research, studies and statistical data on agricultural cooperatives previously conducted by various organizations.

2.3. Sampling Method

The province of Edirne, which has an important position in agricultural production and agricultural organization in Türkiye, was selected as the study area. The cooperatives included in the study have a total of 29 712 members. Using the Simple Random Sampling Mass Proportion Estimation Method of Yamane (2010), the p and q values were taken as 0.5 to maximize the sample size and a 10% margin of error, and the sample size (n) was calculated as 164.21.

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

n= Number of samples

N= Cluster size (29712)

D= Accepted or desired sampling error (0.1)

t= Table value (2.57)

p= Desired ratio to be calculated (0.5)

q= 1-p

The sample number determined in the study was distributed proportionally by taking into account the density of cooperative partners according to the districts. The distribution of the survey study according to the districts is shown in Table 1. The distribution was made proportionally by taking into account the number of partners in the districts. A total of 165 surveys were conducted face to face, 93 with agricultural development cooperative partners and 72 with irrigation cooperative partners.

Table 1. Distribution of interviewed farmers by district

District	Agricultural Development Coop.		Irrigation Coop.		Total	
	Number of Partners (N)	Number of Surveys (n)	Number of Partners (N)	Number of Surveys (n)	Number of Partners (N)	Number of Surveys (n)
Center	1.143	6	1.204	7	2.347	13
Enez	404	2	1.347	8	1.751	10
Havsa	1.242	7	2.184	12	3.426	19
İpsala	3.371	19	3.014	17	6.385	35
Keşan	3.033	17	1.470	8	4.503	25
Lalapaşa	1.404	8	262	1	1.666	9
Meriç	2.579	14	699	4	3.278	18
Süloğlu	922	5	981	5	1.903	11
Uzunköprü	2.721	15	1.732	10	4.453	25
Total	16.819	93	12.893	72	29.712	165

2.4. Analysis Method

2.4.1. Determining the scale

The survey form conducted with cooperative partners used 5-point Likert type questions. It includes questions to determine the expectations and current situations of the partners in terms of management, social and education. One of the most basic and popular scaling methods used in social science research is the Likert scale (Taherdoost 2019). Five-point Likert scale analysis is widely used because participants can easily answer questions in this format (Bulut et al. 2020). The Likert scale used by Palaz and Boz (2008) was preferred. The Likert average of each question was calculated in this scale. The following interpretation scale was developed

for the value of the means: A mean scale of 1.00-1.49 = Strongly Disagree, 1.50-2.49 = Disagree, 2.50-3.49 = Moderately Agree, 3.50-4.49 = Agree and 4.50-5.00 = Strongly Agree was used and the results were interpreted according to this scale.

2.4.2. Reliability analysis

While physical methods-based measurement tools are used for concrete features, a wide variety of scales consisting of survey and test questions can be used to measure abstract features such as behavior, judgment, knowledge, and attitude. Reliability must be ensured in measuring conceptual features that do not have a concrete equivalent (attitude, behavior, etc.). Reliability is an indicator of how resolutely the measurement tool (survey, question, etc.) measures the feature it measures (Tavşancıl 2005). The most widely used and the basis of other methods is the Cronbach Alpha Coefficient method. This method investigates whether the k questions on the scale express a whole that shows a homogeneous structure. The alpha coefficient is a weighted standard change average found by dividing the sum of the variances of the k questions on the scale by the general variance (Özdamar 1999). Cronbach Alpha coefficient is a coefficient that reveals the similarity or closeness of questions in scales obtained by summing the total score of the unit and the scores of each question in the scale (Kayış 2005). Cronbach Alpha coefficient varies between 0 and 1. If the questions are standardized, Cronbach alpha is calculated based on the average correlation or covariance of the questions (Perme and Menevski, 2019). Cronbach Alpha coefficient is a coefficient that reveals the similarity or closeness of questions in scales obtained by summing the total score of the unit and the scores of each question in the scale (Kayış, 2005). Cronbach Alpha coefficient varies between 0 and 1. If the questions are standardized, Cronbach alpha is calculated based on the average correlation or covariance of the questions (Akgül and Çevik, 2005). If there is a negative correlation between the questions, the Alpha coefficient is negative, in which case the reliability model is broken. Because the additivity assumption of the scale was broken and the scale was no longer an additivity scale. The reliability of the scale is interpreted as follows depending on the alpha coefficient; if $0.00 \leq \alpha < 0.40$, the scale is not reliable, if $0.40 \leq \alpha < 0.60$, the reliability of the scale is low, if $0.60 \leq \alpha < 0.80$, the scale is quite reliable, if $0.80 \leq \alpha < 1.00$, the scale is a highly reliable scale (Özdamar 1999; Akgül and Çevik 2005). While conducting the Reliability Analysis, 12 five-point Likert scale statements directed to 165 cooperative members were evaluated for both expectations and the current situation. The reliability coefficient of the statements was found to be $\alpha=0.908$. This shows that we can trust the questions and the answers given to them at a very high level.

2.4.3. Calculating the Expectation Meeting Ratio (EMR)

The statements directed to farmers were evaluated separately for 2 different situations. First, farmers were asked to agree with the statement with a five-point Likert option to determine their expectations, and then the same statement was renewed for the current situation. Thus, 2 separate answers were obtained for each statement. A percentage calculation was made to determine to what extent the current situation meets the farmer's expectations. The Expectation Meeting Rate (EMR) was used to calculate the extent to which the farmer's expectations (%) were met in the operation of the cooperative of which the farmer was a partner, using the formula below.

$$EMR = (\text{Current status value} / \text{Expectation value}) * 100 \quad (2)$$

2.4.4. Statistical Analysis

The Mann-Whitney U test is a nonparametric statistical test used to compare the medians of two independent sample groups. This test is preferred as an alternative to the t-test for independent samples when the data do not meet the normal distribution assumption (Perme 2019). The Mann-Whitney U test evaluates whether the differences observed between groups are significant and works on a rank basis. Therefore, it can be applied on continuous or ordinal data. Application Conditions; Comparisons are made between two independent groups, the data must be measured on a continuous scale, and the distribution of the data does not have to be normal (McKnight and Najab 2010). The p value of 0.05 and 0.10 was used as the criterion to determine the significance of the observed differences.

3. Results

3.1. Expectations, Current Situation and EMR for Administrative Matters

In the analysis of expectations and current status regarding administrative issues, the highest Expectation Meeting Rate (EMR) was determined as 95.16% in the Agricultural Development Cooperative (ADC) regarding “Defining the job descriptions, authorities and responsibilities of employees” (Table 2). In the Irrigation Cooperative (IC), the highest EMR was 90.56% in the “Ensuring democratic participation in decisions taken”. On the other hand, the lowest EMR was observed in both types of cooperatives regarding “The management is composed of competent people”. This rate was 88.28% for ADC and 83.54% for IC. This result shows that management competence is a less satisfactory area for members compared to other administrative issues. Dagnino and Padula (2007) highlighted that managerial skills are vital for navigating the complexities of cooperative governance and ensuring operational efficiency. Similarly, Omari et al. (2013) argued that competent leadership in cooperatives improves decision-making and financial sustainability, particularly in developing contexts. The current findings suggest that cooperatives must prioritize training programs and leadership development initiatives to address this gap.

Table 2. Expectations, current situation and EMR in administrative matters

Issue	Cooperative	Status	Mean	EMR (%)
Keeping records according to appropriate principles	ADC	Expectation	4.69	91.90
		Current	4.31	
	IC	Expectation	4.75	86.53
		Current	4.11	
	Total	Expectation	4.72	90.24
		Current	4.26	
Transparent and informative cooperative management	ADC	Expectation	4.71	91.51
		Current	4.31	
	IC	Expectation	4.77	86.37
		Current	4.12	
	Total	Expectation	4.73	89.26
		Current	7.23	
Defining the job descriptions, authorities and responsibilities of employees	ADC	Expectation	4.55	95.16
		Current	4.33	
	IC	Expectation	4.61	87.64
		Current	4.04	
	Total	Expectation	4.58	91.80
		Current	4.20	
Fair management	ADC	Expectation	4.69	94.67
		Current	4.44	
	IC	Expectation	4.59	89.54
		Current	4.11	
	Total	Expectation	4.65	92.32
		Current	4.29	
The behavior and attitudes of the management towards the members	ADC	Expectation	4.57	94.97
		Current	4.34	
	IC	Expectation	4.63	90.71
		Current	4.20	
	Total	Expectation	4.60	93.15
		Current	4.28	
The management is composed of competent people	ADC	Expectation	4.78	88.28
		Current	4.22	
	IC	Expectation	4.86	83.54
		Current	4.06	
	Total	Expectation	4.81	86.29
		Current	4.15	
Ensuring democratic participation in the decisions taken	ADC	Expectation	4.58	93.67
		Current	4.29	
	IC	Expectation	4.66	90.56
		Current	4.22	
	Total	Expectation	4.61	92.26
		Current	4.26	

It has displayed a higher performance than IC in terms of administrative issues. Particularly, issues such as “Fair management” (94.67%) and “Management’s behavior and attitudes towards partners” (94.97%) were among the strengths of ADC (Table 2). Transparency is crucial for maintaining member trust and ensuring accountability in cooperatives. According to Bijman et al. (2012), transparent governance practices improve member engagement and organizational efficiency, leading to better performance outcomes. Similarly, fair management, as noted by Spear (2004), is integral to promoting equity and cohesion among cooperative members. These higher EMR values in ADC reflect its comparative advantage in fostering trust and fairness.

3.2. Analysis of current situation for administrative issues

Statistical analysis of the current situation in terms of the cooperative of which the partner is in administrative matters. According to the results of the Mann-Whitney U Test, 2 different issues have created a significant difference according to the type of cooperative. In terms of administrative matters, a statistically significant difference has been determined in favor of ADC in terms of “Defining the job descriptions, authorities and responsibilities of employees” and “Having a fair management” at the significance levels of 0.05 and 0.10, respectively. It shows that ADC has a more successful performance compared to IC in both administrative areas.

Table 3. Analysis of current situation for administrative issues by Mann-Whitney U Test

Issue	Current Status		Mann-Whitney U Test	P value
	ADC	IC		
Keeping records according to appropriate principles	4.31	4.19	3233.000	0.679
Transparent and informative cooperative management	4.31	4.12	3016.000	0.233
Defining the job descriptions, authorities and responsibilities of employees	4.33	4.04	2765.500	0.038*
Having fair management	4.44	4.11	2829.000	0.052**
The behavior of management towards members	4.34	4.20	3217.500	0.634
Composed of competent people in management	4.22	4.06	3063.000	0.313
Transparent and informative cooperative management	4.29	4.22	3339.000	0.974

* $p < 0.05$; ** $p < 0.10$ Mann-Whitney U Test is significant for cooperatives

3.3. Expectations, current situation and EMR on economic and social issues

Expectations, current status and EMR on economic and social issues are shown in the table. The highest expectation of farmers on economic and social issues was observed under the heading of “Increase in income of members” (ADC: 4.84 points, IC: 4.86 points). However, the EMR of this expectation was determined as 86.16% in ADC and 82.51% in IC. This finding reflects the economic pressure on cooperatives to deliver financial benefits to their members. Low satisfaction levels here may be attributed to market constraints such as low raw milk prices. Studies by Chaddad and Cook (2004) emphasize that economic benefits, such as higher income, are a primary motivator for cooperative membership, and underperformance in this area directly affects member satisfaction. The highest EMR was obtained in both types of cooperatives under the heading of “Provision of input supply” (ADC: 90.91%, IC: 90.71%). This finding shows that services for the basic needs of farmers are met at a satisfactory level. According to Bijman et al. (2012), input provision is one of the most critical functions of agricultural cooperatives, and efficient service in this area enhances trust and loyalty among members.

The lowest EMR was recorded as 78.00% in IC and 85.68% in ADC regarding “Provision of training to members”. The inadequacy of training programs stands out as a significant deficiency, especially for IC members. Birchall and Simmons (2004) underscored that member training is vital for cooperative sustainability, as it equips members with knowledge to improve productivity and decision-making. The lack of effective training programs could hinder cooperative growth and member engagement.

When the general averages are evaluated, it is determined that the EMR for the price level of the product (milk) sold through the cooperative is at a low level (81.69%). The cooperatives interviewed in Edirne province buy milk from farmers and sell it wholesale to milk processing companies. The main factor in not meeting the expectations in the product sale price is the low market price in raw milk price formation. Although cooperatives achieve a milk sale price slightly above the market price as a result of the wholesale sale of milk, this advantage is very limited.

Table 4. Expectations, current situation and EMR for economic and social issues

Issue	Cooperative	Status	Mean	EMR (%)
Level of product sale price	ADC	Expectation	4.76	83.40
		Current	3.97	
	IC	Expectation	4.80	80.00
		Current	3.84	
	Total	Expectation	4.80	81.69
		Current	3.92	
Increase in partners' income	ADC	Expectation	4.84	86.16
		Current	4.17	
	IC	Expectation	4.86	82.51
		Current	4.01	
	Total	Expectation	4.85	84.52
		Current	4.10	
Provision of inputs	ADC	Expectation	4.51	90.91
		Current	4.10	
	IC	Expectation	4.61	90.71
		Current	3.84	
	Total	Expectation	4.55	87.63
		Current	3.99	
Organization of events that bring partners together	ADC	Expectation	4.15	86.51
		Current	3.59	
	IC	Expectation	4.18	89.23
		Current	3.73	
	Total	Expectation	4.61	87.57
		Current	4.26	
Provision of training to partners	ADC	Expectation	4.47	85.68
		Current	3.83	
	IC	Expectation	4.41	78.00
		Current	3.44	
	Total	Expectation	4.61	82.43
		Current	4.26	

3.4. Analysis of the current situation for economic and social issues

Statistical analysis of the current situation in economic and social issues according to the cooperative of which it is a partner is shown in Table 5. Analysis of the means in economic and social issues, there is a significant difference in favor of ADC in "Providing training to partners" ($p < 0.05$). ADC has shown a more successful performance compared to IC in the fields of training. There is no significant difference in the subjects of "Organizing events that will bring partners together", "Level of product sale price", "Increasing the income of partners", and "Providing input supply" according to the cooperative of which it is a partner.

Table 5. Analysis of the current situation for economic and social issues by Mann-Whitney U Test

Issue	Current Status		Mann-Whitney U Test	P value
	ADC	IC		
Level of product sale price	3.59	3.73	3225.500	0.674
Providing training to partners	3.83	3.44	2682.500	0.024*
Level of product sales price	3.97	3.84	3059.500	0.315
Increase in partners' income	4.17	4.01	3037.000	0.276
Provision of input supply	4.10	3.84	3040.000	0.286

* $p < 0.05$ Mann-Whitney U Test is significant for cooperatives.

3.5. EMR rankings on administrative, economic and social issues

The ranking of EMR rates in administrative, economic and social issues is shown in Figure 1. It was determined that the issue with the highest EMR was the management's behavior and attitude towards the members (93.15%). The fact that the highest rate among administrative issues was observed in the management's attitude towards the members shows that cooperative managements exhibit successful communication and a positive attitude in their relations with farmers. The issue of fair management (92.32%) comes second. Justice in management is another strong point that stands out in meeting the expectations of farmers. Democratic participation (92.26%) and clarity of job descriptions (91.80%) are issues that meet the expectations at a high rate. This result shows that cooperatives ensure democratic participation in administrative processes, that the job descriptions of employees are clear, and that cooperatives have a transparent and organized structure. The issue of "Composed of competent people in the management" (86.29%), where EMR is low in the ranking, shows that farmers still have some reservations about the adequacy of cooperative managements. This situation reveals that the management team needs to be developed further in terms of knowledge and skills. Expectations regarding increasing the income of the members (84.52%) are also low. This rate shows that there are still areas for improvement in economic issues. The fact that milk prices do not meet expectations is directly related to farmers' income. Farmers expect more concrete steps regarding income increase. Providing training to members (82.43%) is one of the issues with low EMR. It indicates an insufficient performance in terms of developing the technical knowledge and skills of farmers. Increasing training activities stands out as an important area that can strengthen the performance of cooperatives. The level of product sale price (81.69%) has the lowest EMR among all issues. The ranking in Figure 1 shows that cooperatives are generally successful in administrative issues, but some areas of economic and social issues require improvement. More efforts should be made in areas such as education, management competence, and the impact of cooperatives on product price formation. Such improvements will increase the general satisfaction of the members and have a positive impact on the performance of cooperatives.



Figure 1. Ranking of EMR for administrative, economic and social issues.

4. Conclusions

When the administrative, economic and social performances of cooperatives are evaluated; ADC is determined to be in a better position than IC in terms of administrative performance. This situation is especially evident in issues such as transparency, fair management and democratic participation. The issue of "establishing management by competent people" is the weakest area of cooperatives. The strongest area regarding economic issues is "Provision of input supply". However, there is a need for improvement in issues such as "Increasing the income of members", "Product sale price" and "Providing training to members". In both types of cooperatives, training activities have the lowest rates of acceptance. This shows that efforts to increase the technical knowledge and skills of farmers are insufficient. These findings indicate that while cooperatives maintain their strong aspects such as the management's treatment of members, fair and

democratic management approach in order to meet farmers' expectations, improvements should be made in weak areas such as product price and therefore income increase.

Several key strategies are recommended to enhance the effectiveness of cooperatives. These include strengthening the management capacity through targeted training programs, improving members' technical knowledge via partnerships with advisory services and academic institutions, and developing transparent pricing and collective marketing mechanisms to boost member income. Regular performance evaluations and member feedback systems should be implemented to ensure continuous improvement. Additionally, public institutions and local authorities should support cooperatives through financial incentives, technical assistance, and enabling regulations.

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References

- Akgül A, Çevik O (2005). İstatistiksel analiz teknikleri SPSS'te işletme yönetim uygulamaları, Mustafa Kitabevi, Ankara.
- Anonymous (2018). Brifing Raporu Edirne. Edirne Tarım ve Orman İl Müdürlüğü.
- Bijman J, Muradian R, Cechin A (2012). Agricultural cooperatives and value chain coordination: Toward an integrated theoretical framework. *Value Chains, Social Inclusion and Economic Development: Contrasting Theories and Realities*. Routledge.
- Birchall J, Simmons R (2004). What motivates members to participate in co-operative and mutual businesses? *Annals of Public and Cooperative Economics* 75(3), 465-495.
- Bulut OD, Çelik Kaysim Z, Karadaş K (2022). Determination of consumers' fresh fruit and vegetable (FFV) purchasing preferences during the Covid-19 pandemic period: the case of Turkey. *Ege Üniversitesi Ziraat Fakültesi Dergisi* 59(4), 567-577.
- Chaddad FR, Cook ML (2004). Understanding new cooperative models: An ownership-control rights typology. *Review of Agricultural Economics* 26(3): 348-360.
- Dagnino GB, Padula G (2007). Untangling the rise of coopetition: The intrusion of competition in the cooperative structure. *International Studies of Management & Organization* 37(2), 32-52.
- Kayış A (2005). SPSS Uygulamalı, güvenilirlik analizi, çok değişkenli istatistik teknikleri. Asil Yayın, Ankara.
- McKnight PE, Najab J (2010). Mann-Whitney U Test. *The Corsini Encyclopedia of Psychology* (1), 1.
- Omari K, Nyamasyo GN, Rambo C (2013). Board member competency and performance of cooperative societies in Kenya. *Nt. Journal of Humanities and Social Science Management* 3(4), 29-39.
- Örmeci Kart ÇM, Demircan V (2014). Dünyada ve Türkiye'de süt ve süt ürünleri üretimi, tüketimi ve ticaretindeki gelişmeler. *Akademik Gıda* 12(1), 78-96.
- Özdamar K (2008). Paket programlar ile istatistiksel veri analizi 2 (çok değişkenli analizler). Kaan Kitabevi Yayın, Eskişehir.
- Palaz S, Boz İ (2008) Üniversite mezunu yetişkinlerin farklı organizasyonlarda gönüllü hizmet vermesini etkileyen faktörler. *Balıkesir Üniversitesi Sosyal Bilimler Enstitüsü Dergisi* 11(19), 95-106.

- Perme MP, Manevski D (2019). Confidence intervals for the Mann-Whitney test. *Statistical Methods in Medical Research* 28(12): 3755-3768.
- Şahin A, Cankurt M, Günden C, Miran B (2014). Türkiye’de tarımsal kooperatifçiliğin iller açısından çok boyutlu analizi. *Research Journal of Agricultural Sciences* 44(1), 51-62.
- Spear R (2004). Governance in democratic member-based organizations. *Annals of Public and Cooperative Economics* 75(1), 33-59.
- Taherdoost H (2019). What is the best response scale for survey and questionnaire design? Review of different lengths of rating scale / Attitude, Scale / Likert Scale. *International Journal of Academy* 8(1), 1-10.
- Tavşancıl E (2005). Tutumların ölçülmesi ve spss ile veri analizi, Nobel Yayınları, Ankara.
- Yamane T (2010). Temel Örnekleme Yöntemleri. Literatür Yayıncılık. İstanbul.
- Yercan M, Kınıklı F (2018). Tarımsal kooperatiflerde ortakların yönetime katılımını etkileyen faktörlerin analizi üzerine bir araştırma: İzmir ili sütçülük kooperatifleri örneği. *Tarım Ekonomisi Dergisi* 24(2), 159-173.



Impact of Bushfire on Soil Heavy Metals in Oil Palm Plantations in Edo State, Nigeria

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HIGHLIGHTS

- Bushfire is a significant environmental disturbance in oil palm plantations.
- Bushfire has significant positive impacts on the heavy metals.
- The concentrations of the heavy metals were enhanced in the burnt oil palm plantation.
- Further studies on the ecological risks of heavy metals in oil palm plantations affected by bushfires are needed.

Abstract

The research examined the impact of bushfires on soil heavy metals in oil palm plantations in Edo State, Nigeria. The objectives of the study were to determine the concentration levels of heavy metals in the unburnt and burnt oil palm plantations, analyze significant differences in the soil heavy metals between both sites, and find out if bushfire has significant positive or negative impacts on the heavy metals. Soil samples were collected from the topsoil of the unburnt and burnt oil palm plantations, and were analyzed for lead (Pb), cadmium (Cd), cobalt (Co), chromium (Cr), nickel (Ni), arsenic (As), and vanadium (V). Data were analyzed using descriptive (range, mean, standard deviation, and coefficient of variation) and inferential (Student t-test) statistics. The impact of bushfires was statistically tested by comparing each heavy metal in unburnt and burnt oil palm plantations. The findings revealed that the concentrations of Pb (15.15 mg kg⁻¹), Cd (0.20 mg kg⁻¹), Co (5.09 mg kg⁻¹), Cr (6.52 mg kg⁻¹), Ni (5.42 mg kg⁻¹), As (3.19 mg kg⁻¹), and V (2.12 mg kg⁻¹) were higher in the burnt oil palm plantation. Statistically significant differences in heavy metal concentrations were observed between both sites, and the findings also indicated that bushfires have significant positive impacts on Pb, Cd, Co, Cr, Ni, As, and V. Overall, bushfire enhanced the concentrations of heavy metals in oil palm plantations. These findings can aid in the formulation of soil quality management strategies for tropical oil palm plantations affected by bushfires.

Keywords: Fire; heavy metals; oil palm plantations; soil quality

1. Introduction

Bushfires are major environmental disturbances in many ecosystems around the world (Carrión-Paladines et al. 2022). The increase in bushfire incidents over the last ten years and its impending danger will have overwhelming ecological consequences (Fennema 2021). Bushfire is regarded as one of the most damaging

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disorders in flora biomes that affect soil quality properties and ecosystem fitness (Dhungana et al. 2024). Bushfires severely affect vegetation ecosystems due to the elimination of the undergrowth and changes in soil quality indicators (Lucas-Borja et al. 2022). Bushfire may leave short-term effects on soil fertility indicators or cause enduring and irremediable changes in soil quality (Ershad et al. 2013). The concept of soil quality can be defined as the ability of a particular soil type, after disturbance in a natural or managed biome, to sustain flora and fauna efficiency, boost water and air quality, and support human health and dwelling (Xifré-Salvadó et al. 2021). Soils can be affected by bushfire through ash deposition, combustion of flora and soil cover, or post-fire erosion (Fernandez-Marcos 2022). However, bushfires may impact particular soil properties contrarily having positive, negative, or neutral effects (Dhungana et al. 2024).

The majority of studies have investigated the impact of bushfires on soil heavy metals in different ecosystems and climates. De Marco et al. (2005) reported that Cd and Pb had significantly increased higher in burnt soils. Bogacz et al. (2011) observed higher contents of Cu, Pb, Ni and Cr in soils affected by bushfires in Lower Silesia (Poland). Stankov Jovanovic et al. (2011) noted that Pb contents were higher in burnt soils comparative to unburnt soils from Vidlic Mountain in Serbia. In *Eucalyptus globulus* Labill. and *Pinus pinaster* Ait. Plantations, Campos et al. (2016) observed significantly higher contents of V, Ni, Cd, and Pb in burnt soils compared to unburnt soils. In the Lviv region (Ukraine), Popovych and Gapalo (2021) reported significant accumulation of Cd in edaphic horizons. Baieta et al. (2022) observed that there was a significant accumulation of Pb in the topsoil. In Naples (Southern Italy), high V contents in forest and bushfire forest soils were reported by Panico et al. (2023). Despite the large and growing body of literature on the impacts of bushfire on heavy metals, the response of heavy metals such as Pb, Cd, Co, Cr, Ni, As, and V to bushfire in oil palm plantations in the tropics is not well known because specific investigations are lacking.

Annually, bushfire occurrences are prevalent in most parts of Nigeria, mainly during the dry season (Orobator and Odjugo 2023), and it has been a significant part of the evolutionary history of most savannah and woodland biomes (Orobator, 2022; Orobator and Ugwa, 2023). Oil palm plantations in Nigeria are major ecosystems affected by bushfires, primarily caused by human agricultural burning. Orobator and Odjugo (2024) reported that the locals carry out bush burning as a customary pre-planting farming practice. In addition to affecting the physicochemical and biological properties of soil, bushfires can produce or discharge heavy metals in the soil (Fernandez-Marcos 2022). After a bushfire, the remained ash comprises variable quantities of heavy metals (Pitman 2006). Furthermore, various studies (Burton et al. 2016; Kristensen et al. 2014; Odigie and Flegal 2011, 2014, etc.) have stated that bushfires have the capacity to release heavy metals from their sequestered stages in soil. The incidence in soil of heavy metals causes a decline in soil quality and establishes a risk to the health of the soil ecosystem when the soil becomes contaminated (Fernandez-Marcos, 2022). Knowledge on the response of heavy metals to bushfire is valuable to comprehend their role in the post-fire restoration of the soil quality of oil palm plantations. The lack of empirical data makes it challenging to comprehend and predict the bushfire impact on soil heavy metals in oil palm plantations. Empirical investigations are required to cover this research gap. To achieve this, the present study examined the impacts of bushfires on the heavy metals of soil in oil palm plantations in Edo State, Nigeria.

The research specifically aims to achieve three key objectives. Firstly, it seeks to determine the concentration levels of Pb, Cd, Co, Cr, Ni, As, and V in both unburnt and burnt oil palm plantations. Secondly, it aims to examine whether there are significant differences in soil heavy metal concentrations between the unburnt and burnt plantations. Lastly, the study intends to assess whether bushfires have significant positive or negative impacts on the levels of these heavy metals (Pb, Cd, Co, Cr, Ni, As, and V).

The research hypothesized that there are no significant differences in Pb, Cd, Co, Cr, Ni, As, and V between the unburnt and burnt oil palm plantations. The novelty of the current study is that it exemplifies a first attempt to examine the impact of bushfire on soil heavy metals in oil palm plantations. The outcomes should give agriculturists, environmentalists, biogeographers, fire ecologists, and soil scientists insights about the

expected impacts of bushfire on soil heavy metals in oil palm plantations. Furthermore, the research culminations should be beneficial for initiating policies and collaborating on strategies for improved management of oil palm plantation ecosystems affected by bushfire. The outcomes of the study will significantly support achieving the following Sustainable Development Goals (SDG's): i. SDG 2 (Zero Hunger), soil contaminated with heavy metals affects the safety and yield of oil palm plantations, which are vital for the production of food and livelihood; ii. SDG 3 (Good Health and Well-being), higher concentrations of heavy metals in soils caused by bushfires pose health risks via food chains or groundwater pollution, and iii. SDG 12 (Responsible Consumption and Production) emphasizes the connection between the accumulation of heavy metals in the soil and chemical safety and ecological stewardship, ensuring that agricultural practices are both sustainable and safe.

2. Materials and Methods

2.1. Study area

The study was carried out in Okunuvbe community, Ovia North East Local Government, Edo State, Nigeria, and it is located within Latitudes 6° 37' 5.24" N - 6° 36' 46.97" N and Longitudes 5° 45' 53.88" E - 5° 45' 49.16" E (Figure 1). Okunuvbe community is spatially bounded by Odiguete village to the north and Igbakhue village to the southwest, and is approximately 37 km from the capital city of Benin. The study area belongs to the Af category of Koppen's climatic classification. The climate is tropical, characterized by relatively wet and dry seasons. The soils are the coastal plain sands, which are extensive red yellow, weathered, and loose, ill-sorted sands overlying the Bendel-Ameki group (Fagbami and Fapohunda, 1986). The topography of Okunuvbe is relatively flat, with an average elevation of 44 m above sea level, and it is drained by River Okhuo, a tributary to the Ovia River, which is the largest and longest river in Edo State. Oil palm (*Elaeis guineensis*) and rubber trees (*Hevea brasiliensis*) are the major perennial tree crops cultivated in the study area. Trees such as Mahogany (*Swietenia macrophylla*) and Iroko (*Milicia excelsa*) are also scattered within the area. *Andropogon spp*, *Pennisetum spp* and *Chromolaena odoranta* are the prevalent grass species in the Okunuvbe community.

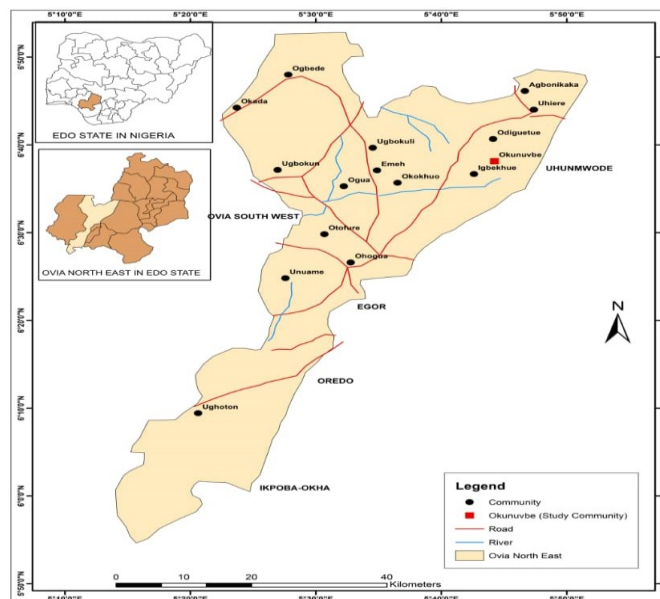


Figure 1. Location of study area

2.2. Fieldwork

Two oil palm plantations (unburnt and burnt) located next to each other and situated in the Okunuvbe community were adopted for the study. The choice of unburnt and burnt oil palm plantations enabled comparisons of Pb, Cd, Co, Cr, Ni, As, and V between the two study sites. Using a grid sampling design, a

sampled area measuring 100×100 m was mapped out for the collection of disturbed soil samples from both the unburnt and burnt oil palm plantations, respectively (Figure 2). Adopting the systematic random methodology, the soil samples were collected at a distance of 15 m apart from each sampling point with the aid of a soil auger at a depth of 0 -15 cm (topsoil). It is well known that the burning process can affect soil properties down to 15 cm soil depth (Terzano et al. 2021). Ten (10) soil samples were collected, each from the burnt and unburnt oil palm plantations. Consequently, a total of twenty (20) soil samples were collected for the purpose of the study. The soil samples collected from the unburnt oil palm plantation served as the control soil samples, while the soil samples collected from the burnt oil palm plantation were the treatment samples. The number of soil samples collected is based on the similarity of soil type, vegetation, and climatic characteristics of the control and treatment plots (Ozgeldinova et al. 2025).

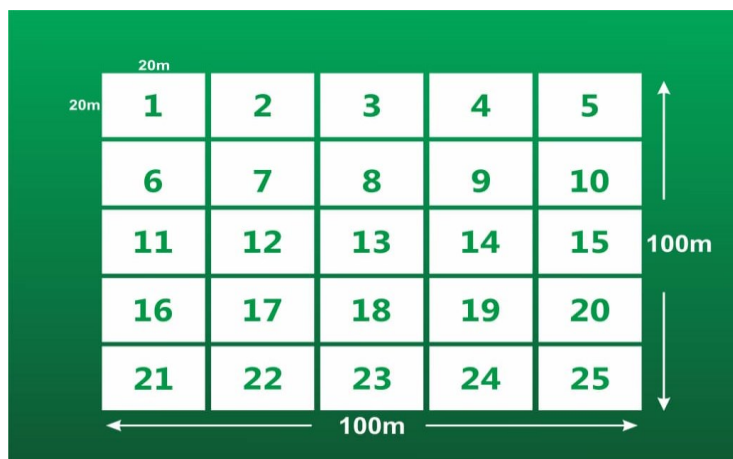


Figure 2. Grid sampling design; Sample area (100 m x 100 m) and plot size (20 m x 20 m) within each oil palm plantation

2.3 Laboratory analysis

Laboratory analysis was undertaken to determine the concentrations of lead (Pb), cadmium (Cd), cobalt (Co), chromium (Cr), nickel (Ni), arsenic (As), and vanadium (V) in the soils of the unburnt and burnt oil palm plantations. The soil samples were air-dried in the laboratory for 72 hours. 5 g of the dried sieved soil from the soil samples was digested with HNO_3 -HCl according to USEPA method 3050B to extract the metals (Orobator et al. 2019). The concentrations of Pb, Cd, Co, Cr, Ni, As, and V were measured by Perkin-Elmer Analyst 300 Atomic Absorption 6 Spectrophotometer (AAS), and amounts obtained were reported in mg kg^{-1} (Khodadoust et al. 2004).

2.4. Statistical analysis

Data of Pb, Cd, Co, Cr, Ni, As, and V contents were analyzed by means of PC applications for the Statistical Package for Social Sciences and Excel. To achieve the objectives of the research, both the descriptive (range, mean, standard deviation and coefficient of variation) and inferential (Student t-test) statistics were adopted. Descriptive statistics revealed that substantial variation exists in the contents of the studied soil parameters between sampling locations (Budak, 2018). Student t-test was used to identify statistically significant differences in heavy metal concentrations between the unburnt and burnt oil palm plantations. This was achieved by comparing the means of each heavy metal between the unburnt and burnt oil palm plantations. The outcomes aided in determining the significant positive or negative impacts of bushfires on heavy metals. Significant levels were designated as significant ($p < 0.05$) and non-significant ($p > 0.05$), respectively.

3. Results and Discussion

3.1. Lead (Pb)

Lead (Pb), a naturally occurring chemical element in the carbon group, is also a heavy metal (Niu et al., 2023). In the burnt oil palm plantation, the Pb values ranged from 10.41 to 22.40 mg kg^{-1} with a mean of 15.15

mg kg⁻¹ and a standard deviation of 4.09, while in the unburnt oil palm plantation, it ranged from 10.38 to 14.04 mg kg⁻¹, with a mean of 11.87 mg kg⁻¹ and a standard deviation of 1.37 (Table 1).

The results showed that Pb concentrations were higher in the burnt oil palm plantation (15.15 mg kg⁻¹) than the unburnt oil palm plantation (11.87 mg kg⁻¹). Oil palm plantation floor is characterized by a blend of organic materials, and the higher Pb contents in the burnt oil palm plantation soils may be due to mineralization of the organic materials caused by the bushfire (Santorufu et al. 2021). Similarly, the presence of ash in the soils of the burnt oil palm plantation may also account for higher Pb contents. The accretion of Pb in soils through ash deposition on soil due to bushfire is predictable (Stankov Jovanovic et al. 2011). Solid wastes from palm oil mills are empty fruit bunches (EFB), which can be utilized as mulch on oil palm plantation soils. The mulch and inorganic fertilizer used can contain Pb (Winarko et al., 2024). This may account for the occurrence of Pb in the unburnt oil palm plantation. The detected values of Pb in both oil palm plantations were below the WHO permissible limit of 85.00 mg kg⁻¹. This inferred that Pb concentrations in the soils are not toxic. The response of Pb in this study mirrors the findings of Bartkowiak and Lemanowicz (2017), who reported higher Pb concentrations in burnt soils. Our results also accord with a previous study of Bogacz et al. (2011), who reported higher levels of Pb in both topsoil and subsoil. However, the outcomes of the research contradicted Panico et al., (2023), who reported lower levels of Pb in burnt forest (2.6 mg kg⁻¹) compared to forest (4.1 mg kg⁻¹) and urban (14.9 mg kg⁻¹) areas. The higher Pb contents in the burnt oil palm plantation diminish the positive impacts of bushfire on Pb in the oil palm plantation. The significant difference ($p < 0.05$) in Pb contents between both oil palm plantations inferred that Pb was considerably higher in burnt oil palm plantations, and the positive impact of bushfire on Pb was significant. Pb also showed significant changes in the standard deviation values when comparing the two oil palm plantations (1.37 to 4.09). In agreement with the research, Rao et al. (2024) reported that Pb concentration was significantly higher ($p < 0.05$).

3.2. Cadmium (Cd)

Cadmium (Cd) is a malleable metal that appears as a bluish or silvery-white powder (Charkiewicz et al. 2023). Among all non-essential heavy metals, cadmium (Cd) is likely the one that has garnered the most attention in soil science and plant nutrition, owing to its potential toxicity to humans and its relatively high mobility within the soil-plant system (McLaughlin and Singh 1999). In the burnt oil palm plantation, the Cd values ranged from 0.15 to 0.33 mg kg⁻¹ with a mean of 0.20 mg kg⁻¹ and a standard deviation of 0.06, while in the unburnt oil palm plantation, it ranged from 0.08 to 0.19 mg kg⁻¹, with a mean of 0.15 mg kg⁻¹ and a standard deviation of 0.03 (Table 1). The results revealed that Cd contents were higher in the burnt oil palm plantation (0.20 mg kg⁻¹) than the unburnt oil palm plantation (0.15 mg kg⁻¹). The observed higher Cd may be as a result of the vertical migration nature of Cd in the soil ecosystem, consequent on ash subsidence in the burnt biome (Smith et al. 2011). Cd increases in soils are associated with the burning of biomass involved in bushfires (Pacifico et al., 2023). Cd concentrations in the environment can be caused by bushfires, and bushfire-induced increases in the concentrations of Cd in soils and ashes have been noted by Demeyer et al. (2001) and Campos et al. (2016). The incidence of Cd in the unburnt oil palm plantation may be due to the application of fertilizers on the soil. Superphosphate fertilizer is a significant anthropogenic source of Cd (Oyedele et al. 2016). The observed values of Cd in both oil palm plantations were below the WHO permissible limit of 0.80 mg kg⁻¹. This deduced that Cd concentrations in the soils are not toxic. The outcome of our study agreed with Rao et al. (2024), who reported higher Cd concentrations in burnt soils. In both beech and oak forests on the Vesuvian slopes, Demirbas (2003) reported higher levels of Cd. Upsurges of total concentrations of Cd were also detected by Abraham et al. (2018b). In the post-fire areas of forests and meadows, Bogacz et al. (2011) reported that Cd increased on surface horizons. In contrast to the findings of the study, Stankov Jovanovic et al. (2011) noted that Cd levels were low in all post-fire areas of *A. genevensis*, *L. galeobdolon*, *T. chamaedrys* and *A. alpinus* for all soil samples. The higher Cd concentrations in the burnt oil palm plantation infer the positive impacts of bushfire on Cd. The significant difference ($p < 0.05$) in Cd between both oil palm plantations suggested that Cd was substantially higher in burnt oil palm plantations, and that the positive impact of bushfire on Cd was significant. Similarly, compared to unburned soils, Campos et al. (2016) reported significantly higher value of Cd in burnt soils. Also, Cd indicated changes in the standard deviation values when comparing the two oil palm plantations (0.03 to 0.06).

Table 1. Concentrations of Pb, Cd, Co, Cr, Ni, As, and V in the soils.

Soil Parameter	Depth (cm)	Unburnt oil palm plantation				Burnt oil palm plantation				<i>p</i> -value	WHO Limits
		Range	Mean	Std.	CV (%)	Range	Mean	Std.	CV (%)		
Pb (mg kg ⁻¹)	0 - 15	10.38 - 14.04	11.87	1.37	11.51	10.41 - 22.40	15.15	4.09	27.03	0.01*	85.00
Cd (mg kg ⁻¹)	0 - 15	0.08 - 0.19	0.15	0.03	21.94	0.15 - 0.33	0.20	0.06	28.91	0.00*	0.80
Co (mg kg ⁻¹)	0 - 15	2.05 - 4.61	3.63	0.77	21.28	3.72 - 8.20	5.09	1.48	29.07	0.00*	24.00
Cr (mg kg ⁻¹)	0 - 15	2.61 - 5.89	4.62	0.97	21.02	4.70 - 10.50	6.52	1.90	29.19	0.00*	100.00
Ni (mg kg ⁻¹)	0 - 15	2.20 - 4.98	3.93	0.83	21.16	4.01 - 8.50	5.42	1.54	28.45	0.00*	35.00
As (mg kg ⁻¹)	0 - 15	1.28 - 2.87	2.26	0.47	21.20	2.30 - 5.12	3.19	0.95	29.79	0.00*	0.8.00
V (mg kg ⁻¹)	0 - 15	0.85 - 2.01	1.52	0.34	22.13	1.55 - 3.42	2.12	0.62	29.26	0.00*	Not specified

3.3. Cobalt (Co)

Cobalt (Co) is a heavy metal in soil, found in comparatively low concentrations in the Earth's crust, and is known for its role in plant metabolism (Srivastava et al. 2022). In the burnt oil palm plantation, the Co values ranged from 3.72 to 8.20 mg kg⁻¹ with a mean of 5.09 mg kg⁻¹ and a standard deviation of 1.48, while in the unburnt oil palm plantation, it ranged from 2.05 to 4.61 mg kg⁻¹, with a mean of 3.63 mg kg⁻¹ and a standard deviation of 0.77 (Table 1). The results indicated that Co contents were higher in the burnt oil palm plantation (5.09 mg kg⁻¹) than in the unburnt oil palm plantation (3.63 mg kg⁻¹). The experiential higher Co signifies that it is less soluble and mobile in soil and persists in the soil, while it is efficiently transformed from ash to soil (Campos et al. 2016). The prevalence of Co in the soils of the unburnt oil palm plantation may be due to micronutrient supplement application. As an agricultural input, micronutrient mixtures used in perennial agricultural systems contain Co. Also, plant litter decomposition may lead to incidences of Co on unburnt soils. Co taken up by plants (together with weeds and understory flora) is reverted to the soil through leaf litter, decaying roots, or pruning residues (Kabata-Pendias 2011). The observed values of Co in both oil palm plantations were below the WHO permissible limit of 24.00 mg kg⁻¹. This suggests that Co concentrations in the soils are not toxic. The findings of the investigation aligned with Campos et al. (2016), who reported a higher level of Co owing to bushfires in eucalypt and pine forest plantations. Similarly, in both Iside Site and Vesuvian area of the Campania region in Southern Italy, Pacifico et al. (2023) stated that Co values increased due to bushfire. In the forest soils of the Lviv region (Ukraine), Popovych and Gapalo (2012) observed that Co (up to 0.9 mg kg⁻¹) was slightly higher. Conversely, in surface forest soils in Victoria (Australia), Abraham et al. (2018a) reported a lower range of Co values (3–16 mg kg⁻¹) in burnt soils compared to unburnt soils (4–25 mg kg⁻¹). The decrease in Co concentrations may be ascribed to volatilization. The higher Co contents in the burnt oil palm plantation constitute the positive impacts of bushfire on Co in the oil palm plantation. The significant difference ($p < 0.05$) in Co contents between both oil palm plantations suggested that Co was substantially higher in burnt oil palm plantations, and that the positive impact of bushfire on Co was significant. Correspondingly, in the Vesuvian area, compared to unburnt soils, Pacifico et al. (2023) reported significantly higher value of Co in burnt soils. Co also showed significant changes in the standard deviation values when comparing the two oil palm plantations (0.77 to 1.48).

3.4. Chromium (Cr)

Chromium (Cr) is the 17th most abundant element in the Earth's mantle (Dwivedi et al. 2023). It is a highly mobile heavy metal within the transition metals group (Chen et al. 2024) and usually occurs in soils (Adel and Norman 2003). In the burnt oil palm plantation, the Cr values ranged from 4.70 - 10.50 mg kg⁻¹ with a mean of 6.52 mg kg⁻¹ and a standard deviation of 1.90, while in the unburnt oil palm plantation, it ranged from 2.61 - 5.89 mg kg⁻¹, with a mean of 4.62 mg kg⁻¹ and a standard deviation of 0.97 (Table 1). The results revealed that Cr contents were higher in the burnt oil palm plantation (6.52 mg kg⁻¹) than in the unburnt oil palm plantation (4.62 mg kg⁻¹). The higher Cr content in burnt oil palm plantation may be due to the extremely caustic character of ash produced during bushfires (Yusiharni and Gilkes 2012). The accelerated migration and transformation of Cr on the topsoil may also account for the increase (Rao et al. 2024). In addition, Cr has a low leaching or volatilization rate (Terzano et al. 2021). The burnt vegetation in the oil palm plantation may also account for the higher contents of Cr. Soil enrichment by Cr was demonstrated to stem also from the burning of the flora (Panchev et al. 2008). Phosphate-based fertilizers, generally used in the cultivation of oil palm, usually contain Cr (Eze et al. 2020). This may account for the prevalence of Cr in the unburnt oil palm plantation. The observed values of Cr in both oil palm plantations were below the WHO permissible limit of 100.00 mg kg⁻¹. This suggests that Cr concentrations in the soils are not toxic. The results of the study agreed with Pacifico et al. (2023), who observed that Cr values increased due to bushfire in both the Iside site (23.5 to 24.9 mg kg⁻¹) and the Vesuvian area (10.9 to 12.9 mg kg⁻¹), respectively. The higher Cr contents in the burnt oil palm plantation imply the positive impacts of bushfire on Cr in the oil palm plantation. The significant difference ($p < 0.05$) in Cr contents between both oil palm plantations demonstrated that Cr was significantly higher in burnt oil palm plantations, and that the positive impact of bushfire on Cr was significant. However, in the Mediterranean region, Santorufo et al. (2021) reported that the concentration of Cr did not significantly change. Cr indicated

significant changes in the standard deviation values when comparing the two oil palm plantations (0.97 to 1.90).

3.5. Arsenic (As)

Arsenic (As) is a naturally occurring element in the Earth's crust and is widely distributed across the environment, including in the air, water, and soil (World Health Organization 2002). Soils can originate from both natural and anthropogenic sources (Kayode et al. 2020). In the burnt oil palm plantation, the values ranged from 2.30 to 5.12 mg kg⁻¹ with a mean of 3.19 mg kg⁻¹ and a standard deviation of 0.95, while in the unburnt oil palm plantation, it ranged from 1.28 - 2.87 mg kg⁻¹, with a mean of 2.26 mg kg⁻¹ and a standard deviation of 0.47 (Table 1). The results showed that as contents were higher in the burnt oil palm plantation (3.19 mg kg⁻¹) than in the unburnt oil palm plantation (2.26 mg kg⁻¹). This may be ascribed to the high ash content from the burning of vegetation, as the vegetation may have absorbed it from the soil, where it was originally concentrated (Abraham et al. 2018a). In addition, soil heating from bushfires can enhance the mobilization (Johnston et al. 2019). Burton et al. (2016) stated that bushfires play a key role in mobilizing As. Furthermore, bushfires can also result in arsenic remobilization via emissions to the atmosphere, change to water-soluble arsenic compounds, and can be bound to eroded deposits in soils (Li et al. 2023). Insufficient application and inappropriate soil nutrient management can result in the accretion of heavy metals in the soil, which may account for the incidences of heavy metal contamination in the unburnt site (Eze et al. 2020; Wu et al. 2024). The observed values of in both oil palm plantations were above the WHO permissible limit of 0.80 mg kg⁻¹. This implies that concentrations in the soils are toxic. The findings of the research agreed with Abraham et al. (2018a), who reported that concentrations increased in the post-burn environment. The higher concentrations in the burnt oil palm plantation diminish the positive impacts of bushfire on As. The significant difference ($p < 0.05$) between the two oil palm plantations suggested that it was substantially higher in burnt oil palm plantations, and that the positive impact of bushfire on was significant. Consistent with the study, Abraham et al. (2018b) reported that concentrations of were significant in burnt soils. Furthermore, there were significant changes in the standard deviation values when comparing the two oil palm plantations (0.47 to 0.95).

3.6. Vanadium (V)

Vanadium is a multivalent, redox-sensitive heavy metal that is widespread in the environment (Harvey et al. 2024). In the burnt oil palm plantation, the V values ranged from 1.55 to 3.42 mg kg⁻¹ with a mean of 2.12 mg kg⁻¹ and a standard deviation of 0.62, while in the unburnt oil palm plantation, it ranged from 0.85 to 2.01 mg kg⁻¹, with a mean of 1.52 mg kg⁻¹ and a standard deviation of 0.34 (Table 1). The results indicated that V contents were higher in the burnt oil palm plantation (2.12 mg kg⁻¹) than in the unburnt oil palm plantation (1.52 mg kg⁻¹). The higher V contents in the burnt oil palm plantation may be due to the combustion of vegetation (Terzano et al. 2021). Occurrences of V in the unburnt oil palm plantation may be attributed to the parent material of the soils. Some parent materials of soils contain V contents (Guagliardi et al. 2018). The results of the study agreed with Pacifico et al. (2023), who observed higher V values due to bushfire in the Vesuvian area (109.2 to 110.6 mg kg⁻¹). Similarly, Terzano et al. (2021) reported that the concentrations of V in the topsoil were up to 1.7 times higher than in unburnt soil. Panico et al. (2023) observed higher V contents in burned forest (9.0 mg kg⁻¹) than in forest (7.7 mg kg⁻¹) and urban areas (7.6 mg kg⁻¹). The higher V concentrations in the burnt oil palm plantation suggest that bushfires have a positive impact on V. The significant difference ($p < 0.05$) in V between both oil palm plantations suggested that V was substantially higher in burnt oil palm plantations, and that the positive impact of bushfire on V was significant. Additionally, V showed significant changes in the standard deviation values when comparing the two sites (0.34 to 0.62).

3.7. Nickel (Ni)

Nickel (Ni) is typically distributed evenly throughout the soil profile, with its concentration varying widely depending on the parent rock, and its higher concentration levels in surface soils are often linked to soil-forming processes and human activities (Iyaka 2011). In the burnt oil palm plantation, the Ni values ranged from 4.01 to 8.50 mg kg⁻¹ with a mean of 5.42 mg kg⁻¹ and a standard deviation of 1.54, while in the unburnt

oil palm plantation, it ranged from 2.20 - 4.98 mg kg⁻¹, with a mean of 3.93 mg kg⁻¹ and a standard deviation of 0.83 (Table 1). The results revealed that Ni contents were higher in the burnt oil palm plantation (5.42 mg kg⁻¹) than in the unburnt oil palm plantation (3.93 mg kg⁻¹). The higher Ni contents in the burnt oil palm plantation may be attributed to the release of Ni in soil due to combustion of vegetation (Campos et al. 2016) and ash interactions with soil (Stankov Jovanovic et al. 2011). The management of palm oil plantations is characterized by extensive agrochemical use, which is a major anthropogenic source of Ni in soils (Dearlove et al. 2024). The use of pesticides and herbicides may account for the prevalence of Ni in the unburnt oil palm plantation soils. The observed values of Ni in both oil palm plantations were below the WHO permissible limit of 35.00 mg kg⁻¹. This suggests that Ni concentrations in the soils are not toxic. The outcomes of the study are consistent with Pacifico et al. (2023), who reported that Ni concentrations increased in both the Ilside site (22.9 to 23.8 mg kg⁻¹) and the Vesuvian area (15.8 to 16.8 mg kg⁻¹), respectively. The higher Ni contents in the burnt oil palm plantation indicate the positive impacts of bushfire on Ni in the oil palm plantation. The significant difference ($p < 0.05$) in Ni contents between both oil palm plantations suggested that Ni was substantially higher in burnt oil palm plantations, and that the positive impact of bushfire on Ni was significant. Equally, compared to unburned soils, Campos et al. (2016) stated that significantly higher values of Ni were detected in soils owing to bushfire. Furthermore, Ni showed significant changes in the standard deviation values when comparing the two data sets (0.83 to 1.54).

4. Conclusions

The study assessed the impacts of bushfire on heavy metals in oil palm plantations in the tropics. Higher concentrations of Pb, Cd, Co, Cr, Ni, As, and V were detected in the burnt oil palm plantation. Significant differences ($p < 0.05$) were observed among the heavy metals between the unburnt and burnt oil palm plantations. Higher As concentrations were observed in the soils of both oil palm plantations when compared with the permissible limit. The study concluded that whereas, bushfire has significant positive impacts on Pb, Cd, Co, Cr, Ni, As and V contents in oil palm plantations, the soils of both the unburnt and burnt oil palm plantations were toxic with As. The research recommended the planting fire-resistant crops such as stone plants (*Aizoaceae spp*), lavender (*Lavandula spp*), Yucca (*Yucca spp*) etc. around the oil palm plantations to act as barriers to prevent the spread of bushfire. This can also aid to reduce the intensity of fires, and constrain the release of heavy metals into the soil. The use of fern plants can be used to reduce the contents of in the soils of the oil palm plantations. The research also suggested frequent soil testing to monitor the concentration levels of Pb, Cd, Cr, Ni, and V in the soils.

Author Contributions: I have read and agreed to the published version of the manuscript.

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References

- Abraham J, Dowling K, Florentine S (2018a). Influence of controlled burning on the mobility and temporal variations of potentially toxic metals (PTMs) in the soils of a legacy gold mine site in Central Victoria, Australia. *Geoderma* 331, 1–14.
- Abraham J, Dowling K, Florentine S (2018b). Controlled burn and immediate mobilization of potentially toxic elements in soil, from a legacy mine site in Central Victoria, Australia. *Science of the Total Environment* 616–617, 1022–1034. <https://doi.org/10.1016/j.scitotenv.2017.10.216>
- Adel Z, Norman T (2003). Chromium in the environment: Factors affecting biological remediation. *Plant and Soil* 249, 139–156.
- Baieta R, Vieira AMD, VAˆ Nkovˆ A M, Mihaljevi M (2022). Effects of forest fires on soil lead elemental contents and isotopic ratios. *Geoderma* 1-8, 414115760.

- Bartkowiak A, Lemanowicz J (2017). Effect of forest fire on changes in the content of total and available forms of selected heavy metals and catalase activity in soil. *Soil Science Annual* 68(3), 140–148. <https://doi.org/10.1515/ssa-2017-0017>
- Bogacz A, Woźniczka P, Abaz B (2011). Concentration and pools of heavy metals in organic soils in post-fire areas used as forests and meadows. *Journal of Elementology* 16(4), 515-524. <https://doi.org/10.5601/jelem.2011.16.4.01>
- Budak M (2018). Importance of spatial soil variability for land use planning of a farmland in a semi-arid region. *Fresenius Environmental Bulletin* 27 (7), 5053-5065.
- Burton CA, Hoefen TM, Plumlee GS, Baumberger KL, Backlin AR, Gallegos E, Fisher RN (2016). Trace elements in storm flow, ash, and burned soil following the 2009 station fire in Southern California. *PLoS ONE* 11, e0153372.
- Campos I, Abrantes N, Keizer JJ, Vale C, Pereira P (2016). Major and trace elements in soils and ashes of *eucalypt* and pine forest plantations in Portugal following a wildfire. *Science of the Total Environment* 572, 13631376. <https://doi.org/10.1016/j.scitotenv.2016.01.190>
- Carrión-Paladines V, Hinojosa MB, Jiménez Álvarez L, Reyes-Bueno F, Correa Quezada L, García-Ruiz R (2022). Effects of the severity of wildfires on some physical chemical soil properties in a humid montane scrublands ecosystem in Southern Ecuador. *Fire* 5, 66. <https://doi.org/10.3390/fire5030066>
- Charkiewicz AE, Omeljaniuk WJ, Nowak K, Garley M, Nikliński J (2023). Cadmium toxicity and health effects—a brief summary. *Molecules* 28(18), 6620. <https://doi.org/10.3390/molecules28186620>
- Chen Z, Chen Y, Liang J, Sun Z, Zhao H, Huang Y (2024). The release and migration of Cr in the soil under alternating wet–dry conditions. *Toxics* 12(2), 140. <https://doi.org/10.3390/toxics12020140>.
- Dearlove E, Harrison S, Svendsen C , Spurgeon D (2024). Agrochemical inputs to managed oil palm plantations are a probable risk to ecosystems: Results from a screening level risk assessment. *Environmental Pollution* 361, 1011.
- Demarco A, Gentile AE, Arena C, De Santo AV (2005). Organic matter, nutrient content and biological activity in burned and unburned soils of a Mediterranean maquis area of southern Italy. *International Journal of Wildland Fire* 14, 365–377.
- Demirbas A (2003). Toxic air emissions from biomass combustion. *Energy Sources* 25, 419–427.
- Dhungana B. P, Sharma SP, Chhetri VT (2024). Low-Intensity wildfire alters selected soil properties in the tropical *Shorea robusta* forest. *International Journal of Forestry Research* 4686760, 1-11. <https://doi.org/10.1155/2024/4686760>
- Dwivedi, BS, Thakur R, Rawat A, Tiwari RK, Nagwanshi A, Pathak J, Dixit BK, Sarvade S (2023). Chromium: in soil, plant, animal, and human. *Theoretical Biology Forum* 15–29. <https://doi.org/10.5281/zenodo.8051969>
- Ershad M, Hemmati V, Hashemi SA, Foroozan AH (2013). The effects of forest fires on the chemical properties of soils in Northern Iran: A case study on *Pinus Taeda* stands. *Bulletin of Environment, Pharmacology and Life Sciences* 2(9), 51-54.
- Eze S, Dougill AJ, Banwart SA, Hermans TDG, Ligowe IS, Thierfelder C (2020). Impacts of conservation agriculture on soil structure and hydraulic properties of Malawian agricultural systems. *Soil and Tillage Research* 201, 104639. <https://doi.org/10.1016/j.still.2020>
- Fagbami A, Fapohunda A (1986). Slur imagery for soil mapping and regional planning in western Nigeria. In Eden MJ (Ed.), *Remote sensing and tropical land management and parry*. New York: John Wiley& Sons Ltd.
- Fennema SJ (2021). Assessment of the impacts of prescribed fires on soil quality and cultural impacts of interdisciplinary collaboration. PhD Thesis, Idaho University (Unpublished), Nigeria.

- Fernandez-Marcos ML (2022). Potentially Toxic Substances and Associated Risks in Soils Affected by Wildfires: A Review. *Toxics* 10, 31. <https://doi.org/10.3390/toxics10010031>
- Guagliardi I, Cicchella D, De Rosa R, Ricca N and Buttafuoco G (2018). Geochemical sources of vanadium in soils: Evidences in a southern Italy area. *Journal of Geochemical Exploration* 184, 358–364.
- Harvey MA, Erskine PD, Harris HH (2024). Plant-soil relations of selenium, molybdenum and vanadium in the Richmond District of Central Queensland, Australia. *Plant and Soil* 504, 435-455. <https://doi.org/10.1007/s11104-024-06633-7>
- Iyaka, YA (2011). Nickel in soils: A review of its distribution and impacts. *Scientific Research and Essays* 6(33). <https://doi.org/10.5897/srex11.035>
- Johnston SG, Karimian N, Burton ED (2019). Fire promotes arsenic mobilization and rapid arsenic (iii) formation in soil via thermal alteration of arsenic-bearing iron oxides. *Frontiers of Earth Science* 7, 139.
- Kabata-Pendias A (2011). Trace Elements in Soils and Plants. 4th Edition. CRC Press.
- Kayode OT, Aizebeokhai AP, Odukoya AM (2021). Arsenic in agricultural soils and implications for sustainable agriculture. IOP Conf. Series: Earth and Environmental Science 655, 012081. <https://doi.org/10.1088/1755-1315/655/1/012081>
- Khodadoust AP, Reddy KR, Maturi R (2004). Removal of nickel and phenanthrene from kaolin soil using different extractants. *Environmental Engineering Science* 21(6), 485 - 495.
- Kristensen LJ, Taylor MP, Odigie KO, Hibdon SA, Flegal AR (2014). Lead isotopic compositions of ash sourced from Australian bushfires. *Environ. Pollution* 190, 159–165.
- Li X, Wang G, Li Y, Han D, Cong J, Gao C (2023). Aerobic and anaerobic burning alter trace metal availability in peat soils: evidence from laboratory experiments. *European Journal of Soil Science* 74, e13385.
- Lucas-Borja ME, Fernández C, Plaza-Alvarez PA, Carrà BG, Zema DA (2022). Variability of soil properties with fire severity in pine forests and reforested areas under Mediterranean conditions. *Journal of Hydrology and Hydromechanics*, 70(4):462–474. <https://doi.org/10.2478/johh-2022-0028>
- McLaughlin MJ, Singh BR (1999). Cadmium in soils and plants. In: McLaughlin MJ, Singh BR (eds) *Developments in plant and soil sciences*. 85. Springer, Dordrecht. https://doi.org/10.1007/978-94-011-4473-5_1
- Niu C, Dong M, Niu Y (2023). Lead toxicity and potential therapeutic effect of plant-derived polyphenols. *Phytomedicine* 114, 154789. <https://doi.org/10.1016/j.phymed.2023.154789>
- Odigie KO, Flegal AR (2011). Pyrogenic Remobilization of Historic Industrial Lead Depositions. *Environmental Science & Technology* 45, 6290–6295.
- Odigie KO, Flegal AR (2014). Trace metal inventories and lead isotopic composition chronicle a forest fire's remobilization of industrial contaminants deposited in the Angeles National Forest. *PLoS ONE* 9, e107835.
- Orobator PO, Ekpenkhio E, Jideonwo O (2019). Assessment of point - source pollution of anthropic soils in Benin City, Nigeria. *The Nigerian Geographical Journal* 13(2), 51-64.
- Orobator PO (2022). Effect of bushfire on soil bacteria and fungi in perennial tree plantation ecosystems. *Journal of Geographic Thought & Environmental Studies* 17(1), 1-11.
- Orobator PO, Ugwa IK (2023). Indigenous communities' knowledge of bushfire impacts on specific soil quality indicators in rubber plantations of Southern Edo State, Nigeria. *Journal of Agriculture, Forestry and Fisheries* 20(1& 2), 7-14.
- Orobator PO, Odjugo PAO. (2023). Do locals' perception of bushfire impact on rubber trees match or mismatch with empirical data? Evidence from Edo State, Nigeria. *Kastamonu University Journal of Forestry Faculty* 23 (1), 52-63.

- Orobator PO, Odjugo PAO (2024). Natives' perception on causes and mitigation of bushfire in rubber plantations: A social-ecological system approach. *Acta Geographica Universitatis Comenianae* 68 (1), 113-138.
- Oyedele DJ, Asonugbo C, Awotoye OO (2006). Heavy metals in soil and accumulation by edible vegetables after phosphate fertilizer application. *Electronic Journal of Environmental, Agricultural and Food Chemistry* 5(4), 1446-1453.
- Ozgeldinova Z, Mukayev Z, Zhanguzhina A, Ulykpanova M, Gulnar A (2025). Impact of forest fire on the heavy metal content in the soil cover of the Amankaragay pine forest, Kostanay Region. *Journal of Ecological Engineering* 26(3), 350–364.
- Pacifico LR, Pizzolante A, Guarino A, Iannone A, Esposito M, Albanese S (2023). Wildfires as a Source of Potentially Toxic Elements (PTEs) in Soil: A Case Study from Campania Region (Italy). *International Journal of Environmental Research and Public Health* 20, 4513.
- Panichev N, Mabasa W, Ngobeni P, Mandiwana K, Panicheva S (2008). The oxidation of Cr (III) to Cr (VI) in the environment by atmospheric oxygen during the bush fires. *Journal of Hazardous Materials* 153, 937–941. <https://doi.org/10.1016/j.jhazmat.2007.09.044>
- Panico SC, Santorufo L, Memoli V, Esposito F, Santini GDI, Natale G, Trifuoggi M, Barile R, Maisto G (2023). Evaluation of soil heavy metal contamination and potential human health risk inside forests, wildfire forests and urban areas. *Environments* 10, 146. <https://doi.org/10.3390/environments10080146>
- Pitman RM (2006). Wood ash use in forestry – a review of the environmental impacts. *Forestry* 79(5): 563–588. <https://doi.org/10.1093/forestry/cpl041>
- Popovych V, Gapalo A (2021). Monitoring of ground forest fire impact on heavy metals content in edafic horizons. *Journal of Ecological Engineering*, 22, 5, 96–103 <https://doi.org/10.12911/22998993/135872>
- Rao L, Zheng C, Chen J, Cai J, Yang Z, Xu X, Lv G, Xu C, Wang G, Man Y, Wong M, Cheng Z (2024). Ecological and human health hazards of soil heavy metals after wildfire: A case study of Liangshan Yi autonomous prefecture, China. *Chemosphere* 352, 141506. <https://doi.org/10.1016/j.chemosphere.2024.141506>
- Santorufu L, Memoli V, Panico SC, Santini G, Barile R, DI Natale G, Trifuoggi M., De Marco A, Maisto G (2021). Early post-fire changes in properties of Andosols within a Mediterranean area. *Geoderma* 394. <https://doi.org/10.1016/j.geoderma.2021.115016>
- Smith HG, Sheridan GJ, Lane PNJ, Nyman P, Haydon S (2011). Wildfire effects on water quality in forest catchments: A review with implications for water supply. *Journal of Hydrology* 396, 170–192.
- Stankov Jovanovic VP, Ilic MD, Markovic MS, Mitic VD, Nikolic Mandic SD, Stojanovic GS (2011). Wild fire impact on copper, zinc, lead and cadmium distribution in soil and relation with abundance in selected plants of Lamiaceae family from Vidlic Mountain (Serbia). *Chemosphere* 84(11), 1584-91. <https://doi.org/10.1016/j.chemosphere.2011.05.048>
- Srivastava P, Bolan N, Casagrande V, Benjamin J, Adejumo SA, Sabir M, Farooqi, Saifullah Z (2022). Cobalt in soils: sources, fate, bioavailability, plant uptake, remediation, and management. *Appraisal of Metal(oids) in the Ecosystem* 81-104. <https://doi.org/10.1016/B978-0-323-85621-8.00007-8>
- Terzano R, Rascio I, Allegretta I, Porfido C, Spagnuolo M, Khanghahi MY, Crecchio C, Sakellariado UF, Gattullo CE (2021). Fire effects on the distribution and bioavailability of potentially toxic elements (PTEs) in agricultural soils. *Chemosphere* 281, 130752. <https://doi.org/10.1016/j.chemosphere.2021.130752>
- Winark SD, Ermadani, Yanova S (2024). Lead and cadmium content in soil, oil palm fiber, and palm kernel in the oil palm plantation with mulch application. *Revista Verde* 19(2), 95-99.
- World Health Organization (WHO) (1996) Permissible Limits of Heavy Metals in Soil and Plants. Geneva, Switzerland.

- World Health Organization (WHO) (2002). Arsenic. Retrieved from <https://www.who.int/news-room/fact-sheets/detail/arsenic> (access date: 1st December, 2024).
- Wu M, Qi Q, Derrible S, Choi Y, Fourie A, Ok YS (2024). Regional and global hotspots of arsenic contamination of topsoil identified by deep learning. *Communications Earth & Environment*. 5,1, <https://doi.org/10.1038/s43247-023-01177-7>
- Xifré-Salvadó MÀ, Prat-Guitart N, Francos M, Úbeda X, Castellnou M (2021). Effects of fire on the organic and chemical properties of soil in a *Pinus halepensis* Mill. Forest in Rocallaura, NE Spain. *Sustainability* 13, 5178. <https://doi.org/10.3390/su13095178>
- Yusiharni E, Gilkes RJ (2012). Changes in the mineralogy and chemistry of a lateritic soil due to a bushfire at Wundowie, Darling Range, Western Australia. *Geoderma* 191, 140e150.



Determination of the Agricultural Mechanization Level of Agricultural Enterprises in Eskişehir District of Aksaray Province

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HIGHLIGHTS

- In Eskişehir district of Aksaray province, the average agricultural enterprise size is 459.62 decares, and irrigated farming is carried out on all cultivated land. This numeral is approximately six times larger than the national average in Turkey, which is around 76 decares.
- Wheat (40.94%) is the most widely cultivated crop in the agricultural production area. Other important crops, cultivated both as feed and industrial crops, include barley (17.48%), grain corn (16.10%), silage corn (9.54%), sugar beet (7.30%), and alfalfa (7.14%).
- The average age of tractors in the region is 5.5 years, with an average engine power of 79.12 kW. Compared to the national average, tractors in Eskişehir are significantly newer and more powerful. Notably, 75% of the tractor park is between 1 and 5 years old.
- Only 21.70% of the enterprises engage in both crop and livestock production. This rate is below the national average and indicates a need for greater integration of plant and animal farming to support sustainable agriculture.

Abstract

In this research, the agricultural structure, production, and mechanization characteristics of agricultural enterprises in the Eskişehir district of Aksaray province were determined. Data were collected through face-to-face surveys determined with 106 agricultural enterprises, which were selected using a stratified sampling method in the Eskişehir district. As a result of the research, it was determined that the average farming duration was 34.8 years, the average age of the farmers was 45 years, the average number of family members was 4.75, and 44.34% of the farmers were high school graduates, while 5.66% had higher education degrees. It was determined that the enterprises owned an average of 226.93 da of agricultural land, with approximately 459.62 da of land per enterprise used for the production of 2.5 different crop types. In Eskişehir district, 68.87% of the enterprises cultivated wheat, 49.06% cultivated grain maize, 45.08% cultivated barley, 35.85% cultivated silage maize, 22.64% cultivated sugar beet, and 19.81% cultivated alfalfa. The study also found that the number of tractors per enterprise was 1.74, with an average tractor engine power of 137.34 kW per enterprise. The average tractor power was

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79.12 kW, and the average tractor age was 5.5 years. Additionally, there were 6.80 implements and machines per tractor, with an average implement-machine weight of 6.07 tons per tractor. Regarding mechanization density, it was determined that there were 37.76 tractors per 1 000 ha, with each tractor working on 26.48 ha of cultivated land. The number of combine harvesters per 1 000 ha was found to be 0.62.

Keywords: Eskil District; Mechanization Level; Agricultural Mechanization; Agricultural structure

1. Introduction

The rapid increase in the world population is hindering people's access to basic food and causing nutritional problems. According to FAO data, in 2022, 9.2% of the global population, approximately 735 million people, were affected by global hunger (FAO 2023). Agricultural production plays a critical role in food security, economic development, environmental sustainability, and technological advancement. However, the sustainability of current agricultural production systems needs to be re-evaluated in light of the growing global population. Furthermore, in the coming years, agricultural policies must be shaped around sustainability and innovative approaches to ensure long-term resilience and efficiency.

Agricultural mechanization is a scientific discipline that encompasses all activities related to design, manufacturing, development, marketing, agricultural extension, agricultural education, selection, operation, repair and maintenance, and protection of various types of agricultural tools and machines powered by different energy sources and mechanical power. These technologies are essential for developing agricultural areas, conducting all types of agricultural production, and processing agricultural products (Ertekin et al. 2021). Within production technologies, agricultural mechanization holds a distinctive position. It is a crucial and complementary element that enhances the efficiency of other technological applications, ensures economic feasibility, and improves working conditions in the agricultural sector.

The impact of machines used in agriculture on increasing crop yield depends on several factors, including land availability, parcel size, soil structure, climatic conditions, crop pattern, production techniques, the type and capacity of machines used, tractor power, compatibility with agricultural machinery, and skilled labor. These factors can individually or collectively contribute to improving productivity. Additionally, agricultural enterprises must be at a sufficient level in terms of knowledge and optimal input usage to achieve maximum efficiency in agricultural mechanization.

In Turkey, numerous studies have been determined at the province, regional, and national levels to establish agricultural mechanization databases using survey studies and statistical data. Some of the recent studies focusing on agricultural mechanization include; Amasya province (Dertlioğlu and Altuntaş 2023), Şırnak province (Toraman 2023), Tokat province (Gül et al. 2022), Turkey-wide analysis (Aybek et al. 2021), Niğde province (Saygılı and Çakmak 2021), Konya Plain Project Region (Malaslı et al. 2020), Çanakkale province (Özpınar 2020), Karaman province (Kaya and Örs 2020), Çankırı province (Çanakcı and Kaba 2019), Turkey, Thrace Region, Edirne, Kırklareli, and Tekirdağ provinces (Abdikoğlu 2019). These studies assess the agricultural production potential along with the availability of agricultural mechanization tools, determine mechanization levels and challenges, and provide solution-oriented recommendations.

Eskil district is part of Aksaray province, and agriculture and livestock farming play a significant role in the local economy and employment. A review of existing literature revealed that no dedicated research has been determined to identify the agricultural mechanization characteristics specific to the Eskil district. This study aims to fill the existing research gap by evaluating the mechanization structure and agricultural characteristics of the Eskil district, where no such comprehensive study has been determined to date. The findings provide valuable data that can support policy-making, strategic planning, and interregional comparative studies.

2. Materials and Methods

Aksaray is a province located in the Central Anatolia Region of Turkey, partially situated in the Konya Basin and partially in the Cappadocia region. The province consists of 8 districts including the central district,

22 municipalities, 157 neighborhoods within these municipalities, and additionally 175 villages (Anonymous 2023a). Aksaray is bordered by Nevşehir to the east, Niğde to the southeast, Konya to the west, Ankara to the north, and Kırşehir to the northeast. It has a surface area of 7 997 km² (Anonymous 2025a).

Eskil District is located to the south of Lake Tuz, approximately 67 km from Aksaray and 115 km from Konya, and is generally established on a flat plain. It lies along the Aksaray–Konya state highway. It is bordered by Lake Tuz to the north, towns and villages of Konya Province to the west, the Karapınar district of Konya to the south, and towns and villages of Aksaray Province to the east. Eskil experiences a typical continental climate characteristic of the Central Anatolia Region (Anonymous 2023b).

It is one of the largest districts of Aksaray province in terms of agricultural intensity and population. According to the 2022 census, the population of Eskil was recorded as 27 188 people. The district consists of 1 town, 11 villages, and 17 neighborhoods within the central area. Eskil covers a total area of approximately 1 152 km². The total male population is 13 889 and the total female population is 13 299, 51.08% of which is male and 48.92% is female (Anonymous 2025b). The geographical map of Aksaray is shown in Figure 1 (Anonymous 2025c).



Figure 1. Geographical Map of Aksaray Province

Eskil district is the most significant agricultural center in Aksaray province due to its different crop patterns and widespread irrigated farming. For this reason, it was selected as the research area for this study. There is a total agricultural area of 609 660 da in the district, silage and grain corn is produced in 226 414 da, wheat in 168 174 da, barley in 99 393 da, alfalfa in 35 564 da and sunflower in 14 764 da (Anonymous 2023b).

In the research, a sampling method was used in the process of collecting primary data. The population of the study consisted of 3 286 agricultural enterprises registered in the ÇKS (Farmer Registration System) in Eskil district. The sample size was determined using the Simple Random Sampling Method according to the Neyman Method, and the corresponding formula is expressed as follows (Yamane 1967).

$$n = \frac{N_p(1-p)}{(N-1)\sigma_{p_x}^2 + p(1-p)} \quad (1)$$

In the formula;

n : Sample size

N : Number of enterprises in population

$\sigma_{p_x}^2$: Variance of the rate

p : 0.5

The sample size representing the population was determined to be 106 at a 99% confidence level with a 10% margin of error (Çiçek and Erkan 1996). The stratification of agricultural enterprises by land size, along

with the corresponding number of surveys and the number of enterprises allocated to each stratum, is shown in Table 1.

Table 1. The Number of Determined Agricultural Enterprises

Layers	Number of Enterprises	Number of Surveys
I. Layer (0-49 da)	609	2
II. Layer (50-199 da)	1362	18
III. Layer (200-499 da)	925	24
IV. Layer (500 da+)	390	62
Total	3 286	106

The agricultural land sizes have been examined in four layers and classified as follows: the first layer includes areas between 0 and 49 decares, the second layer covers 50 to 199 decares, the third layer ranges from 200 to 499 decares, and the fourth layer consists of 500 decares and above.

Face-to-face surveys were conducted with agricultural enterprises to represent the designated layer. The data obtained was supported by observation techniques. The data obtained were further enriched through direct field observations. The survey explored various aspects including enterprise characteristics, farming structure, land use, production practices, ownership of tractors and other agricultural machinery, and the level of mechanization.

Additionally, within the scope of the survey, the characteristics of the agricultural machinery park were determined, and data from agricultural machinery manufacturers companies were utilized.

The following criteria have been used to determine the mechanization level of enterprises:

- Number of tractors per enterprise (tractors. enterprises⁻¹)
- Tractor engine power per enterprise (kW. enterprise⁻¹)
- Average tractor power (kW. tractor⁻¹)
- Number of implements and machines per tractor (implements and machines. tractor⁻¹)
- Weight of implements and machines per tractor (tons. tractor⁻¹)
- Cultivated land per tractor (ha. tractor⁻¹)
- Tractor engine power per unit area (kW. ha⁻¹)
- Number of tractors per 1 000 ha [tractors (1 000 ha)⁻¹]
- Number of combine harvesters per 1 000 ha [harvesters (1 000 ha)⁻¹]

In the evaluation of the research findings, the Statistical Package for the Social Sciences (SPSS) software was employed to conduct quantitative data analysis. The data obtained from field surveys were systematically coded and entered into the SPSS environment for statistical processing. During the analysis phase, descriptive statistical methods such as frequency distribution, percentage calculations, and arithmetic mean were utilized to summarize and interpret the general characteristics of agricultural enterprises. Furthermore, the chi-square (χ^2) test was applied to examine potential relationships and associations between variables such as education level, number of livestock, and fuel consumption of tractors across different layer. This approach enabled the identification of statistically significant differences or dependencies within the dataset, thereby enhancing the validity and interpretability of the research results.

3. Results and Discussion

3.1. Demographic Characteristics of Farm Owners

In Eskil district, the ages of farm owners range from 20 to 82 years, with an average age of 45 years. It has been determined that, considering all enterprises, 32.08% of farm owners are between the ages of 50 and 60.

In comparison, the average age of farmers in the United States is reported to be 58 years, in Japan 67 years, and in Europe, more than one-third of farmers are over the age of 65 (Anonymous 2024a). In our country, the ages of farmers range from 19 to 90 years, with an average age of 53.4 years. Additionally, the rate of young farmers (under 40 years old) is reported to be 14% (Anonymous 2023d). The relatively low average age of farm owners in Eskişehir district (45 years) and the high proportion of young farmers (32.70%) indicate that agricultural enterprises in the region are managed by a younger generation.

As part of the survey, it was found that the operational duration of agricultural enterprises ranges from 4 to 75 years, with an average farming experience of 34.8 years. In the Harran Plain of Şanlıurfa province, 38% of agricultural enterprises have been engaged in farming for 11 to 20 years (Bozkurt and Aybek 2016), while in Çankırı province, the average farming experience of agricultural enterprises is reported to be 28.6 years (Çanakçı and Kaba 2019). Based on these findings, it can be stated that farmers in Eskişehir district are experienced.

Education level has a significant impact on individuals' behaviors. The educational background of farm owners is shown in Table 2. It was found that 44.34% of farm owners are high school graduates, 33.02% have completed primary education, 16.98% have secondary education, and 5.66% hold a university degree. According to the Chi-square test results, no statistically significant relationship was found between the education levels of farmers and the enterprise layers ($p=0.854$). In comparison, 75% of farm owners in Çankırı province have only a primary education (Çanakçı and Kaba 2018), while in Uşak province, 38.36% of enterprises engaged in black cumin production are primary school graduates (Can 2020). These results suggest that farmers in the surveyed area possess a relatively high level of education, which could facilitate their ability to embrace innovations and apply modern agricultural methods.

Table 2. Educational Background of Farm Owners

Layers	Educational Status of Farm Owners						Total
	Primary Education	Secondary Education	High School	Associate degree	Bachelor's degree	Master's Degree	
I	-	-	2 (100%)	-	-	-	2
II	5 (27.78%)	3 (16.67%)	9 (50%)	-	1 (5.56%)	-	18
III	7 (11.29%)	5 (8.06%)	10 (16.13%)	2 (3.23%)	-	-	24
IV	23 (37.10%)	10 (16.13%)	26 (41.94%)	1 (1.61%)	1 (1.61%)	1 (1.61%)	62
Total	35 (33.02%)	18 (16.98%)	47 (44.34%)	3 (2.83%)	2 (1.89%)	1 (0.94%)	106
$\chi^2=9.42$; SD=15; P-değeri=0.854							

3.2. Number of Family Person

The average number of individuals per enterprise ranges between 2 and 7, with an average of 4.75. Özpınar and Ürkmez (2017) reported that the average number of family members per agricultural enterprise in Çanakkale province is 3.72, while Aydın and Unakıtan (2016) stated that the number of family members per producer in Edirne, Kırklareli, and Tekirdağ provinces is 3.47. Additionally, Kayhan et al. (2017) reported that the average family size in Kırklareli province is 3.56. Turkey, young farmers should be encouraged to contribute to agricultural production, and efforts should be made to increase the number of family members involved in agricultural labor. From this perspective, the fact that the average family size in Eskişehir district is 4.75, which is higher compared to recent research findings, is promising for the future.

3.3. Economic Structure of Enterprises

In Eskişehir district, the total agricultural land owned by enterprises amounts to 24 055 decares, with an average of 226.93 decares per enterprise. In comparison, the average land size in Turkey is 76 decares (Anonymous 2019), while in Çumra district, the average privately owned land per enterprise is 105.33 decares (Keleş and Haciseferoğulları 2016). Based on these to the numbers, it can be stated that the land sizes of enterprises in the research area are above the national average. The rented land area varies between 31 and 1 600 decares, with an average of 229.53 decares per enterprise, and the total rented land is 24 330 decares. It has been determined that all owned and rented agricultural lands are used for irrigated farming. Only one enterprise engages in joint agricultural production on 325 decares, while another enterprise has left 10 decares fallow. The total agricultural land used for farming amounts to 48 720 decares, with an average of approximately 459.62 decares

per enterprise. The size of agricultural lands varies between 32 and 2 000 decares. It has been determined that parcel sizes range between 2 and 600 decares, with the most general parcel size being 200 decares, accounting for 6.30% of all parcels. The average parcel size in Eskişehir district is 133.48 decares. The number of parcels In Turkey, agricultural enterprises with 2 to 5 parcels constitute 57.40% of the total number of enterprises, accounting for 44.18% of the total parcels and 50.76% of the total agricultural land (Kuşlu 2023). Additionally, a significant number of enterprises are reported to own 6 to 9 parcels. Another study determined that the average number of parcels per enterprise in Turkey is 5.9 (Anonymous 2019). Currently, the support policies implemented in Turkey may be insufficient in ensuring the sustainability of small-scale agricultural enterprises. Supporting large agricultural areas and implementing land consolidation projects are crucial in addressing this issue.

3.4. Agricultural production of Eskişehir district

All enterprise included in the survey was actively full in crop cultivation. In addition, 21.70% of these enterprises also carry out livestock activities. A total of 23 enterprises operate in both crop and livestock production. Of these enterprises, just one is involved in the fattening of small ruminants, whereas another specializes in dairy production from small ruminants. Furthermore, 11 enterprises are concerned in cattle fattening, while 10 are involved in cattle dairy farming. One enterprise performs both cattle fattening and dairy production simultaneously. In Turkey, the proportion of enterprises engaged solely in crop production is 64%, while 36% of enterprises carry out both crop and livestock production. The role of mixed (integrated) farming enterprises is emphasized on international platforms, highlighting their contribution to ensuring economic, social, and environmental sustainability in the agricultural sector. Moreover, it is stated that a decrease in the number of mixed farming enterprises may indicate a decline in the agricultural production system (Anonymous 2023d). The cultivated areas for crop production, yield values, and the number of enterprises by layer in the Eskişehir district are shown in Table 3.

Table 3. Status of Crop Production in Agricultural Areas

Crop Type	Production Area (da)	Yield (kg da ⁻¹)	Number of Enterprises by Layer				Total Enterprises
			I	II	III	IV	
Grain Corn	7 843 (16.10%)	1 390.38	1	6	6	35	52 (49.06%)
Silage Corn	4 646 (9.54%)	7 238.94	-	5	4	29	38 (35.85%)
Triticale Silage	20 (0.04%)	4 000.0	-	-	-	1	1 (0.94%)
Sugar Beet	3 557 (7.30%)	10 270.79	-	3	5	16	24 (22.64%)
Barley	8 513 (17.48%)	933.33	-	5	7	36	48 (45.08%)
Wheat	19 940 (40.94%)	867.61	1	15	18	49	83 (68.87%)
Potato	122 (0.25%)	5 000.0	-	-	-	1	1 (0.94%)
Garlic	5 (0.01%)	1 800.0	-	-	-	1	1 (0.94%)
Sunflower (Seed)	471 (0.97%)	441.67	-	1	1	1	3 (2.83%)
Sunflower (Oil)	94 (0.19%)	168.38	-	-	-	2	2 (1.89%)
Alfalfa	3 477 (7.14%)	8 452.38	1	4	4	12	21 (19.81%)
Tomato	5 (0.01%)	7 500.0	-	-	-	1	1 (0.94%)
Black Cumin	17 (0.03%)	90.0	-	-	-	1	1 (0.94%)
Total	48 710 (100%)		2	34	51	165	

The data offer valuable insights into crop preferences, production scale, and mechanization levels among local agricultural enterprises. Survey results revealed that farms grow between 1 and 6 different crops, with an average of 2.5 different crop types per enterprise.

Wheat is the most widely cultivated crop, accounting for 40.94% of the total agricultural land (19 940 da), produced by 83 enterprises (68.87%). The average yield is 867.61 kg da⁻¹.

Barley and grain corn follow wheat in terms of cultivated area, with 8 513 da (17.48%) and 7 843 da (16.10%), respectively. Barley is cultivated by 48 enterprises (45.08%), while grain corn is grown by 52 enterprises (49.06%). These two crops are primarily preferred due to their significance as animal feed and their potential for economic return

Silage corn covers an area of 4 646 da (9.54%) and is notable for yield of 7 238.94 kg da⁻¹. It serves as a key feed crop for enterprises engaged in cattle farming and is predominantly cultivated by enterprises in Layer IV, which comprises farms with large landholdings. This indicates that silage corn cultivation demands higher levels of investment and mechanization.

Sugar beet is different high-yield crop (10 270.79 kg da⁻¹) grown on 3 557 da (7.30%) by 24 enterprises (22.64%), reflecting the district's integration with agro-industrial production chains.

Alfalfa, cultivated on 3 477 da (7.14%), shows a high yield of 8 452.38 kg da⁻¹, indicating its importance in supporting mixed farming systems (crop and livestock production). Its prominence reinforces the coexistence of animal husbandry with plant production in the district.

Crops such as sunflower (seed and oil), potato, garlic, black cumin, and tomato are cultivated in limited areas by a small number of enterprises.

An analysis of enterprise layers reveals that most of the agricultural production is intensive in Layer IV, indicating that large-scale farms dominate the district's agricultural activities. These farms typically cultivate a wider variety of crops and are more actively involved in high-yield, commercially driven production systems.

In Turkey, farmers commonly apply crop rotation practices on different parcels and cultivate an average of 3 to 4 crop types. This diversified crop portfolio is driven by a combination of agricultural, biological, and regulatory factors, such as national production planning policies. Furthermore, this strategy allows farmers to balance income and expense risks, contributing to more sustainable farm management (Anonymous 2023d).

The distribution of cattle numbers is shown in Table 4. The number of cattle by enterprise layer was recorded as 146 in Layer II, 87 in Layer III, and 577 in Layer IV. The number of cattle per enterprise ranged from 12 to 150, with an average of 38.57 cattle among those engaged in cattle farming. The highest concentration of cattle was observed in enterprises within Layer IV, accounting for 22.58% of the total cattle population. However, no statistically significant relationship was found between enterprise layers and the number of cattle ($p=0.198$).

Eleven dairy enterprises produced a combined total of 1 350 tons of milk annually, with individual production ranging from 50 to 240 tons. The average annual milk production per enterprise was calculated as 122.7 tons. Additionally, it was noted that one enterprise owned 20 lambs, while another specialized in lamb fattening with a total of 400 lambs.

Table 4. Distribution of Culture Breed Cattle by Enterprise Layer and Herd Size

Layers	Number of Culture Breed Cattle										Total Enterprises	
	12	20	22	25	30	35	36	40	50	80		150
II	-	-	-	-	1	-	1	-	-	1	-	3 (14.28%)
III	-	2	1	1	-	-	-	-	-	-	-	4 (19.04%)
IV	1	2	-	2	2	1	-	2	3	-	1	14 (66.16%)
Total	1	4	1	3	3	1	1	2	3	1	1	21 (100%)
χ ² =25.083; SD=20; P-değeri=0.198												

$\chi^2=25.083$; SD=20; P-değeri=0.198

3.5. Distribution of tractors by brand and power levels

The survey determined in Eskişehir district identified a total of 184 tractors, with numbers ranging from 1 to 5 per farm. It was determined that 64.2% of the farms had two or more tractors, with an average of 1.74 tractors per farm. In comparative terms, 33.96% of farms in İzmir and only 3.5% in Erzurum are reported to own more than one tractor (Mavişoğlu Çobanoğlu 2019; Baybaş Aksoy 2021). The rate of farms with more than two tractors in the study area is relatively high. The ages of tractors in the tractor park range between 1 and 47 years, with an average tractor age of 5.45 years. It has been reported that the average tractor age in Turkey in 2018 was 24 years (Anonymous 2019; Ertekin et al. 2021). The survey results indicate that the proportion of tractors aged 25 years and older in the Eskişehir district is 2.72%. This suggests that the life of older tractors in Eskişehir is significantly lower than the national average. Considering the average economic lifespan of tractors is 15 years (Sabancı et al. 2003), only 4.35% of tractors in Eskişehir have exceeded their economic lifespan. Another

notable characteristic of the tractor park is that 75.54% of the tractors are in the 1-5 year age range. In Erzurum, the proportion of tractors within this age range has been reported to be 45% (Aksoy et al. 2019).

In the Eskişehir district tractor park, New Holland the great rate with a 44.57% share, followed by Massey Ferguson at 19.02% and Tümosan at 14.13%. John Deere and Erkunt follow with market shares of 5.43% and 4.89%, respectively, as shown in Figure 2. In comparison, the five most preferred tractor brands in Turkey as of August 2024 are New Holland (32.5%), Deutz (12.8%), Case (10.2%), Başak (8%), and Tümosan (7.3%) (Anonymous 2024b).

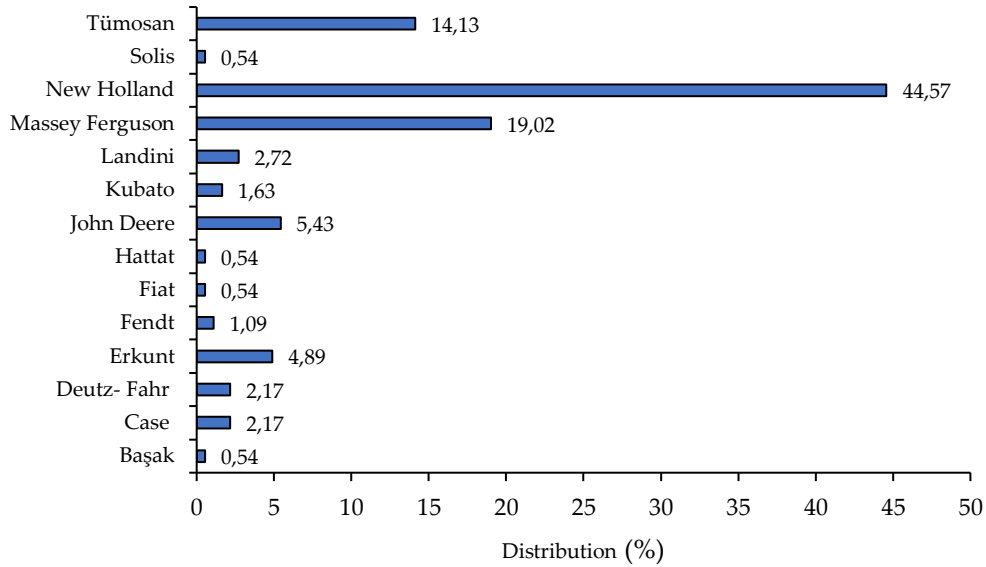


Figure 2. Distribution of Tractors by Brand

In the tractor park, the New Holland TD5.110 Bluemaster and New Holland TT65 models have the highest proportion, each accounting for 8.70%. The Massey Ferguson 5712M model follows with 5.43%, while the New Holland T6.135S accounts for 4.35%. Additionally, the New Holland T5.140 DC makes up 3.80%, and the New Holland TD5.100 Bluemaster represents 2.72% of the park. Following these models, the Massey Ferguson 5710M, Massey Ferguson 6S.135, New Holland TT75, and Tümosan 7065 tractors each hold a 2.17% share (Table 5). It has been determined that the tractors in the park belong to 68 different power groups, with power ratings ranging from 24.60 kW to 234.70 kW. The average tractor power in the park is 79.12 kW. Considering that the average tractor power in Turkey is 56.9 kW (Anonymous 2023c), it can be concluded that the average power value of tractors in the Eskişehir district is relatively high. Additionally, the total power value of the tractor park in Eskişehir has been calculated as 14 557.61 kW.

The distribution of tractors in the Eskişehir district by power groups is shown in Figure 3. The highest distribution is in the 70-79 kW power range, accounting for 17.65% of the park. This is followed by the 40-49 kW power range with 13.24%, and the 50-59 kW power range with 11.76%. The lowest proportions, at 1.47%, are observed in the 24.6-29 kW, 30-39 kW, 140-149 kW, 150-159 kW, 170-179 kW, and 234 kW+ power ranges. In Turkey, the largest tractor power range in the national park is reported to be 70-79 HP (52-60 kW), accounting for 20.6% of all tractors (Anonymous 2023c). However, in Eskişehir, the corresponding power range has been recorded at 10.39%, indicating a lower proportion compared to the national level.

The survey determined among the examined enterprises identified a total of three combine harvesters. Among them, one is in the third layer accounting for 4.17%, while two are in the fourth layer, making up 3.22%. Overall, 2.83% of the enterprises own a combine harvester. The combine harvesters in these enterprises include one 2015 model Fendt 5225 E and two 2013 model John Deere W540 machines.

Table 5. Distribution of Tractors by Brand and Engine Power

Tractor Brand	Number	Percentage (%)	Power (kW)	Total Power (kW)
Başak 2060	1	0.54	43.21	43.21
Case IH Puma 185 CVX	1	0.54	137.8	137.83
Case IH JX55E	1	0.54	41.0	40.98
Case IH JX75B	1	0.54	55.9	55.88
Case IH JX90	1	0.54	65.6	65.56
Deutz- Fahr 4100EF	1	0.54	76.0	75.99
Deutz-Fahr 5110G	1	0.54	82.0	81.95
Deutz-Fahr 6125C	1	0.54	93.1	93.13
Deutz-Fahr 6155.4	1	0.54	116.2	116.22
Erkunt Bereket 60E	1	0.54	44.7	44.70
Erkunt Bereket 65E	3	1.63	48.4	145.28
Erkunt Bereket 65M	2	1.09	50.7	101.32
Erkunt Haşmet 100 Lüks	1	0.54	74.5	74.50
Erkunt Haşmet 110 Lüks	1	0.54	82.0	81.95
Erkunt Haşmet 125 Lüks	1	0.54	93.1	93.13
Erkunt Kudret 105E+	1	0.54	76.0	75.99
Fendt 200 Vario	1	0.54	74.5	74.50
Fendt 500 Vario	1	0.54	107.3	107.28
Fiat 6056	1	0.54	41.7	41.72
Hattat 3055 DT	2	1.09	78.2	156.45
John Deere 5075E	1	0.54	122.9	122.93
John Deere 5105M	3	1.63	78.2	234.68
John Deere 6115MC	2	1.09	90.1	180.29
John Deere 6125R	1	0.54	160.2	160.18
John Deere 6155R	1	0.54	111.8	111.75
John Deere 6215R	1	0.54	160.2	160.18
John Deere 6310	1	0.54	82.0	81.95
Kubato M 7040	1	0.54	52.2	52.15
Kubato M 8540	1	0.54	63.3	63.33
Kubato M 9540	3	1.63	73.0	219.03
Landini Mistral 55	1	0.54	41.0	40.98
Massey Ferguson 135S	1	0.54	24.6	24.59
Massey Ferguson 240S	2	1.09	36.5	73.01
Massey Ferguson 2635	1	0.54	55.9	55.88
Massey Ferguson 288G	2	1.09	67.1	134.10
Massey Ferguson 3WF.85	1	0.54	63.3	63.33
Massey Ferguson 5710M	4	2.17	74.5	298.00
Massey Ferguson 5711M	2	1.09	82.0	163.90
Massey Ferguson 5712M	10	5.43	89.4	894.00
Massey Ferguson 5S.115	1	0.54	85.7	85.68
Massey Ferguson 5S.125	1	0.54	93.1	93.13
Massey Ferguson 6S.135	4	2.17	100.6	402.30
Massey Ferguson 7620	1	0.54	149.0	149.00
Massey Ferguson 7716S	1	0.54	119.2	119.20
Massey Ferguson 7S.165	2	1.09	122.9	245.85
Massey Ferguson 7S.180	1	0.54	134.1	134.10
Massey Ferguson 7S.210	1	0.54	156.5	156.45
New Holland 75-565	1	0.54	55.9	55.88
New Holland TD5.100 BLM	5	2.72	74.5	372.50
New Holland TD5.110 BLM	16	8.70	82.0	1311.20
New Holland T5.120	1	0.54	89.4	89.40
New Holland T5.140 DC	7	3.80	104.3	730.10
New Holland T5060	1	0.54	79.0	78.97
New Holland TR6.135S	8	4.35	100.6	804.8
New Holland T7.230 AutoCommand	1	0.54	171.4	171.35
New Holland T7.165S	1	0.54	122.9	122.93
New Holland T7.315 HD AC	1	0.54	234.7	234.68
New Holland TR6.135S	8	4.35	100.6	804.60
New Holland TT55	5	2.72	41.0	204.88
New Holland TT65	16	8.70	48.4	774.80
New Holland TT75	4	2.17	55.9	223.50
New Holland TD90	7	3.80	67.1	469.35
Solis S90	1	0.54	67.1	67.05
Tümosan 7065	4	2.17	48.4	193.70
Tümosan 7075	3	1.63	55.9	167.63
Tümosan 8005	16	8.70	78.2	1251.60
Tümosan 8095	2	1.09	70.8	141.55
Tümosan 8180	1	0.54	59.6	59.60
Total	184	100	-	14 557.61

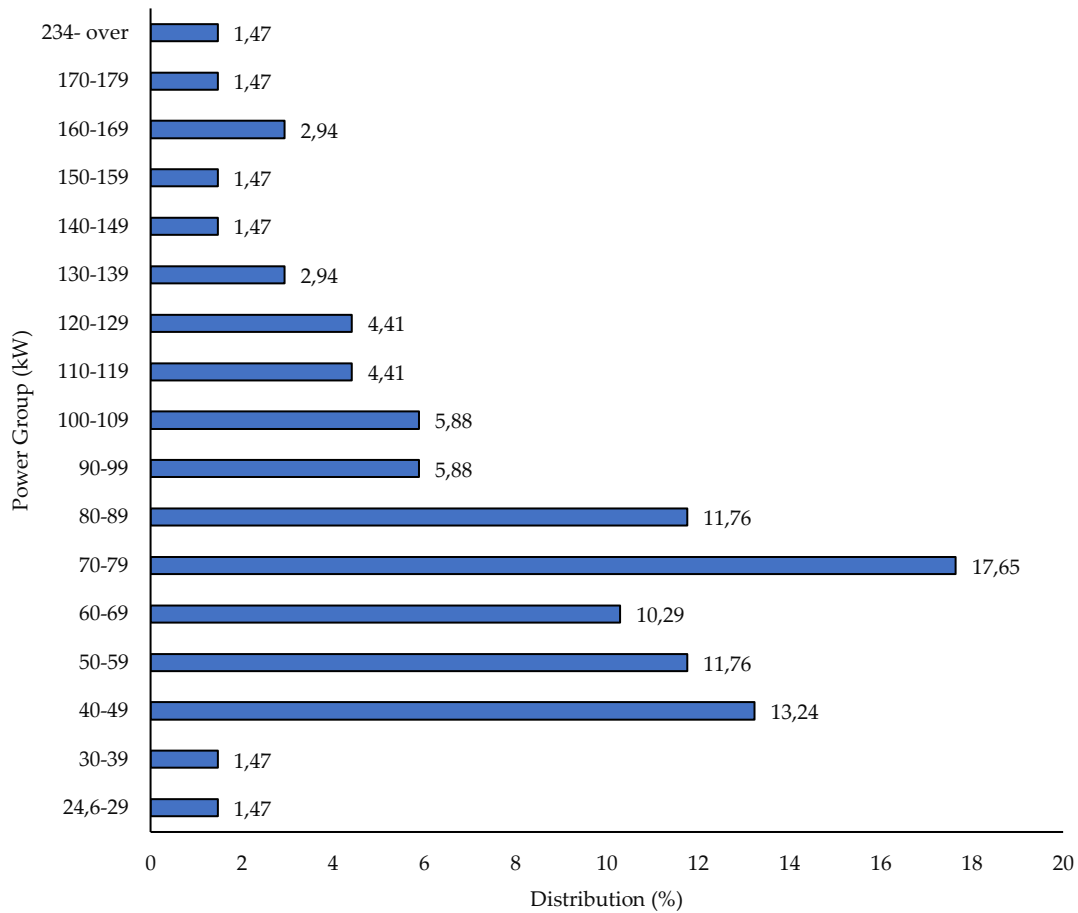


Figure 3. Distribution of Tractors by Power Groups

3.6. Annual Fuel Consumption

The annual fuel consumption values of agricultural enterprises are shown in Figure 4. When analyzing these values, it was observed that 8.5% of enterprises consume between 2 000 and 10 000 liters of fuel annually. According to the survey results, the annual fuel consumption of agricultural enterprises ranges from 350 liters to 39 000 liters, with a total fuel consumption of 851 750 liters. The average annual fuel consumption per enterprise was calculated as 8 035.38 liters. Based on the data evaluation, the fuel consumption per tractor was calculated as 4 629.08 liters per tractor, and the fuel consumption per cultivated area was determined as 174.82 liters per hectare. In comparison, a study reported by Keleş and Haciseferoğulları (2016) in Çumra district of Konya found that the fuel consumption per tractor was 3 163.2 liters per tractor, and the fuel consumption per cultivated area was 220 liters per hectare. These findings indicate that while the fuel consumption per tractor in Eskişehir is higher than in Çumra, the fuel consumption per hectare is lower.

Table 6 shows the annual fuel consumption values of agricultural enterprises based on different layer. The average annual fuel consumption values for each layer were determined as 850 L, 32,200 L, 107,800 L, and 714,500 L, respectively. A statistically significant difference was found among the total annual fuel consumption values across the different layer ($p < 0.01$). The average fuel consumption per enterprise in each layer was calculated as 425 L, 1 788.9 L, 4,491.7 L, and 11 524.2 L, respectively. The increase in total and per-enterprise average fuel consumption values across the layer is attributed to larger land sizes and greater production diversity.

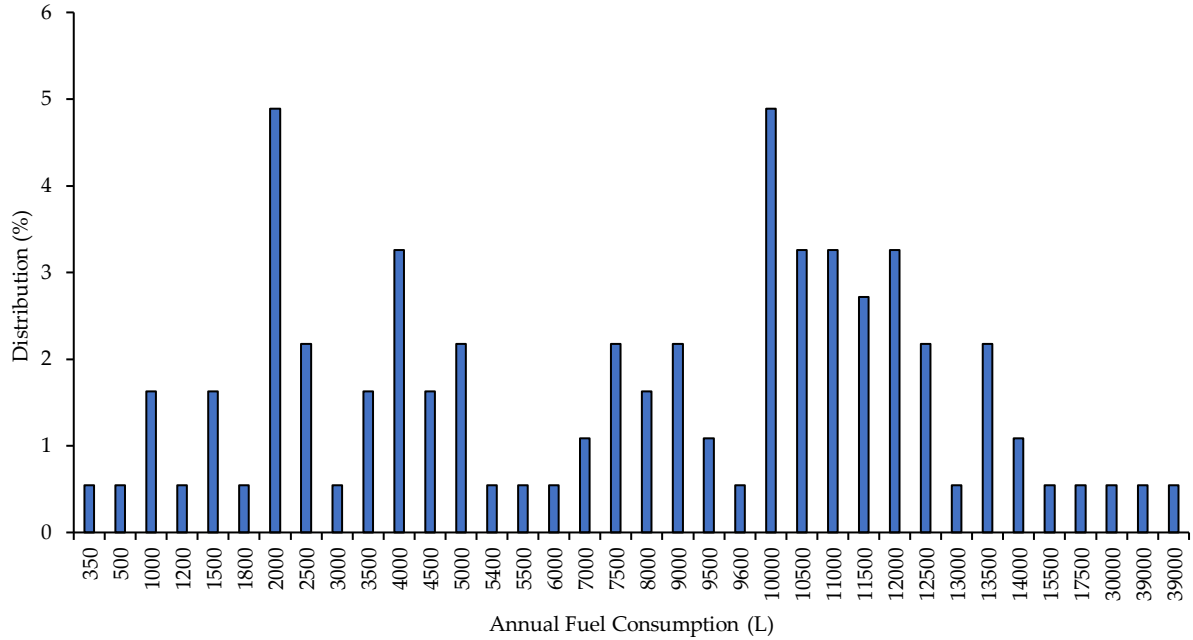


Figure 4. Annual Fuel Consumption of Agricultural Enterprises (L)

Table 6. Annual Fuel Consumption of Tractors

Layers	Annual Fuel Consumption		
	Total (L)	Average L (enterprises) ⁻¹	Total
I	850	425	2
II	32 200	1 788.9	18
III	107 800	4 491.7	24
IV	714 500	11 524.2	62
Total	851750	-	106

$\chi^2 = 298.546$; SD=102; P-değeri=0.000

3.7. Agricultural Machinery Park in Eski District

The number and types of agricultural tools and machinery in agricultural enterprises and the average number of machines per farm and per tractor in Eski district are shown in Table 7.

All machines belong to farmers and there are a total of 1 603 agricultural machines in the district. The machinery in the district is distributed as follows: 20.09% are deep well pumps, 11.23% are farm carts, 8.61% are plows, 7.36% are sprayers, 6.74% are combined drill/fertilizer mashine, and 6.30% are centrifugal broadcasters. Additionally, 5.99% of the machines are pneumatic precision drill, 4.30% are rollers, 4.00% are cultivator and cultivator rotary harrow combinations, and 3.87% are horizontal-vertical axis rotary tillers. Other machinery includes 2.18% corn forage harvesters, 1.75% rear loaders, 1.25% water tanker trailers and Feed Mixing Wagons, and 1.12% hay rakes. These represent the most commonly used types of agricultural machinery in the district.

The number of machines per tractor in Eski district is as follows: trailer rank first with 0.98 units per tractor, followed by moldboard plows with 0.75 units, sprayers with 0.64 units, combined seed drills with 0.59 units, fertilizer broadcaster with 0.55 units, pneumatic precision seeders with 0.52 units, and rollers with 0.38 units. For comparison, in the Central Anatolia Region, the number of machines per tractor has been reported as 0.98 for trailer, 0.36 for sprayers, 0.37 for combined seed drill, and 0.25 for Centrifugal broadcasters (Ünsal 2021). These findings indicate that the number of machines per tractor in Eski district is relatively high.

Table 7. Total Number and Weight of Machines in Agricultural Enterprises, and Number of Machines per Enterprise and Tractor

Agricultural Tools and Machines	Layers / Number Machines				Total Number	Machine (Tractor) ¹	Machine (Enterprise) ⁻¹	Total Weight
	I	II	III	IV				
Moldboard Plow	2	18	26	92	138	0.75	1.30	131 760
Disc Plow	-	-	-	6	6	0.03	0.06	3 360
Subsoiler	-	-	6	26	32	0.18	0.30	16 327
Toothed Harrow	-	2	1	10	13	0.07	0.12	4 300
Disc Harrow	-	2	3	11	16	0.09	0.15	25 580
Centrifugal broadcasters	2	16	21	62	101	0.55	0.95	22 085
Rotary and Toot Harrow Combined Soil Preparation Machine	-	1	4	12	17	0.09	0.16	11 600
Combined drill/fertilizer machine	1	15	23	69	108	0.59	1.02	125 018
Sprayer	2	16	23	77	118	0.64	1.11	35 905
Cultivator and Cultivator + Rotary Harrow	-	8	16	40	64	0.35	0.60	59 996
Roller	-	5	14	50	69	0.38	0.65	46 190
Corn Forage Machine	-	5	5	25	35	0.19	0.33	39 700
Grass Silage Machine	-	-	1	6	7	0.04	0.07	4 340
Pneumatic spacing drills	1	16	12	67	96	0.52	0.91	101 185
Rotary cultivators with vertical axes	-	7	6	22	35	0.19	0.33	55 553
Rotary cultivators with horizontal axes	-	1	3	23	27	0.15	0.25	18 210
Straw Collecting Baler	-	1	-	-	1	0.005	0.009	1 590
Threshing Machine	-	-	-	1	1	0.005	0.009	1 500
Water tanker trailer	2	-	-	18	20	0.11	0.19	20 640
Trailer	2	18	34	126	180	0.98	1.70	330 150
Drum mowers	-	6	7	18	31	0.16	0.29	9 300
Disc movers	-	-	1	15	16	0.09	0.15	8 230
Bale collecting and stacking trailers	-	-	-	1	1	0.005	0.009	500
Feed Mixing Wagons	-	2	4	14	20	0.11	0.19	32 370
Rear loader	-	2	7	19	28	0.15	0.26	16 800
Reciprocating cutter bar	-	-	1	1	2	0.01	0.02	480
Pick-up balers	-	-	-	8	8	0.04	0.08	12 410
Fertilized Interrow Cultivato	-	1	8	16	25	0.14	0.24	29 018
Non-Fertilized Interrow Cultivator	-	-	1	-	1	0.005	0.009	700
Straw Chopper	-	-	1	-	1	0.005	0.009	750
Complete sugar beet harvester with hopper	-	-	1	6	7	0.04	0.07	23 700
Hay Rake	-	-	2	16	18	0.10	0.17	8 120
Heavy Disc Harrow	-	-	-	4	4	0.02	0.04	6 900
Feed Grinder*	-	-	-	9	9	0.05	0.08	2 600
Manure spreaders	-	-	-	3	3	0.02	0.03	12 140
Land Leveler Blade	-	-	-	4	4	0.02	0.04	850
Portable Milking Machine*	-	5	1	11	17	-	0.16	-
Milking systems design as a milking parlour	-	-	-	2	2	-	0.02	-
Deer well Pump*	-	30	58	234	322	-	3.03	-

* It has not been included in the number of machines per tractor in the calculations

In Eskil district, the survey results indicate that moldboard plows and traditional tillage systems are widely used due to the prevalence of grain production. As a result, the machinery number per enterprise is relatively high, with 1.30 moldboard plows, 1.02 Combined drill/fertilizer machine, 1.11 sprayers, 0.95 centrifugal fertilizer broadcaster, and 0.65 rollers per enterprise. In addition to traditional tillage, conservation tillage methods are also practiced in the region. It was determined that there are 0.33 vertical axis rotary tillers and 0.25 horizontal axis rotary tillers per enterprise, with a total of 62 units recorded in the district. For comparison, a study determined in Izmir found that the highest number of machines per enterprise were 0.81 trailers, 0.67 plows, 0.51 disc harrows, 0.47 cultivators, 0.34 sprayers, and 0.33 Centrifugal broadcasters (Mavioğlu and Çobanoğlu 2019).

The survey results indicate that each enterprise has an average of 3.03 deep well pumps, highlighting the intensive use of irrigation in the region. In addition, 21.70% of agricultural enterprises engage in both crop production and animal farming. As a result, these enterprises produce part of their feed needs, while some sell excess feed as an additional source of income. As a result, the number of forage-related machines per enterprise in the district has been determined as follows: 0.32 corn forage harvester, 0.29 drum mowers, 0.25 disc mowers, 0.17 hay rakes, and 0.19 feed mixing wagons. Additionally, based on the crop pattern of the district, there is an average of 0.17 sugar beet harvesters per enterprise. Excluding electrically powered

machines from the calculation, the number of machines per tractor was determined to be 6.80, while the number of tools and machines per enterprise was calculated as 15.12.

The status of the machines in terms of being new or second-hand and whether they are domestic manufactured or imported is shown in Table 8.

Table 8. Number and Percentage Distribution of Agricultural Tools and Machines by Situation and Origin

Agricultural Tools and Machines	New	Distribution (%)	Second-Hand	Distribution (%)	Domestic Production	Distribution (%)	Imported	Distribution (%)
Moldboard Plow	92	66.67	46	33.33	138	100	-	-
Disc Plow	4	66.67	2	33.33	6	100	-	-
Subsoiler	11	34.38	21	65.63	32	100	-	-
Toothed Harrow	5	38.46	8	61.54	13	100	-	-
Disc Harrow	3	18.75	13	81.25	15	93.75	1	6.25
Centrifugal broadcasters	56	55.45	45	44.55	101	100	-	-
Rotary and Toot Harrow Combined Soil Preparation Machine	7	41.18	10	58.82	17	100	-	-
Combined drill/fertilizer machine	88	81.48	20	18.52	106	98.15	2	1.85
Sprayer	76	64.41	42	35.59	115	97.46	3	2.54
Cultivator and Cultivator + Rotary Harrow	25	39.06	39	60.94	63	98.44	1	1.56
Roller	28	40.58	41	59.42	68	98.55	1	1.45
Corn Forage Machine	17	48.57	18	51.43	34	97.14	1	2.86
Grass Silage Machine	3	42.86	4	57.14	7	100	-	-
Pneumatic spacing drills	78	81.25	18	18.75	82	85.42	14	14.58
Rotary cultivators with vertical axes	20	74.07	7	25.93	27	100	-	-
Rotary cultivators with horizontal axes	25	71.43	10	28.57	30	85.71	5	14.29
Straw Collecting Baler	-	-	1	100	1	100	-	-
Threshing Machine	-	-	1	100	1	100	-	-
Water tanker trailer	4	20.00	16	80.00	20	100	-	-
Trailer	150	83.33	30	16.67	180	100	-	-
Drum mowers	18	58.06	13	41.94	31	100	-	-
Disc movers	13	81.25	3	18.75	16	100	-	-
Bale collecting and stacking trailers	1	100	-	-	1	100	-	-
Feed Mixing Wagons	20	100	-	-	20	100	-	-
Rear loader	22	78.57	6	21.43	28	100	-	-
Reciprocating cutter bar	2	100	-	-	2	100	-	-
Pick-up balers	8	100	-	0.00	8	100	-	-
Fertilized Interrow Cultivato	18	72.00	7	28.00	25	100	-	-
Non-Fertilized Interrow Cultivator	-	-	1	100	1	100	-	-
Straw Chopper	1	100	-	-	-	-	1	100
Complete sugar beet harvester with hopper	7	100	-	-	6	85.71	1	14.29
Hay Rake	11	61.11	7	38.89	18	100	-	-
Heavy Disc Harrow	3	75.00	1	25.00	4	100	-	-
Feed Grinder*	7	77.78	2	22.22	9	100	-	-
Manure spreaders	3	100	-	-	3	100	-	-
Land Leveler Blade	4	100	-	-	4	100	-	-
Portable Milking Machine*	17	100	-	-	16	94.12	1	5.88
Milking systems design as a milking parlour	322	100	-	-	322	100	-	-

In general, most machines, except those used for seedbed preparation, are purchased as new. Among tillage tools and machines, 81.25% of disc harrows, 65.63% of subsoilers, 61.54% of toothed harrows, 60.94% of cultivators and cultivator-rotary harrow combinations, 59.42% of rollers, and 58.82% of rotary and toodle combined harrow machines were found to be acquired second-hand. Additionally, 51.43% of corn forage harvesters, 41.94% of drum mowers, and 38.89% of hay rakes were found to be acquired as second-hand equipment. It has been determined that 14.58% of pneumatic precision drills, 14.29% of vertical-axis rotary tillers and sugar beet harvesters, 6.25% of disc harrows, and the single stalk chopper machine in the park are imported.

3.8. Level of Agricultural Mechanization

The mechanization values calculated using data obtained from the surveyed enterprises in Eskişehir district are shown in Table 9. Upon examining Table 9, it is observed that the agricultural land per enterprise is 459.62 da, the number of parcels is 3.44, and the average parcel size is 133.48 da. Although these values are higher than the national averages, the fragmented land ownership model is also evident in Eskişehir district. It is a fact that this situation has negative consequences on agricultural management and productivity.

The average age of tractors was determined to be 5.5 years, indicating that the tractor park in the region is relatively modern. On average, there are 1.74 tractors per enterprise, and the average engine power per tractor was calculated as 79.12 kW. The total tractor power per enterprise amounted to 137.34 kW, while the tractor power per unit of cultivated land was determined as 2.99 kW ha⁻¹.

Enterprises possessed an average of 15.12 implements and machines, while the number of implements per tractor was 6.80. The average implement-machine weight per tractor was found to be 6.07 tons, suggesting a preference for high-capacity equipment.

Table 9. Agricultural Mechanization Level Indicators of Eskişehir District

Level of Mechanization	Value
Number of enterprises	106
Agricultural land per enterprise (area (da)·enterprise ⁻¹)	459.62
Number of parcels per enterprise	3.44
Average parcel size (da)	133.48
Number of tractors	184
Average tractor age (years)	5.5
Average tractor power (kW)	79.12
Number of tractors per enterprise (tractor·enterprise ⁻¹)	1.74
Number of and machines per enterprise (machine·enterprise ⁻¹)	15.12*
Power per enterprise (kW·enterprise ⁻¹)	137.34
Tractor power per cultivated area (kW·ha ⁻¹)	2.99
Number of machines per tractor (machine·tractor ⁻¹)	6.80**
Cultivated area per tractor (ha·tractor ⁻¹)	26.48
Machine Weight per tractor (ton·tractor ⁻¹)	6.07**
Number of tractors per 1 000 ha of cultivated land	37.76
Number of combine harvesters per 1 000 ha of cultivated land	0.62

According to the Turkey Agricultural Machinery Sector Report, the average tractor power is reported as 40.2 kW, while the average tractor age is 24.4 years. Additionally, the number of tractors per 1 000 hectares is 52.5, the agricultural land per tractor is 19 hectares, and the tractor power per hectare is 2.1 kW (Anonymous 2019). When these values are compared with those obtained in Eskişehir district, it is observed that the average tractor age is approximately 4.5 times lower, the average tractor power is 2.1 times higher, the number of tractors per 1 000 hectares is lower, and the tractor power per hectare is higher.

In the Central Anatolia Region, the agricultural mechanization levels for the provinces of Kayseri, Kırşehir, Nevşehir, Niğde, Sivas, Yozgat, Aksaray, and Kırıkkale have been determined as follows: the average tractor power is 40.38 kW, the tractor power per unit agricultural area is 2.18 kW ha⁻¹, the number of tractors per 1 000 hectares is 53.90, the cultivated area per tractor is 18.55 hectares, and the number of combine harvesters per 1 000 hectares is 1.34 (Sağlam and Kuş 2016).

When comparing Eskişehir district with the Central Anatolia Region, it can be observed that Eskişehir has higher values for average tractor power, agricultural land per tractor, and the number of agricultural machines per tractor. However, the number of tractors per 1 000 hectares and the number of combined harvesters per 1 000 hectares are lower in Eskişehir. Additionally, according to Anonymous (2015), the number of implements and machines per tractor in Turkey is reported as 5.2 number, with an average machine weight of 4.2 tons. In Çumra district, these values are 13.54 number and 10.77 tons, respectively (Keleş and Haciseferoğulları 2016). For Konya province, the reported values are 7.05 number and 5.57 tons (Oğuz et al. 2017).

4. Conclusions

This study aimed to determine the mechanization level of the Eskişehir district and to establish a baseline to support future agricultural investment planning. The collected data should be updated periodically to effectively evaluate agricultural production and contribute to the development of the local economy. The research was conducted during the post-COVID-19 recovery period, a time when Turkey's agricultural markets showed signs of economic optimism. Following the year 2020, the agricultural sector in Turkey experienced relatively favorable economic conditions. Several factors—such as high market prices for agricultural products, cash-based payment systems, improved access to credit, low interest rates, and advantageous exchange rates—contributed to enhanced financial stability among farmers. These positive trends were reflected in the agricultural machinery and tractor park of Eskişehir. The low average age of the tractors and the relatively high engine power indicate a modern tractor park. Favorable exchange rates particularly encouraged the purchase of imported tractors with engine powers exceeding 100 kW, increasing their prevalence within the region's machinery park. Although Turkey's agricultural machinery park is commonly considered old (Evcim et al. 2015), for PTO-driven equipment, working hours are often more relevant than age. Therefore, further research is needed on both machinery age and usage value to obtain a more accurate assessment. The survey also revealed a very low number of manure spreaders per farm or per tractor, underscoring the need to promote manure use and offer relevant farmer training programs. In the region, irrigation is commonly carried out using deep-well pumps. Given the impact of energy costs, motor power, and operational duration, improving pump efficiency could lead to significant water savings and reduced operating expenses. Promoting the adoption of modern irrigation systems could further enhance water resource management and support sustainable agricultural planning.

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References

- Abdikoğlu Dİ (2019). Trakya bölgesinde tarımsal mekanizasyon düzeyinin illere göre belirlenmesi. *Kahramanmaraş Sütçü İmam Üniversitesi Tarım ve Doğa Dergisi* 22(6), 865-871.
- Aksoy A, Demir N, Demir O (2019). An analysis on determinants of farmers' tractor purchasing behavior in Erzurum Province. *Atatürk Univ., J. of the Agricultural Faculty* 50(1), 75-83.
- Anonymous (2019). Türkiye Tarım Makinaları Sektörü Raporu. Derleyen Selami İleri.
- Anonymous (2023a). Aksaray İl Tarım ve Orman Müdürlüğü Verileri.
- Anonymous (2023b). T.C. Eskişehir Kaymakamlığı. <http://www.eskil.gov.tr/cografi-yapi> (access date: 15.11.2024).
- Anonymous (2023c). Tarım Makine Sanayi Etkileşimi Raporu. Türk Tarım Alet ve Makineleri İmalatçıları Birliği.
- Anonymous (2023d). Türkiye tarımsal görünüm saha araştırması, KKB (Kredi Kayıt Bürosu) <https://www.kkb.com.tr/Resources/ContentFile/Tarimsal-gorunum-saha-arastirma-raporu2023.pdf> (access date: 11.03.2025).
- Anonymous (2024a). Scispace. What is the average age of a global farmer? <https://typeset.io/questions/what-is-the-average-age-of-a-global-farmer-sqwy6pcsl1>: (access date: 11.12.2024).
- Anonymous (2024b). Türk Tarım Makinaları Endüstrisi Aylık Traktör İstatistikleri Raporu. Dönem Eylül 2024.

- Anonymous (2025a). Aksaray İl Kültür ve Turizm Müdürlüğü <https://aksaray.ktb.gov.tr/TR-63622/cografya.html> (access date: 15.01.2025).
- Anonymous (2025b). <https://www.nufusune.com/eskil-ilce-nufusu-aksaray> (access date: 15.01.2025).
- Anonymous (2025c). https://tr.wikipedia.org/wiki/Dosya:Aksaray_%C4%B0l_Haritas%C4%B1.jpg (access date: 15.01.2025).
- Aybek A, Kuzu H, Karadöl H (2021). Türkiye'nin ve tarım bölgelerinin tarımsal mekanizasyon düzeyindeki değişimlerin son on yıl (2010-2019) ve gelecek yıllar (2020-2030) için değerlendirilmesi. *Kahramanmaraş Sütçü İmam Üniversitesi Tarım ve Doğa Dergisi* 24(2), 319-336.
- Aydın B, Unakıtan G (2016). Trakya bölgesinde faaliyet gösteren tarım işletmelerinin yapısal özellikleri ve tarımsal uygulamalara yaklaşımları. *Tarım Ekonomisi Araştırmaları Dergisi* 2(2), 11-25.
- Baybas S, Aksoy A (2021). Determination of Factors Affecting Tractor Brand Preference Farmer of Erzurum Province. *Turkish Journal of Agricultural Engineering Research* 2 (2): 376-389.
- Bozkurt M, Aybek A (2016). Şanlıurfa ili harran ovasının tarımsal yapı ve mekanizasyon özellikleri. *KSÜ Doğa Bilimleri Dergisi* 19(3), 319-331.
- Can M (2020). Çörek otu tarımında üretici davranışlarının belirlenmesi, sorunlar ve çözümler: Uşak ili örneği. *Ziraat Mühendisliği* 370, 18-33.
- Çanakçı M, Kaba H (2019). Çankırı ili tarım işletmelerinin tarımsal yapı, üretim ve mekanizasyon özelliklerinin belirlenmesi. *Mediterranean Agricultural Sciences* 32(2), 185-192.
- Çiçek A, Erkan O (1996). Tarım Ekonomisinde Araştırma ve Örneklem Yöntemleri. Gaziosmanpaşa Üniversitesi Ziraat Fakültesi Yayınları No:12, Ders Notları Serisi No:6, Tokat.
- Dertlioğlu U, Altuntaş E (2023). Amasya ilinin tarımsal makinalaşma düzeyinin 2016-2021 yılları arasındaki değişiminin incelenmesi. *Tarım Makinaları Bilimi Dergisi* 19(1), 36-52.
- Ertekin C, Akman HE, Boyar İ (2021). Türkiye'de tarımsal mekanizasyona bir bakış. *Yuzuncu Yıl University Journal of Agricultural Sciences* 31(3), 786-798.
- FAO (2023). Statistical Yearbook. <file:///C:/Users/SAMSUNG/Downloads/cc8166en.pdf> (access date: 26.02.2025).
- Gül EN, Özgöz E, Altuntaş E (2022). Tokat ilinin tarımsal mekanizasyon düzeyi, toprak işleme alet ve makinaları ve ekim makinaları projeksiyonu. *Gaziosmanpaşa Bilimsel Araştırma Dergisi* 11(2), 12-24.
- Işık A, Atun İ (1998). Şanlıurfa-Harran Ovasında Tarımsal Yapı ve Mekanizasyon Özellikleri. *Turkish Journal of Agriculture and Forestry* 22, 151-160.
- Kaya E, Örs A (2020). Evaluation of agricultural mechanization level of Karaman province. *Turkish Journal of Agriculture-Food Science and Technology* 8(1), 260-265.
- Kayhan İ, Aydın B, Baran MF (2017). Kırklareli ili tarım işletmelerinin tarımsal yapısı ve mekanizasyon düzeyi. *Türk Tarım ve Doğa Bilimleri Dergisi* 4(3), 263-270.
- Keleş İ, Haciseferoğulları, H (2016). Determination of Agricultural Structure and Mechanization Levels of Agricultural Enterprises Located in Cumra district of Konya Province. *Selcuk Journal of Agriculture and Food Sciences* 3(1), 48-58.
- Kuşlu Y (2023). Technical Analysis of the General Structure of Agricultural Lands and Rural Population Situation in Turkey. In: de Souza, GHS (Eds), *An Overview on Business, Management and Economics Research* Vol. 6, Federal Institute of The North of Minas Gerais, Brazil BP International.
- Malaslı MZ, Palta Ç, Argon ZÜ (2020). Agricultural mechanization properties of KOP Region. *Turkish Journal of Agriculture - Food Science and Technology* 8(4), 826-82.

- Mavioğlu MN, Çobanoğlu F (2019). İzmir yöresindeki üreticilerin mekanizasyon düzeylerinin belirlenmesi üzerine bir araştırma. *Adnan Menderes Üniversitesi Ziraat Fakültesi Dergisi* 16(1), 19-26.
- Oğuz C, Bayramoğlu Z, Ağızhan S, Ağızhan K (2017). Tarım İşletmelerinde Tarımsal Mekanizasyon Kullanım Düzeyi, Konya İli Örneği. *Selcuk Journal of Agriculture and Food Sciences* 31(1), 63-72.
- Özpınar S, Ürkmez Ü (2017). Determination of Structural Properties of Agriculture in Çanakkale. *Journal of Tekirdag Agricultural Faculty* 14 (1), 103-113.
- Özpınar S (2020). Mechanization and agricultural farm structure in the agricultural area of the Dardanelles region. *International Journal of Agriculture Environment and Food Sciences* 4(1), 39-56.
- Sabancı A, Sumer SK, Say SM, Has M (2003). Türkiye'de ekonomik traktör parkı ve gelişimi. In: *Tarımsal Mekanizasyon 21. Ulusal Kongresi*, Konya, 125-131.
- Sağlam C, Kuş ZA (2016). Orta Anadolu Bölgesi illerinde tarımsal mekanizasyon düzeyinin yıllara göre değişimi. *Nevşehir Bilim ve Teknoloji Dergisi* 5, 364-371.
- Saygılı YS, Çakmak B (2021). Niğde ilinin tarımsal mekanizasyon düzeyinin incelenmesi. *Bursa Uludağ Üniversitesi Ziraat Fakültesi Dergisi* 35(2), 389-413.
- Toraman MC (2023). Şırnak İli ve İlçelerinin Tarımsal Mekanizasyon Düzeyi, *Turkish Journal of Agriculture-Food Science and Technology* 11 (9), 1628-1638.
- Ünsal Y (2021). Türkiye'de Tarımsal Mekanizasyon Düzeyi, Sorunları ve Çözüm Önerileri. Tarımsal Ekonomi ve Politika Geliştirme Enstitüsü Müdürlüğü, TEPGE Yayın No 346.
- Yamane T (1967). Elementary Sampling Theory. Prentice-Hall, Inc., Englewood Cliffs.



Investigation of Medium-Scale Enterprises Manufacturing Agricultural Machinery in Konya Province in Terms of Occupational Health and Safety

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HIGHLIGHTS

- Five medium-sized factories were visited, and the Fine-Kinney Risk Analysis Method was applied to assess occupational hazards based on probability, severity, and exposure.
- Identified risks per factory were A (117), B (96), C (102), D (91), and E (104). All were assessed across 15 hazard categories and classified as "Hazardous," indicating significant occupational safety concerns.
- Enterprises' ability to foresee and manage risks enhances emergency preparedness, protects employee health and safety, and supports long-term sustainability and efficiency.

Abstract

The agricultural machinery manufacturing sector is an area where agriculture and integration develop together and combine with technology. Rapidly increasing industrialization and technological developments also increase the risks to the health and safety of employees. Occupational health and safety provide employees with the opportunity to work in a healthy and safe environment, while also enabling employees to work in a workplace free from dangers. In the study, the characteristics of the agricultural machinery manufacturing industry in Konya province were discussed. For this purpose, when the companies were evaluated according to their sizes, it was determined that approximately 32% of the 49 companies in the province were micro-scale companies, 42% were small-scale companies, and 22% were medium-scale companies. The main purpose of this study is to examine the agricultural machinery manufacturing enterprises in terms of occupational health and safety in Konya. Five medium-sized factories producing agricultural machinery were visited, and observations were made in the working environment. In this study, it is investigated that these enterprises, which are classified as "Dangerous Fines are analyzed by using the Fine-Kinney Risk Analysis Method, and measures are taken against risks. Factory A was classified according to 15 weld of danger and the total number of risks was 117, Factory B was classified according to 15 weld of danger and the total number of risks was 96, Factory C was classified according to 15 weld of danger and the total number of risks was 102, Factory D was classified according to 15 weld of danger and the total number of risks was 91, and Factory E was classified according to 15 weld of danger and the total number of risks was 104. Recognizing the risks in the agricultural machinery manufacturing industry can help companies improve their management and prepare for emergencies.

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Keywords: Finney-Kinney risk assessment method; Occupational health and safety; Konya medium-sized enterprises; Agricultural machinery manufacturing industry

1. Introduction

Providing a safe working environment for employees and ensuring that employees identify threatening machines, situations or events, and taking protective or protective practices against these events ensure the formation of Occupational Health and Safety conditions. The risk assessments used in our Occupational Health and Safety Law No. 6331, dated 30.06.2012 and numbered 28339, and our Occupational Health and Safety Risk Assessment Regulation No. 28512, dated 29.12.2012 are listed below.

Risk assessment: These are studies that need to be conducted to determine the damages that existing or external hazards in workplaces may cause to employees, the workplace, and the environment, and the precautions that can be taken.

Hazard: It refers to the potential for damage or harm that exists in the workplace or may come from outside and may affect the employee or the workplace.

The purpose of determining the hazard is to determine the problems that may arise due to the work done in the workplace environment and their levels.

Risk: Risk is a concept that includes the possibility of a recognized hazard occurring and the situations that may arise as a result of the hazards (Özkiliç 2005).

Today, more than 150 risk assessment methods are used in risk assessment studies (Çakmak 1999; Yılmaz and Gürbüz 2009). Risk assessment methods can be classified as qualitative, quantitative and mixed methods by considering their specific characteristics. The agricultural machinery manufacturing sector is an area where agriculture and agricultural mechanization develop in tandem, combining with technology. The agricultural machinery sector encompasses the design, production, sales, marketing, maintenance, and repair of machines used in agricultural production. The agricultural machinery manufacturing industry is recognized as a challenging working environment, particularly in terms of occupational health and safety. The increasing machinery manufacturing, coupled with technological developments, also causes many work accidents and occupational diseases. Since the machines, benches, and various hand tools used in the agricultural machinery manufacturing phase are not used in accordance with work safety, many work accidents and occupational diseases occur. In the sector, elements such as mechanical hazards (caused by machinery and equipment), physical hazards (noise, inadequate ventilation, inadequate or excessive lighting), chemical hazards (metals, gases, paints), and hazards originating from hazardous methods and processes come to the fore in the field of occupational health and safety.

Dyjack et al. (2003), in their project study on occupational health and safety management systems, showed that the application tests and the reorganization of these tests are important in the reliability audit of the occupational health and safety management system.

In our country, agricultural machinery manufacturing is generally carried out by medium and small-scale enterprises. When we look at developing countries, we see that occupational safety and health are in a much worse situation compared to industrialized countries. According to research conducted by the International Labor Organization (ILO), as enterprises grow, the number of accidents decreases, whereas accident rates are higher in small and medium-scale enterprises (Uysal et al. 2005)

A new approach in accident risk analyses conducted by Öztaş (2009), in his study titled "Questioning Risks", he presented a new approach, especially aimed at application, regarding risk analysis.

In his study, Can (2010) tried to reveal the status, problems, and solution suggestions of the agricultural equipment and machinery manufacturing industry in Polatlı district. For this purpose, data were obtained from the evaluation of survey forms conducted face-to-face with 41 enterprises in the region, as well as from related research, examinations, compilations, reports prepared by various institutions and organizations, and data obtained from relevant websites.

In Yiğit's (2015) study, it was prepared to determine the hazards and risks encountered in feed production activities classified as "Hazardous" in terms of occupational health and safety and to provide detailed information on the subject. Within the scope of the thesis, general information about the relevant sector and its associated risks, as well as risk assessment steps and methods, was provided. Additionally, the workplace where the study was conducted and the risk assessment methods employed were introduced, along with an explanation of the application stages. The risks identified as a result of the risk assessments carried out with Fine Kinney, Error Types and Effects Analysis and Risk Scoring methods and the statistical distributions of the risks in the business departments were examined together with the risk factors identified in the measurements performed, the similarities and differences of the methods were analyzed, the identified deficiencies were explained and suggestions were presented.

In the study conducted by Gülce (2016), a risk assessment was carried out with the Fine-Kinney method in a structure constructed of steel. Instead of the original coefficients in the Fine-Kinney method, the risk assessment was recalculated using the coefficients determined with the interpolation method. Thus, the aim was to adapt the coefficients according to the sector and area of use. While determining the table values, the reference ranges for the probability and frequency coefficients were taken and changed with a different approach. Then, the risk assessment calculated with the classical Fine-Kinney method was compared with the risk assessments calculated with the new approach.

In the study by Ateş (2018), risk analysis and assessment were made for the use and design of the hardware and equipment required for the safe use of conventional machine technologies in many furniture enterprises. Among the machines where many work accidents occur, the hazards that cause work accidents and occupational diseases in the workplace were determined for milling machines, circular saws, band saws, planers, etc., and the factors that cause these hazards to turn into risks and the risks arising from the hazards were analyzed and graded, and precautions were taken against these risks.

Advanced stochastic risk assessment approaches, such as the integration of quality function deployment (QFD) and Kemeny Median Indicator Rank Accordance (KEMIRA-M), have been proposed to enhance the FINE-KINNEY method. These approaches enable a more dynamic and robust risk assessment process (Can and Toktaş 2021).

Duran and Topuz (2023) conducted a survey study to compare the occupational health and safety practices of some agricultural machinery manufacturers in Aydın province and to determine the deficiencies and the current situation. It was observed that the agricultural machinery manufacturers generally fulfilled occupational health and safety practices, but some deficiencies were detected. It was observed that the company managers who participated in the survey had a lack of knowledge about the occupational health and safety law, the level of implementation of measures in the companies was not sufficient, the employer and employee did not fully know their obligations, and the controls and inspections were not carried out effectively.

The FINE-KINNEY method is used to identify potential hazards in agricultural machinery factories, such as equipment failure, inadequate safety guards, and operator error. Once hazards are identified, the method calculates a risk score for each hazard, allowing for the prioritization of risks based on their severity and likelihood of occurrence. Between 2021 and 2025, the Fine-Kinney method was applied across various sectors, including metal industries using fuzzy logic, nursing homes through a hybrid Fine-Kinney and ANFIS approach (Gökler et al. 2022), dairy factories in Iğdır, and agricultural machinery risk analysis via FMEA (Pilarczyk and Ulewicz 2024). Comparative studies were conducted with the 3T method in Ağrı Cement Factory (Inanlı and Özbakır 2024) and with FMEA in textile manufacturing. Additional applications included sub-leather processing (Milli et al. 2021), forestry hazard analysis, environmental laboratories combining AHP and Fine-Kinney, energy company winding sections, and natural disaster risk assessment in Van Province, Turkey, focusing on avalanche, landslide, rockfall, and flood hazards.

This study was conducted to examine medium-sized enterprises in terms of occupational health and safety and to assist in the evaluation of the precautions to be taken against the identified risks.

2. Materials and Methods

2.1. Material

In this study, medium-sized factories manufacturing agricultural machinery in Konya Province were used as models for our research. The fact that the Konya industrial zone is at the forefront of agricultural machinery manufacturing in our country, and that there are many enterprises, has been effective in selecting the relevant region.

Five medium-sized enterprises out of 11 manufacturing agricultural machinery in Konya province, which has 35% of the Turkish market in the agricultural machinery manufacturing industry sector, were selected for our study. To simplify, understand, and apply the study, the FINE-KINNEY risk assessment method, a frequently used method in the factory and industry field, was employed.

The Factories and Production Areas Analyzed are in the Organized Industrial Zone, and information about the enterprises is given in Table 1. In the closed area, there are management and administrative works, a machining and chipless manufacturing department, cutting, welding, a paint shop, and sandblasting departments. In the open area, there are manufactured products, scrap, and stacked waste materials.

Table 1. Factories, production areas and produced materials.

Factories	Closed Space	Open Space	Produced Material	Number of Employees
A	12000	9000	Agricultural machinery	150
B	40000	24000	Corn Silage Machine, Drum Mower and Grass Silage Machine	210
C	30000	13000	Agricultural Equipment and Machinery	105
D	25000	20000	Agricultural Equipment and Machinery	140
E	50000	25000	Agricultural Equipment and Machinery	120

2.2. Method

2.2.1. Risk Assessment Method Applied in Factories

FINE -KINNEY risk analysis method applied in factories is calculated with the help of the following equation. Here;

$$\text{Risk} = P \times F \times C, \quad (1)$$

Pu: Possibility (0,1 – 10 a value between)

F:Frequency (0,5 – 10 a value between)

C: Severity of Consequences (1 - 100)

Categories related to the probability value, which is the probability of damage or loss occurring over time, are given in Table 2.

Table 2. Fine-Kinney method probability ranking

Probability Value	Categories For Probability Value
0,1	Impossible
0,2	Unexpected
0,5	Unexpected but possible
1	Possible but unlikely
3	Rare but possible
6	Very possible, highly probable
10	Very strong probability, expected

The values of the category and rating of frequency, which is the frequency of exposure to danger, are given in Table 3.

Table 3. Fine Kinney method frequency ranking

Frequency	Categories For Frequency Value	Rating
0,5	Rare	Once a year or less
1	Very rare	Once a year or a few times
2	Rare	Once a month or a few times
3	Occasionally	Once a week or a few times
6	Frequently	Once a day or more
10	Constantly	Constantly, more than once an hour

The values and categories regarding the severity of the damage or harm that will occur to people, workplaces, and the environment in case of a hazard are given in Table 4.

Table 4. Fine Kinney method severity rating

Intensity Value	Categories For Intensity Value	Description
1	Considerable	No harm
3	Significant	Injury, internal first aid
7	Serious	Injury, external treatment, lost workday
15	Very serious	Disability, loss of limb, loss of work
40	Very bad	Death
100	Catastrophic	Multiple deaths, permanent damage

The expressions used in determining the risk score, evaluation and categories are given in Table 5.

Table 5. Fine-Kinney method risk score rating

Risk Score	Risk Assessment Categories	Description
$R \geq 400$	Very High Risk	Necessary measures should be taken immediately.
$200 \leq R < 400$	High Risk	Should be improved in the short term (within a few months).
$70 \leq R < 200$	Significant Risk	Should be monitored carefully and improved in the long term (within a year).
$20 \leq R < 70$	Possible Risk	Should be kept under surveillance. Control methods should be developed.
$R < 20$	Acceptable Risk	Current protection measures should be continued.

2.2.2. Risk Assessment Application

The weld of danger identified in the factories, the consequences of possible accidents and the existing precautions were evaluated using the risk assessment template created according to Table 6.

Table 6. Occupational safety risk analysis and action plan

		Fine Kinney Method Work Safety Risk Analysis And Action Plan									
Activity	Danger	Risk	Those At Risk	Current Control Measures	Risk Assessment			Risk Value	Priority Order	Legal Condition	Precautions To Be Taken
					POSSIBILITY	FREQUENCY	SEVERITY				
Sources of Danger											

The sources of danger and possible dangers in the occupational safety risk analysis and action plan given in Table 6 have been observed. The results of these observations are given in Table 7.

Table 7. Source of danger in Businesses

Serial No	Source of Danger	Danger
1	Inputs-Outputs	Falling Door Hits Door Touching Door
2	Administrative Office	Tripping Falling Thermal Comfort Eye Disorders Joint Diseases
3	General Working Environment	Tripping Falling Thermal Comfort Fire Electrical
4	Electrical Installations	Electric Shock
5	Machines And Machines	Spreading Pieces Crushing Respiratory System Disorders Electric Shock Hearing Loss Spreading Burrs Hand Fracture Limb Interruption Joint-Waist Disorders
6	Weld	Fire Electricity Explosion Respiratory Disorders Eye Disorders
7	Lifting Vehicles	Falling From A Height Crushing-Fracture Vehicle Crash Respiratory Disorder Vehicle Overturning Waist-Joint Disorders
8	Dyehouse	Explosion Fire Eye And Skin Diseases Electricity Poisoning
9	Chemical Substances	Fire Occupational Diseases Skin Diseases Respiratory Diseases
10	Pressure Vessels	Explosion Hearing Loss Electric Shock
11	Refectory	Fire Tripping-Falling Electricity Infectious Disease Poisoning Gas Leakage
12	Dressing Rooms-Shower-Wc	Infectious Disease
13	Fire System	Fire
14	Warehouse Area	Material Falling Sticking-Falling

After the source of danger observed in the factories and the possible risks were determined, they were evaluated using the Fine-Kinney method and an occupational safety risk analysis was created for each factory.

3. Results

3.1. Source of danger risk table for Factory A

The risk assessment of factory A according to Fine-Kinney is shown in Table 8.

Table 8. The risk assessment of factory A to Fine-Kinney

Source of Danger	Very High Risk $R \geq 400$	High Risk $200 \leq R < 400$	Significant Risk $70 \leq R < 200$	Possible Risk $20 \leq R < 70$	Acceptable Risk $R < 20$	Total
Entrance	-	-	-	1	-	1
Administrative Office	-	-	-	1	5	6
General Work Area	-	-	-	3	-	3
Machines And Machines	11	5	21	18	-	55
Dyehouse	1	2	-	1	-	4
Lifting Vehicles	-	-	4	2	-	6
Pressure Vessels	1	-	1	1	1	4
Weld	-	3	4	4	-	11
Warehouse Area	-	-	1	3	-	4
Electrical Installations	-	-	1	1	-	2
Fire System	-	-	1	-	-	1
Refectory	-	-	1	4	1	6
Locker Area, Shower and Wc	-	-	2	-	-	2
Chemicals	-	1	-	2	-	3
Others	-	-	6	3	-	9
Total	13	11	42	44	7	117

Factory A was classified according to 15 sources of danger, and the total number of risks was determined as 117. A total of 13 risks were determined in the “very high risk” group, 11 of which were observed to originate from machinery and benches. 1 hazardous situation was observed in the paint shop section, and 1 related to pressure vessels. A total of 11 risks were observed in the “high risk” group, 5 of which were determined to originate from machinery and equipment. There were 2 hazardous situations in the paint shops, 3 in the welding section, and 1 in the working with chemicals. A total of 42 risks were determined in the “significant risk” group, 21 of which were risks originating from machinery and benches, and 4 were observed in lifting equipment and welding; 2 in the changing area, shower and WC section; 1 risky situation was observed in the storage area, electrical installation, fire system and dining hall section. 6 significant risks were determined in the section examined under the title “Others”. A total of 44 risky situations were determined in the “possible risk” group. The highest number of risks was determined to be from machines and benches, 18 of which were identified. 4 in the welding section and dining hall; 3 in the general work area, storage area, and others; 2 in working with chemicals and lifting equipment; 1 in the factory entrance, administrative office, paint shop, pressure vessels, and electrical installation. There are a total of 7 risks in the “acceptable risk” group, with the highest number of risks identified in the administrative office. In addition, there is 1 acceptable risk in the pressure vessels and dining hall section.

As a result of the risk assessment conducted at Factory A, “Very high risk” was observed in three hazardous welding operations.

Fatal accidents may occur when electricity passes to the machine body due to the lack of grounding or inability to inspect the metal parts of the machines and benches. The presence of materials in front of the electrical panels that will prevent the passage of employees, the absence of an insulating mat in front of the panel, and the absence of a residual current relay in the main panel and secondary electrical panels in the plant increase the risk of accidents.

The fact that the materials used in the paint shop of the plant exceed daily needs and that there is an electrical leak in the storage area increases the risk of fire.

3.2. Source of danger risk table for Factory B

The risk assessment of Factory B according to Fine-Kinney is shown in Table 9.

Table 9. Risk table according to weld of danger for factory B

Source of Danger	Very High Risk R≥400	High Risk 200≤R<400	Significant Risk 70≤R<200	Possible Risk 20≤R<70	Acceptable Risk R<20	Total
Entrance	-	-	1	-	-	1
Administrative Office	-	-	1	1	3	5
General Work Area	-	-	-	3	-	3
Machines And Machines	-	8	16	16	-	40
Dyehouse	-	2	1	1	-	4
Lifting Vehicles	-	1	4	2	-	7
Pressure Vessels	-	1	1	-	1	3
Weld	-	1	1	2	-	4
Warehouse Area	-	1	1	2	-	4
Electrical Installations	-	-	1	1	-	2
Fire System	-	1	-	-	-	1
Refectory	-	-	1	5	1	7
Locker Area, Shower and Wc	-	-	2	-	-	2
Chemicals	-	-	1	2	-	3
Others	-	-	5	5	-	10
Total	-	15	36	40	5	96

Factory B was classified according to 15 sources of danger, and the total number of risks was determined as 96. No risk was detected in the “very high risk” group. A total of 15 risks were observed in the “high risk” group, 8 of which were identified as risks originating from machinery and equipment. There were two hazardous situations in the paint shops: one in the welding section, involving lifting devices, pressure vessels, welding, storage areas, and the fire system. A total of 36 risks were detected in the “significant risk” group, 16 of which were identified as risks originating from machinery and benches. 4 risks were detected in lifting devices; 1 risk in the entrance, administrative office, paint shop, pressure vessels, welding, storage area, electrical installation, dining hall, and chemical use; 2 in the changing area, shower, and WC section; and 5 significant risks were detected in other sections. A total of 40 risky situations were detected in the “possible risk” group. The highest number of risks among these was identified as 16 risks originating from machinery and benches. 5 in the section addressed as dining hall and other sections; 3 risky situations were observed in the general work area; 2 in the lifting equipment, welding, storage area, and chemical substance working section; 1 risky situation was observed in the administrative office, paint shop section, and electrical installation. There are a total of 5 risks in the “acceptable risk” group, with the majority detected in the administrative office. In addition, there is 1 acceptable risk in the pressure vessels and the dining hall section.

15 “High Risk” were identified in Factory B. Personnel working on machines and benches do not use personal protective equipment and do not take precautions when working with rotating parts on machines and benches. Tearing and crushing of electrical cables in the machines used, lack of local ventilation in welding areas, and failure to perform daily checks of load lifting and carrying equipment increase the possibility of work accidents.

3.3. Source of danger risk table for Factory C

The risk assessment of Factory C according to Fine-Kinney is shown in Table 10. Factory C was classified according to 15 sources of danger, and the total number of risks was determined as 102. A total of 4 risks were identified in the “very high risk” group, with 2 located in the paint shop section and the other 2 in the fire system and the cafeteria. A total of 9 risks were observed in the “high risk” group, and 4 of them were determined to be risks originating from machinery and equipment. A total of 2 risks were identified in the lifting of vehicles, with 1 risk in the pressure vessels and storage area. A total of 34 risks were determined in the “significant risk” group and 19 of these risks were risks originating from machinery and benches. 2 in lifting vehicles, welding and changing area, shower and WC; 1 risk in the paint shop, pressure vessels, storage area and electrical installation; and 4 significant risks were determined in other sections. A total of 49 risky situations were determined in the “possible risk” group. The most risky situations were observed in 23 of these, originating from machinery and benches. 4 in the cafeteria section; 3 risks were identified separately in

the general work area and lifting equipment. 2 risks were observed in the administrative office, working with welding, the storage area and working with chemicals; 1 risk in the entrance and paint shop and a total of 6 risky situations were observed in other sections. 5 were observed in the section considered as the cafeteria and other sections; 3 in the general work area; 2 in the section where lifting tools, welding, storage area and chemicals are worked; 1 risky situation was observed in the administrative office, paint shop and electrical installation. There are a total of 6 risks in the “acceptable risk” group, with the administrative office having the maximum of 4 risks. In addition, 2 acceptable risks were identified in the cafeteria section.

Table 10. Risk table for Factory C according to the source of danger.

Source of Danger	Very High Risk $R \geq 400$	High Risk $200 \leq R < 400$	Significant Risk $70 \leq R < 200$	Possible Risk $20 \leq R < 70$	Acceptable Risk $R < 20$	Total
Entrance	-	-	-	1	-	1
Administrative Office	-	-	-	2	4	6
General Work Area	-	-	-	3	-	3
Machines And Machines	-	4	19	23	-	46
Dyehouse	2	-	1	1	-	4
Lifting Vehicles	-	3	2	3	-	8
Pressure Vessels	-	1	1	-	-	2
Weld	-	-	2	2	-	4
Warehouse Area	-	1	1	2	-	4
Electrical Installations	-	-	1	-	-	1
Fire System	1	-	-	-	-	1
Refectory	1	-	1	4	2	8
Locker Area, Shower and Wc	-	-	2	-	-	2
Chemicals	-	-	-	2	-	2
Others	-	-	4	6	-	10
Total	4	9	34	49	6	102

4 “Very High Risk” was observed in Factory C. The inadequacy of lighting in the paint shop, the failure of personnel to use personal protective equipment, the absence of a fire detector, and the lack of a gas leakage detector in the cafeterias increase the risk of fire, loss of life, and material damage.

3.4. Source of danger risk table for Factory D

The risk assessment of Factory D according to Fine-Kinney is shown in Table 11. Factory D was classified according to 15 sources of danger, and the total number of risks was determined as 91. In the “very high risk” group, a total of 3 risks were determined, including 1 in the machinery and benches, the paint shop, and the electrical installations. In the “high risk” group, a total of 15 risks were observed, 11 of which were risks originating from machinery and equipment. 1 risk was determined in the lifting equipment, welding, storage area, and fire system. In the “significant risk” group, a total of 34 risks were determined, 15 of which were risks originating from machinery and benches, and 4 in lifting equipment; 2 in the paint shop, welding, and dining hall section; 1 risk was determined in pressure vessels, storage area, and working with chemicals. In other sections, a total of 6 significant risks were encountered. In the “possible risk” group, a total of 35 risky situations were determined. Of these, 12 risky situations originating from machinery and benches were observed the most. 3 in the work area and welding section; 2 in the administrative office, dining hall and changing rooms, shower and WC section; 1 risk was identified in the entrance, paint shop, lifting equipment, pressure vessels, storage area and working with chemicals. 4 risks were identified in the sections described as other sections. In the “acceptable risk” group, there are a total of 4 risks and the most were identified in the administrative office, 3 risks. In addition, 1 acceptable risk was identified in the cafeteria section.

Table 11. Risk table for Factory D according to source of danger

Source of Danger	Very High Risk R $\geq$ 400	High Risk 200 $\leq$ R<400	Significant Risk 70 $\leq$ R<200	Possible Risk 20 $\leq$ R<70	Acceptable Risk R<20	Total
Entrance	-	-	-	1	-	1
Administrative Office	-	-	-	2	3	5
General Work Area	-	-	-	3	-	3
Machines And Machines	1	11	15	12	-	39
Dyehouse	1	-	2	1	-	4
Lifting Vehicles	-	1	4	1	-	6
Pressure Vessels	-	-	1	1	-	2
Weld	-	1	2	3	-	6
Warehouse Area	-	1	1	1	-	3
Electrical Installations	1	-	-	1	-	2
Fire System	-	1	-	-	-	1
Refectory	-	-	2	2	1	5
Locker Area, Shower and Wc	-	-	-	2	-	2
Chemicals	-	-	1	1	-	2
Others	-	-	6	4	-	10
Total	3	15	34	35	4	91

3 “Very High Risks” were identified in Factory D. It was observed that personal protective equipment was not used while using the machines and equipment, there were no visors, operating instructions, warning lights on the machines, personal protective equipment was insufficient and not specific to the person. Irregular storage was observed in the storage areas.

3.5. Source of danger risk table for Factory E

The risk assessment of Factory E according to Fine-Kinney is shown in Table 12.

Table 12. Risk table for Factory E according to source of danger

Source of Danger	Very High Risk R $\geq$ 400	High Risk 200 $\leq$ R<400	Significant Risk 70 $\leq$ R<200	Possible Risk 20 $\leq$ R<70	Acceptable Risk R<20	Total
Entrance	-	-	-	1	-	1
Administrative Office	-	-	1	1	4	6
General Work Area	-	-	-	4	-	4
Machines And Machines	1	6	16	24	-	47
Dyehouse	1	-	2	1	-	4
Lifting Vehicles	-	1	3	2	-	6
Pressure Vessels	-	-	2	-	-	2
Weld	-	2	3	4	-	9
Warehouse Area	-	-	-	2	-	2
Electrical Installations	1	-	-	1	-	2
Fire System	-	-	1	-	-	1
Refectory	1	-	3	2	1	7
Locker Area, Shower and Wc	-	-	2	-	-	2
Chemicals	-	1	-	1	-	2
Others	-	-	5	4	-	9
Total	4	10	38	47	5	104

Factory E was classified according to 15 hazard sources and the total number of risks was determined as 104. In the “very high risk” group, a total of 4 risks were determined, including 1 in the machinery and benches, paint shop and electrical installation and cafeteria. In the “high risk” group, a total of 10 risks were observed

and 6 of these were determined to be risks originating from machinery and equipment. 2 in the source; 1 high risk was encountered in lifting equipment and working with chemicals. A total of 38 risks were detected in the “significant risk” group and 16 of these risks were risks originating from machinery and benches, 3 in lifting equipment, source and cafeteria; 2 in the paint shop, pressure vessels, changing area, shower and WC; 1 in administrative office and fire systems; 5 significant risks were encountered in the sections called others. A total of 47 risky situations were detected in the “possible risk” group. The most risky situations were observed to be 24 from machinery and benches. 4 in the work area and welding section and other sections; 2 possible risks were found in the lifting equipment, storage area and cafeteria section; 1 possible risk was found in the entrance, administrative office, paint shop, working with chemicals and electrical installation. In the “acceptable risk” group, there are a total of 5 risks and the most risks were found in the administrative office, 4. In addition, 1 acceptable risk was found in the cafeteria section.

4 “Very High Risks” were identified in Factory E. It was observed that the electrical cables in the Machinery and Equipment used in the facility were not in protective covers, workers in the paint shops did not use personal protective masks, there was no E-type fire extinguisher for fires that could arise from electrical panels in the machines and benches, and there was no leakage gas detector and fire extinguisher in the cafeteria section.

In this study, a total of 512 hazards were identified as a result of the risk analyses conducted in Factories A, B, C, D, E. The identified hazards are evaluated according to their risk levels in Table 13.

Table 13. Risk Score Assessment

Risk Score	Risk Assessment Categories	A Factory	B Factory	C Factory	D Factory	E Factory
$R \geq 400$	Very High Risk	13	-	4	3	4
$200 \leq R < 400$	High Risk	11	15	9	15	10
$70 \leq R < 200$	Significant Risk	42	36	34	37	38
$20 \leq R < 70$	Possible Risk	44	40	49	32	47
$R < 20$	Acceptable Risk	7	5	6	4	5
Total Risk		117	98	102	91	104

The hazards observed in factories A, B, C, D, E are generally listed below, according to the risk score values created according to the Fine-Kinney risk assessment method given in Tables 4 and 5 according to the risk rating.

At the entrance;

- No warning and emergency exit direction signs on transparent doors,
- No shapes visible to personnel on the door,

In the administrative office;

- Not performing eye examinations on personnel working with screened vehicles,

In working with machines and looms;

- In an environment where there are noisy machines and benches, no noise measurement is performed,
- The cables of the machines and benches are irregular and not in a casing,
- There is no protective shield to protect the eyes of the workers in some machines and benches,
- The personnel uses gloves in some machines and benches where they should not use gloves,

Risks in the examined factories were classified according to the source of danger and are given in Table 14.

Table 14. Risk scores according to hazard sources

Source Of Danger	Very High Risk					High Risk					Significant Risk					Possible Risk					Acceptable Risk				
	R ≥ 400					200 ≤ R < 400					70 ≤ R < 200					20 ≤ R < 70					R < 20				
	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E
Entrance	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	1	-	1	1	1	-	-	-	-	-
Administrative Office	-	-	-	-	-	-	-	-	-	-	-	1	-	-	1	1	1	2	2	1	5	3	4	3	4
General Work Area	-	-	-	-	-	-	-	-	-	-	-	-	-	3	-	3	3	3	-	4	-	-	-	-	-
Machines And Machines	11	-	1	1		5	8	4	11	6	21	16	19	15	16	18	16	23	12	24	-	-	-	-	-
Dye Shop	1	-	2	1	1	2	2	-	-	-	-	1	1	2	2	1	1	1	1	1	-	-	-	-	-
Lifting Vehicles	-	-	-	-	-	-	1	3	1	1	4	4	2	4	3	2	2	3	1	2	-	-	-	-	-
Pressure Vessels	1	-	-	-	-	-	1	1	-	-	1	1	1	1	2	1	-	-	1	-	1	1	-	-	-
Welding Machine	-	-	-	-	-	3	1	-	1	2	4	1	2	2	3	4	2	2	3	4	-	-	-	-	-
Warehouse Area	-	-	-	-	-	-	1	1	1	-	1	1	1	1	-	3	2	2	1	2	-	-	-	-	-
Electrical Installations	-	-	-	1	1	-	-	-	-	-	1	1	1	-	-	1	1	-	1	1	-	-	-	-	-
Fire System	-	-	1	-	-	-	1	-	1	-	1	-	-	-	1	-	-	-	-	-	-	-	-	-	-
Dining Halls	-	-	1	-	1	-	-	-	-	-	1	1	1	2	3	4	5	4	2	2	1	1	2	1	1
Locker Area, Shower and Wc	-	-	-	-	-	-	-	-	-	-	2	2	2	-	2	-	-	-	2	-	-	-	-	-	-
Chemicals	-	-	-	-	-	1	-	-	-	1	-	1	-	1	-	2	2	2	1	1	-	-	-	-	-
Others	-	-	-	-	-	-	-	-	-	-	6	5	4	6	5	3	5	6	4	4	-	-	-	-	-
Total	13	-	4	3	4	11	15	9	15	10	42	36	34	37	38	44	40	49	32	47	7	5	6	4	6

- There is no protector on the belt pulley section during the use of presses,
- There is no two-hand button system,
- The personnel does not use glasses against burr splashes,
- The personnel is not given steel-toed shoes that are not suitable for the work being done,
- There is no insulating mat on the base of some machines and benches and it is not fixed to the floor,
- Although headphones are given to the personnel in noisy machines and benches, their use is not ensured,
- The instructions for use are not hung on some machines and benches,
- The personnel wears dust masks in machines that produce metal dust not using,
- No guard on the grinding machine,

In lifting vehicles;

- No warning lights on cranes,
- No road markings in the forklift usage area,
- No maximum load tonnage written on the forklift,
- Personnel using the forklift doing other work while driving

In pressure vessels;

- Pressure vessels are not taken to an explosion-proof area,
- Ventilation is inadequate,

In welding works;

- Personnel do not use masks,
- Lack of local ventilation,
- Personnel do not use heat-resistant gloves,
- Lack of a screen between the source and other workers,

In the paint shop;

- Employees not using protective glasses, uniforms and masks,
- MSDS information forms of the paints used are not hung in the environment,
- There are no safety catches on the hoist hooks in the paint shop,

When working with chemicals;

- They are not stored in a separate room,
- No precautions are taken against chemicals tipping over,
- There is no fire extinguisher in the place where chemicals are located,
- No MSDSs,
- No posters or writings about the storage of chemicals,

In sandblasting;

- Electrical panel covers are not closed while working with sandblasting,
- There is material around the electrical panel,

- No type E fire extinguisher,
- Warning signs are not hung on the panel,
- Employees do not use headphones despite noise measurement while working with sandblasting machines,
- Inappropriateness of slings and hooks on lifting vehicles,
- In the storage area;
- Irregular stacking in the warehouse area,
- Most of the shelf systems do not take precautions against falling materials,
- Lack of warning and caution signs,

Electrical panel;

- Lack of insulating mat in front of the electrical panel,
- Material in front of the electrical panel,
- Panel covers are in open position,

Cafeteria;

- Lack of leakage gas detectors in some cafeterias,
- Open-lidded materials and food in factories,
- Lack of disposable cups in water dispensers,

Locker room;

- Lack of stools in the locker room,
- Inadequate ventilation in most factories,
- Single-compartment cabinets,

Factory guests;

- Not providing personal protective equipment to visitors.

Factory A was classified according to 15 weld of danger and the total number of risks was 117, Factory B was classified according to 15 weld of danger and the total number of risks was 96, Factory C was classified according to 15 weld of danger and the total number of risks was 102, Factory D was classified according to 15 weld of danger and the total number of risks was 91, and Factory E was classified according to 15 weld of danger and the total number of risks was 104.

4. Discussion

As a result of risk assessment studies conducted in factories, 512 hazardous situations were identified across 15 different activities. These hazards were evaluated using the Fine-Kinney risk analysis method, considering the probability and severity of potential accidents. In their research, Över Özçelik et al. (2025) tested the developed fuzzy Fine-Kinney model for 252 cases and compared it with the traditional Fine-Kinney method.

The highest-risk areas were primarily related to machine and bench use. Hazards such as flying parts, sawdust splashes, electric shock, failure to follow instructions, and improper work clothing can lead to serious consequences. In machines with rotating parts, such as band saws and presses, the lack of protective shields, grounding, and proper personal protective equipment (PPE) can result in fatal accidents. In their work, Gül and Çelik (2018) successfully demonstrated the application of a new OSH risk assessment approach, including the Fine-Kinney method and a fuzzy rule-based expert system.

To minimize these risks, safety buttons should be installed, PPE should be properly used, and practical training must be provided. Machines must have protective guards, operating instructions should be clearly posted, and warning signs should be visibly placed. Machines and benches used in factories should have guards, and the instructions for use should be hung on the machine. In addition, warning-caution signs should be hung in appropriate places and employees should be reminded to comply with these rules. In the study by Akman and Koç (2013), many factories were found to have electrical systems that were unsafe, characterized by open panels, poor insulation, and disorganized cables. Electrical work must be supervised by an engineer, and all systems should be properly grounded and clearly labeled.

Lifting devices often lacked warning lights and load indicators. Some forklift operators were observed performing unrelated tasks while driving. PPE provided to workers was often not suitable for their body size or the job, and machine noise levels were not properly managed. In storage areas, irregular stacking and unprotected shelving systems created further hazards. Not providing PPE to visitors was another major concern, as it exposes them to serious risks. Karahan and Aydoğmuş (2023) conducted risk analysis and assessment using the Fine Kinney method within the scope of occupational health and safety.

The FINE-KINNEY method is a valuable tool for risk analysis in agricultural machinery plants. Its simplicity, flexibility, and ability to provide quantitative risk scores make it a popular choice for identifying and prioritizing risks. As a result, the FINE-KINNEY method has been successfully applied in practical settings to reduce risks associated with agricultural machinery and provide a safer and more productive work environment.

5. Conclusions

The risk assessment studies conducted in agricultural machinery manufacturing facilities revealed significant hazards, particularly in areas such as machine and bench use, electrical safety, inadequate personal protective equipment (PPE), and lifting equipment. The Fine-Kinney method proved effective in prioritizing risks and guiding appropriate control measures.

To reduce these hazards, it is essential to:

Ensure the proper implementation of protective systems and guards,

Provide and monitor the use of suitable PPE,

Apply strict electrical safety standards,

Improve training and awareness for all personnel.

This study highlights the importance of a proactive and systematic approach to prevent workplace accidents and create a safer working environment.

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References

- Akman A and Koç U (2013). Makinelerin hareketli noktalarına temas riskinin değerlendirilmesi. *Çalışma Dünyası Dergisi* 1, 120–136.
- Ateş ÖT (2018). İş sağlığı ve iş güvenliğinde risk analizi: Mobilya sektöründe bir uygulama. *Master Thesis, Süleyman Demirel University, Türkiye*
- Can E (2010). Polatlı ilçesinde tarım makineleri imalat durumu, sorunları ve çözüm önerileri. *Master Thesis, Selçuk University, Türkiye*

- Can GF, Toktaş A (2021). A stochastic risk assessment approach using QFD and KEMIRA-M for occupational health and safety risks. *Process Safety and Environmental Protection* 153, 242–254.
- Çakmak B (1999). Yerli yapım bazı tarım makinalarında malzeme bakımından kalite kavramı ve kalitenin iyileştirilmesi üzerinde bir araştırma. *PhD Thesis, Ege University, Turkey*
- Duran E, Topuz N (2022). Aydın ili bazı tarım makinaları imalatçıların iş sağlığı ve güvenliği uygulamalarının araştırılması. *Adnan Menderes Üniversitesi Ziraat Fakültesi Dergisi* 20(2), 237–246.
- Dyjack D, Redinger C, Ridge R (2003). Health and safety management system audit reliability pilot project. *AIHA Journal* 64(6), 785–791.
- Gökler SH, Yılmaz D, Ürük ZF, Boran S (2022). A new hybrid risk assessment method based on Fine-Kinney and ANFIS methods for evaluation spatial risks in nursing homes. *Heliyon* 8(10), e11028.
- Gül M, Çelik E (2018). Fuzzy rule-based Fine–Kinney risk assessment approach for rail transportation systems. *Human and Ecological Risk Assessment: An International Journal* 24(7), 1786–1812.
- Gülce OH (2016). Çelik konstrüksiyon stadyum çatılarında risklerin belirlenmesi ve betonarme yapıları ile karşılaştırılması. *T.C. Çalışma ve Sosyal Güvenlik Bakanlığı.*
- Güney G, Kahraman B (2022). Implementation of the analytic hierarchy process (AHP) and Fine–Kinney method (FKM) against risk factors to determine the total cost of occupational health and safety precautions in environmental research laboratories. *International Journal of Occupational Safety and Ergonomics* 28(4), 2606–2622.
- İnanlı A, Özbakır O (2024). Ağrı Çimento Fabrikası'nda tehlike tanımlama ve Fine-Kinney ile 3T risk değerlendirme yöntemlerinin karşılaştırılması: Bir kritik inceleme. *Karadeniz Fen Bilimleri Dergisi* 14(2), 448–467.
- Karaçizmeli İH (2023). Comparison of FMEA and Fine Kinney methods for risk analysis in textile manufacturing. *Quality* 2023, 173–176.
- Karahan V, Aydoğmuş E (2023). Risk analysis and risk assessment of laboratory work by Fine Kinney method. *International Journal of Advanced Natural Sciences and Engineering Researches* 7(4), 442–446.
- Matpay B, Mutlu S (2023). Determining the natural disaster diversity of Van province by Fine Kinney Risk Assessment Method (FK-RAM). *Journal of Natural Hazards and Environment* 9(2), 324–340.
- Milli A, Salman S, Sancak E (2021). A case of risk assessment by using Fine-Kinney method in sub-leather processing. *Usak University Journal of Engineering Sciences* 4(1), 42–57.
- Özçelik ÖT, Yılmaz Yalçiner A, Çetinkaya M, Aker A (2025). Risk assessment with the fuzzy Fine–Kinney method in a business operating in the metal industry. *International Journal of Occupational Safety and Ergonomics* 31(1), 308–317.
- Özbakır O (2023). Hazard and risk assessment in a dairy products factory in Iğdır province using the Fine Kinney Risk Method: Recommendations for mitigation. *International Journal of Agriculture Environment and Food Sciences* 7(3), 563–572.
- Özçelik TÖ, Yalçiner AY, Çetinkaya M, Aker A (2025). Risk assessment with the fuzzy Fine–Kinney method in a business operating in the metal industry. *International Journal of Occupational Safety and Ergonomics*, 31(1), 308–317.
- Özkılıç Ö (2005). İş sağlığı ve güvenliği: Yönetim sistemleri ve risk değerlendirme metodolojileri (Yayın No. 246). *TİSK Yayınları.*
- Öztaş S (2009). Kaza risk analizlerinde yeni bir yaklaşım “Risklerin Sorgulanması”. *Maden İşletmelerinde İş Sağlığı ve Güvenliği Sempozyumu*, 19–20.

- Pilarczyk B, Ulewicz R (2024). Evaluating risk in the operation of agricultural machinery based on farm size. Scientific papers of Silesian University of technology organization and management series no. 198, 393-408.
- Şengül Ü, Tokal A (2021). Risk analysis with Fine Kinney method in forestry production studies. *EJONS International Journal* 5(20), 865–877.
- Tümay AK (2023). Determination of high risks and elimination of possible risks in the winding section of an energy company using the Fine-Kinney method. *International Scientific and Vocational Studies Journal* 7(2), 62–71.
- Uysal B, Özçiftçi A, Kurt Ş (2005). Türkiye’de küçük ve orta ölçekli mobilya imalat işletmelerinde meydana gelen iş kazalarının analizi. *Gazi Üniversitesi Fen Bilimleri Dergisi* 18(3), 439–451.
- Yiğit Ö (2015). Yem üretim proseslerinde üç farklı risk değerlendirme metodunun uygulanması ve yöntemlerin karşılaştırılması. *Çalışma ve Sosyal Güvenlik Bakanlığı*.
- Yılmaz G, Gürbüz B (2009). İş kazalarının n edenleri ve maliyeti. *Mühendis ve Makine* 592, 27–32.



Population Development and Infestation Rate of Pistachio twig Borer [*Kermania pistaciella* Amsel (Lepidoptera: Tineidae)] in Pistachio Orchards in Middle Euphrates Valley, Türkiye

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HIGHLIGHTS

- *Kermania pistaciella* formed a high population in pistachio orchards.
- The pest causes infestations above the economic damage threshold.
- Chemical control does not provide sufficient success against the pest.
- Pistachio farmers must adopt environmentally friendly biotechnical control methods.

Abstract

Pistachio is a strategic crop for Türkiye, and the country ranks third in global pistachio production after Iran and the United States. Numerous pests adversely affect pistachio production, with one of the most significant being *Kermania pistaciella* Amsel (Lepidoptera: Tineidae). This study was conducted to determine the population development of *Kermania pistaciella* adults and the infestation rate in shoots and fruit clusters in pistachio orchards of Innaplı, Surtepe, and Keskince villages in the Middle Euphrates Valley in 2019. Three delta-type pheromone traps were installed in each orchard. Trap counts were conducted weekly. To determine the pest's infestation rates in shoots and fruit clusters, 100 shoots and 100 clusters were inspected in each orchard. The results showed that the first adult flights of *K. pistaciella* began in the last days of March. The pest population peaked on April 20 in all three locations, with 1263, 977, and 513 adult trap⁻¹ captured in Innaplı, Surtepe, and Keskince, respectively. After an approximately six-week flight period in nature, the last adult flight was recorded on May 11. Throughout the season in Innaplı, Surtepe, and Keskince, a total of 3,306, 2,574, and 1,651 adult trap⁻¹ were captured, respectively. The infestation rates in the terminal shoots were 16%, 12%, and 8% while in fruit clusters were determined to be 12%, 9%, and 6% in Innaplı, Surtepe, and Keskince, respectively. In conclusion, *K. pistaciella* formed a high population in pistachio orchards of the Middle Euphrates Valley, causing infestations above the economic damage threshold. Since chemical control measures have not provided sufficient success against *K. pistaciella*, the pest population and damage rates can be reduced through environmentally friendly biotechnical control methods, such as mass trapping, which all producers must implement.

Keywords: harmful insect; damage; pheromone; pest management; *Pistacia vera*

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1. Introduction

Pistachio (*Pistacia vera* L.), belonging to the Order Sapindales and the family Anacardiaceae, is one of the oldest fruits in the world and is referred to by names such as "Green Gold," "King of Fruits," "Golden Tree," and "Royal Fruit." (Karuserci 2020). Although the origin of pistachios is the arid regions of Central and Western Asia, they have spread across the Mediterranean basin (Tomaino 2010). It was first reported to have been domesticated by the Hittites in Anatolia (Açar 2016). The cultivation of pistachio varieties began in the ancient Persian Empire (Hormaza and Wünsch 2007), and it was later domesticated in its wild forms in regions such as Anatolia, Syria, and Afghanistan. In the first century AD, pistachios were brought from Syria to Italy, from where they spread to other Mediterranean countries and began to be cultivated (Gül Yavuz 2011). Currently, it can be cultivated in suitable microclimates between 30° and 45° latitudes in both hemispheres (Tekin et al. 2001). Pistachio can grow in soils where other fruits cannot easily thrive, particularly in Asia and Europe (Bellomo and Fallico 2007).

Pistachio is predominantly grown in the Near East, Mediterranean, and Western Asian regions. The leading pistachio-producing countries are the United States (USA), Iran, Türkiye, Italy, Syria, Tunisia, and Greece (Bellomo and Fallico 2007; Tsantili et al. 2010; Bayram 2011; Gül Yavuz 2011; Sürücü et al. 2020; Sabuncu et al. 2021). The global production of pistachio is 1,214,743.34 tons, with Türkiye (239,289 tons) ranking third after the USA (400 070 tons) and Iran (241,668 tons) (FAO 2022). According to these data, approximately 85% of the world's pistachio production is carried out by the USA, Iran, and Türkiye.

In Türkiye, pistachio is cultivated in 56 provinces, predominantly in the Southeastern, Aegean, Mediterranean, and Central Anatolia regions (Babadoğan 2007). However, the primary production areas are Şanlıurfa, Gaziantep, Adıyaman and Siirt. Approximately 93% of pistachio production in Türkiye is sourced from the Southeastern Anatolia region (TUIK 2024). Şanlıurfa ranks first with a production of 107,034 tons, followed by Gaziantep with 55,939 tons (TUIK 2022).

The Middle Euphrates Valley holds a special significance for pistachio production, both for Türkiye in general and specifically for the Southeastern Anatolia region and Şanlıurfa. Within the crop pattern of the Euphrates Valley, pistachio ranks first in importance.

In Türkiye, which holds a significant share in global pistachio production, pistachio orchards are affected by various diseases and pests that negatively impact production. Surveys conducted in the provinces of Şanlıurfa, Adıyaman, Siirt, Mardin, and Batman reported the presence of 70 insect species in pistachio orchards (Mehrnejad 2001; Yanık and Yücel 2001; Bolu 2002; Mamay and Şimşek 2017; Kaplan et al. 2018; Mehrnejad 2020; Sabuncu et al. 2021). However, the primary pests causing economic damage in pistachio orchards have been identified as *Kermania pistaciella* Amsel (Lep.: Tineidae), *Hylesinus* (= *Chaetoptelius*) *vestitus* (Mulsant and Rey 1860) (Col.: Scolytidae), *Agonoscena pistaciae* Burckhardt and Lauterer (Hem.: Psyllidae), and *Capnodis cariosa* Pallas (Col.: Buprestidae) (Sabuncu et al. 2021; Mamay et al. 2022; Sönmez and Mamay 2022).

Among these, *K. pistaciella* is considered the most significant pest causing substantial economic damage in pistachio orchards in Türkiye (Bolu 2002; Özgen et al. 2012; Bolu 2020; Sabuncu et al. 2021; Özgen et al. 2022; Mamay et al. 2022; Sönmez and Mamay 2022). Numerous studies have documented the economic damage caused by this pest in pistachio orchards in Türkiye (Küçükarslan 1966; Mart et al. 2003; Bolu 2002; Günaydın 1978; Şimşek 2012), Iran (Davatchi 1956; Mehrnejad 2001; Abbaszadeh et al. 2006; Izadi et al. 2011), Syria (Khoja et al. 2009), and Greece (Mourikis et al. 1998).

The adults of *K. pistaciella* appear in early spring (between late March and early April) and lay their eggs on flowers and fruit clusters. During periods of high population density, it has been observed that the pest also lays eggs on shoots and petioles (Tezerji 2011). The eggs are orange in color (Anonymous 2011). Larvae emerge about a week after the eggs are laid, bore into the shoots or clusters at the point of attachment, and create galleries (Abbaszadeh et al. 2006). Mature larvae form cocoons close to the entry point, where they

pupate. The color of the cocoon typically matches the bark of the tree, ranging from brown to various shades of light or dark brown (Kubat Şengel 2020; Özdemir 2024).

Kermania pistaciella causes significant damage, including the formation of blind clusters, thinning and shrinking of fruits within clusters, bud drop, and developmental stunting due to larval destruction within the shoots (Küçükarslan 1966; Tezerji 2009; Basirat and Mehrnejad 2019; Fakhri and Abbasipour 2019; Mamay et al. 2022). The damaged upper buds generally fail to produce leaves and dry out during the next growth period. The damage caused by *K. pistaciella* leads to significant economic losses by reducing both the quantity and quality of pistachio harvests (Sürücü et al. 2020; Tezerji 2009).

Given its economic importance as a pest that significantly reduces yield and quality in pistachio production, every study on *K. pistaciella* holds special value. This study was conducted in the Southeastern Anatolia Region of Türkiye, which accounts for more than 90% of the country's pistachio production. The research focused on different pistachio orchards in the Middle Euphrates Valley, where pistachio is the leading crop in the region's agricultural pattern. The study aimed to determine the initial flight period of *K. pistaciella* adults, the development of adult populations, peak periods of pest activity, the last adult flight time, the duration of adult activity throughout the year, and the infestation rates in shoots and clusters.

2. Materials and Methods

2.1. Material

The study was conducted in 2019 in three pistachio orchards located in the villages of Innaplı, Surtepe, and Keskince in the Middle Euphrates Valley (Table 1).

Table 1. Characteristics of the orchards where the study was conducted.

Location	Variety	Area (da)	Number of Tree	Age of Tree (year)	Coordinates	Altitude (m)
Innaplı	Uzun and Kırmızı	50	1000	40	N37°04'12.3" E37°56'40.3"	520
Surtepe	Uzun and Kırmızı	18	180	50	N37°03'41.4" E37°56'47.1"	490
Keskince	Uzun and Kırmızı	10	150	50	N37°04'10.0" E37°53'14.9"	480

The primary materials of the study included *K. pistaciella* (Figure 1), pistachio orchards in the Middle Euphrates Valley, pest-infested shoots and clusters (Figure 2), and sex pheromone traps.

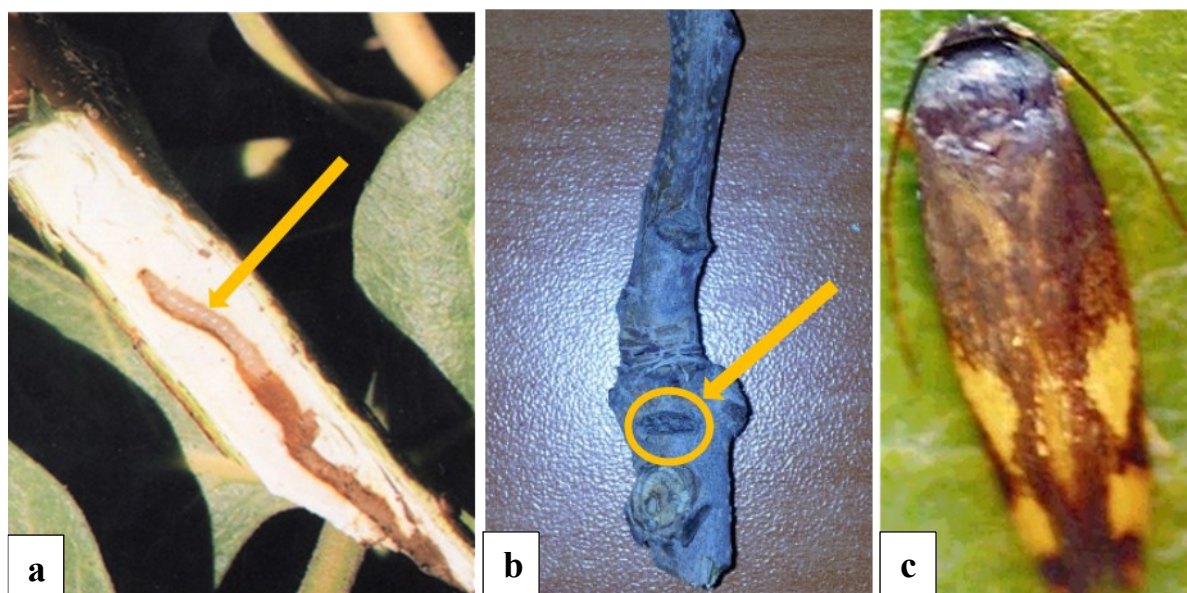


Figure 1. *Kermania pistaciella*: a) larva, b) pupa, c) adult.



Figure 2. Galleries formed by *Kermania pistaciella* in pistachio shoots.

In this study, delta-type sex pheromone traps containing (2S,12Z)-2-acetoxy-12-heptadecene, obtained from Scentomos Research & Development Inc. (Coquitlam BC, V3C 4X7, Canada), were used (Figure 3).



Figure 3. Sexual attractant pheromone traps used in monitoring of *Kermania pistaciella* population.

2.2. Method

2.2.1. Determination of population development of *Kermania pistaciella*

The study was conducted in 2019 in three pistachio orchards located in the villages of Innaplı, Surtepe, and Keskince in the Middle Euphrates Valley. The adult population dynamics of the pest were determined using sex pheromone traps (Figure 3).

As part of the study, three sex pheromone traps were installed in each orchard in mid-March. The traps were hung at a height of 1.5–2 meters on a branch facing the south side of the trees. From the date of installation, the traps were inspected every two days until the first adult was captured and then once a week following the initial adult flight. Monitoring of the traps was terminated two weeks after the end of adult flight activity was confirmed. Pheromone capsules in the traps were replaced every 4–5 weeks, while the sticky plates were replaced as needed when they lost their adhesive properties.

The number of *K. pistaciella* adults captured in the pheromone traps in the orchards was recorded weekly as the average number of adults per trap. These data were then plotted as graphs to create the pest's population

dynamics curves. This approach enabled the determination of key population parameters, including the first adult flight, population fluctuations, periods of high population density, the last adult flight, and the estimated number of generations under natural conditions (Mamay and Ünlü, 2013; Mamay and Yanık, 2013; Mamay, 2018).

2.2.2. Determination of the infestation rate of *Kermania pistaciella* in pistachio orchards

2.2.2.1. Determination of the infestation rate of *Kermania pistaciella* in pistachio shoots

In order to determine the infestation rate of *K. pistaciella* in pistachio shoots in the studied orchards, at least 10 trees were randomly selected from each orchard after the harvest, ensuring they represented the entire orchard. From each selected tree, 10 shoots were collected from different directions and interior parts of the tree, resulting in a total of 100 shoots per orchard, which were then brought to the laboratory. These shoots were longitudinally split in half from the tip, and the number of larva-damaged shoots and healthy shoots was recorded. Based on this, the infestation rate in each orchard was calculated as a percentage. The following formula was used to determine the rate of infested shoots (Mamay et al. 2014):

$$\text{Infested shoot rate (\%)} = \frac{\text{Infested shoot number}}{\text{Inspected total shoots number}} \times 100, \quad (1)$$

2.2.2.2. Determination of the infestation rate of *Kermania pistaciella* in pistachio fruits

To determine the infestation rate of *Kermania pistaciella* in pistachio fruits, a total of 100 fruit clusters were inspected before the harvest (early august) from randomly selected trees in each orchard. The numbers of infested and healthy clusters were recorded separately, and the infestation rate was calculated as a percentage using the following formula:

$$\text{Infested cluster rate (\%)} = \frac{\text{Infested cluster number}}{\text{Inspected total cluster number}} \times 100, \quad (2)$$

2.3. Statistical Analysis

The study was conducted at three different locations. At each location, three sex pheromone traps were used, with each trap considered as a replicate. Population development was assessed based on the average of the replicates. The infestation rate of the pest in shoots and clusters was calculated using the formulas provided in Equation 1 and Equation 2, as described above. The chord diagram was generated using the Origin Pro software package (OriginLab 2024). Curve graphs were prepared using Microsoft Excel.

3. Results

3.1. Population Development of *Kermania pistaciella*

The adult population dynamics of *K. pistaciella* in pistachio orchards within the Middle Euphrates Valley were determined. The data regarding the number of adult pests captured in the sex pheromone traps placed in the pistachio orchard located in the village of Innaplı are presented in Figure 4.

The first adult capture in the sex pheromone traps was recorded on March 30, two weeks after the traps were installed in the pistachio orchard located in the village of Innaplı. On this date, 59 adults were captured per trap, while in the following weeks, the numbers of adults captured per trap were recorded as 512, 1008, 1263, 351, 112, and 1 respectively. Over the entire season, a total of 9918 adults were captured across the three traps (Figure 4). According to these data, the pest population reached its peak on April 20, with 1263 adults per trap (Figures 4 and 5). The adult flight period in the Innaplı pistachio orchard lasted seven weeks, with the last adult flight observed on May 11.

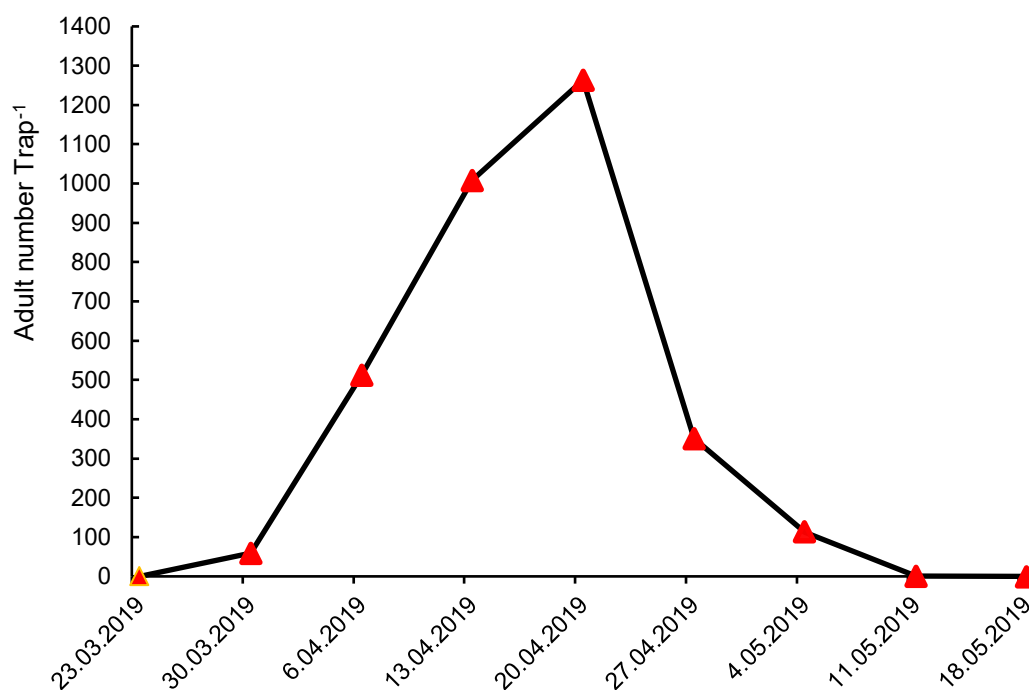


Figure 4. *Kermania pistaciella* population development in the pistachio orchard in Innaplı.



Figure 5. High density of *Kermania pistaciella* adults captured in sex pheromone traps.

The population dynamics of *K. pistaciella* in the pistachio orchard located in Surtepe village are presented in Figure 6.

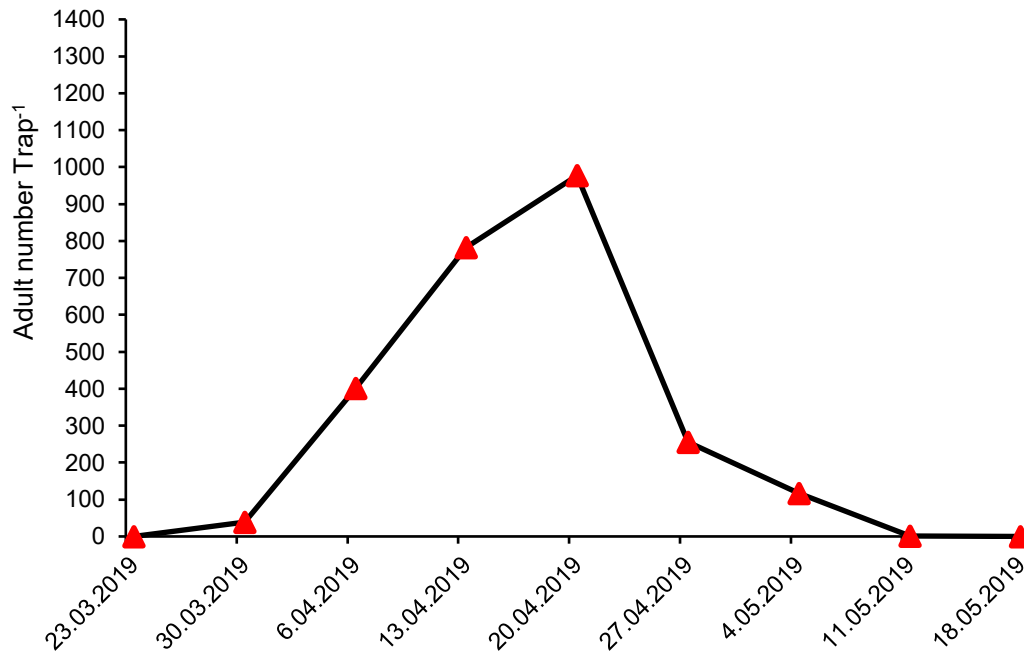


Figure 6. *Kermania pistaciella* population development in the pistachio orchard in Surtepe.

The first adult was caught in the pheromone traps on March 30 in the pistachio orchard located in Surtepe village, coinciding with the date observed in Innaplı village. On this date, 39 adults were captured per trap. In the subsequent weeks, the number of adults caught per trap was recorded as 401, 783, 977, 256, 117, and 1, respectively. Over the season, a total of 7,722 adults were caught in the pheromone traps in Surtepe. The population dynamics of the pest in this orchard showed a strong similarity to those in Innaplı village, with a rapidly rising population peaking at 977 adults per trap on April 20. Similarly, the adults of *K. pistaciella* remained active in the field for seven weeks, with the last adult flight observed on May 11 (Figure 6). The data obtained from the studies conducted in the pistachio orchard located in Keskince regarding the population dynamics of *K. pistaciella* are presented in Figure 7.

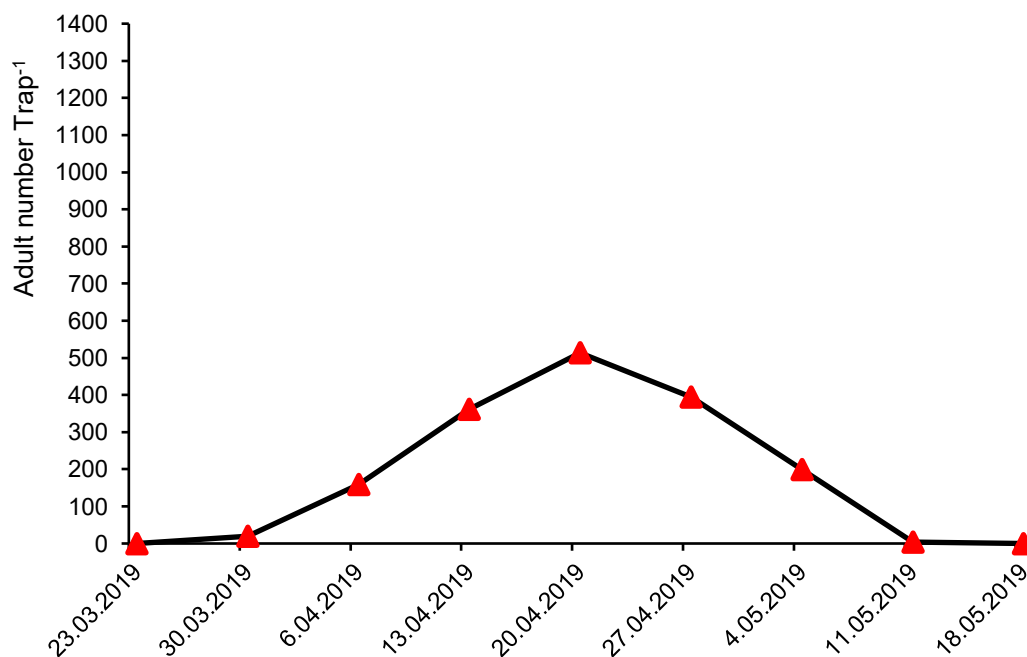


Figure 7. Population development of *Kermania pistaciella* in the pistachio orchard in Keskince.

Although a relatively lower population of *K. pistaciella* was observed in the pistachio orchard located in Keskince compared to the other two study locations, the pest exhibited a similar population fluctuation. The first adult capture in the pheromone traps in Keskince occurred on March 30, with 20 adults per trap. Following this, the population increased steadily, reaching its peak on April 20, and then declined, ending on May 11, as observed in the other two locations (Figures 4, 6 and 7). Weekly inspections conducted after the first adult capture revealed that the pest's population was recorded as 159, 361, 513, 394, 200, and 4 adults per trap on April 6, 13, 20, and 27, as well as May 4 and 11, respectively (Figure 7). While the peak population recorded on April 20 (513 adults per trap) was lower compared to the other two locations, the pest's population in subsequent weeks was higher than those in Innaplı and Surtepe villages. Throughout the season, a total of 4953 adults were captured in the pheromone traps set up in the pistachio orchard in Keskince. The study concluded that the pest remained active in the field for a total duration of seven weeks.

The chord diagram in Figure 8, which illustrates the weeks during which the pest exhibited higher population densities across different locations, presents the results in a more striking and impactful manner.

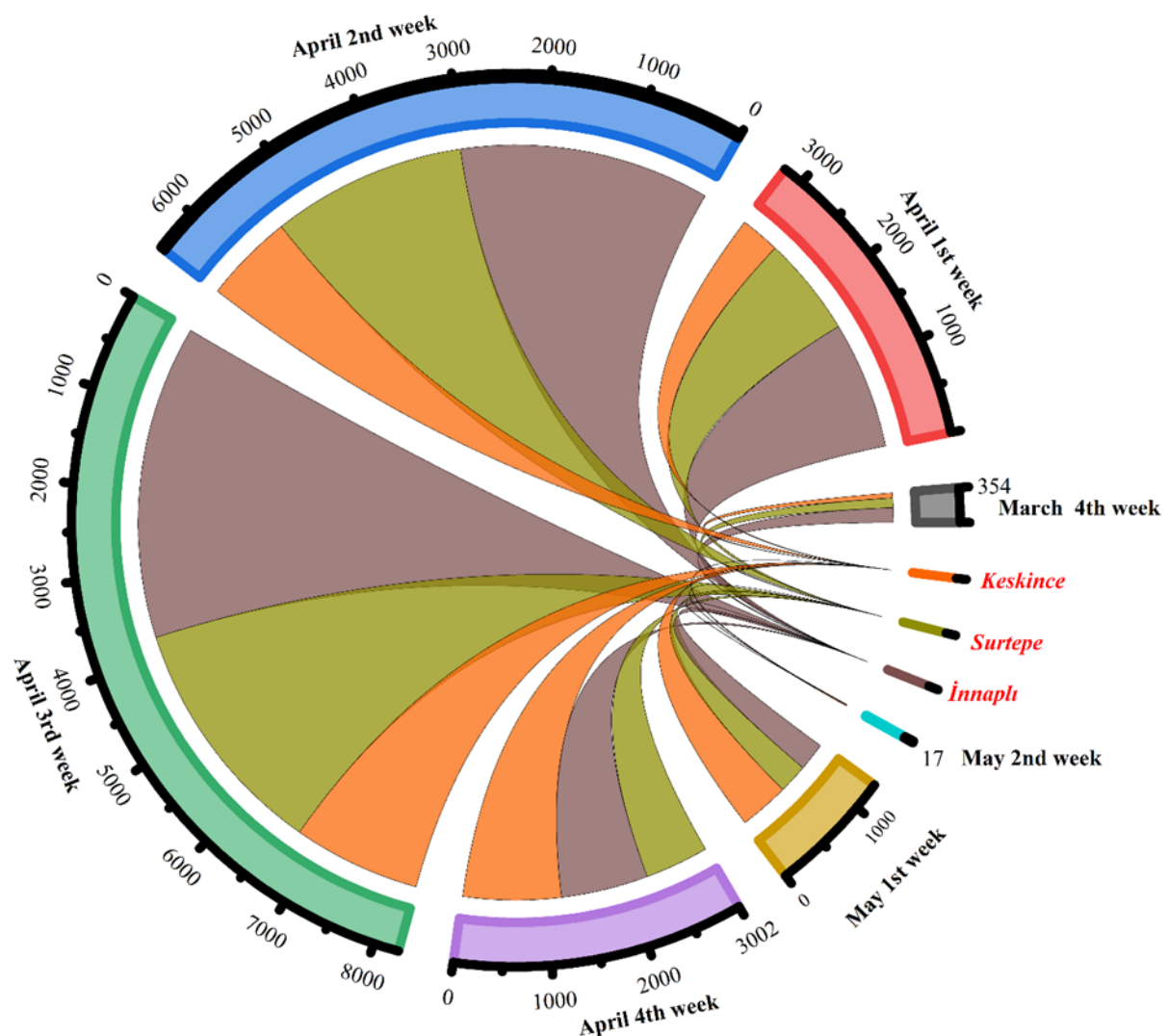


Figure 8. Total number of *Kermania pistaciella* adults caught by pheromone traps by weeks in pistachio orchards based on locations in Middle Euphrates Valley in 2019.

When Figure 8 is examined, it is observed that the majority of the population in all three locations where the study was conducted occurred during the second and third weeks of April. In the last week of April and in May, relatively fewer adults were caught in sexual pheromone traps at all three locations (Figure 8). In Innaplı, 30.4% of the population was captured during the second week of April, and 38.2% during the third

week of April. These values were determined to be 30.4% and 37.9% in Surtepe and 21.9% and 31.0% in Keskince, respectively. These data clearly demonstrate the necessity of initiating pest control measures promptly in April.

According to the 2019 climate data obtained from the Şanlıurfa Provincial Meteorology Directorate, the daily average temperature and humidity values are presented in Figure 9. An analysis of Şanlıurfa's climate data revealed an inverse relationship between temperature and humidity values. Specifically, as the temperature decreased, the relative humidity increased, whereas an increase in temperature corresponded to a decrease in relative humidity (Figure 9).

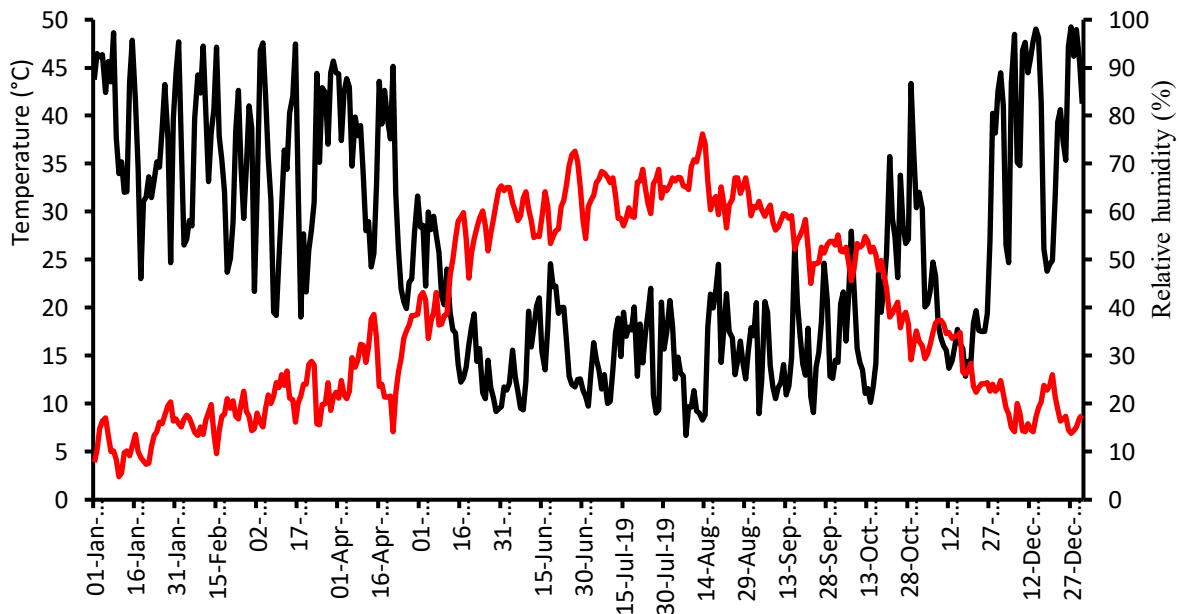


Figure 9. Daily average temperature and humidity values of Şanlıurfa Province in 2019.

When the climate data and the population development of *K. pistaciella* were evaluated together, it was observed that the first adult flight occurred during the last week of March, when the average temperature was measured at 11.2°C, and the relative humidity was 91.4%. The last adult flight was recorded in the second week of May, with an average temperature of 21.7°C and an average relative humidity of 45.5%. On April 20, the date when the highest number of adults was caught in pheromone traps, the recorded average temperature and relative humidity were 10.8°C and 75.2%, respectively.

3.2. Determination of the Infestation Rate of *Kermania pistaciella* in Pistachio Orchards

3.2.1 Determination of the infestation rate of *Kermania pistaciella* in pistachio shoots

The shoot infestation rates were determined as 29% in Innaplı, 23% in Surtepe, and 17% in Keskince in 2018, while the inspections conducted in 2019 revealed these rates to be 16%, 12%, and 8%, respectively (Figure 10).

For the pistachio twig borer, an infestation rate of 10% in the terminal shoots constitutes the economic damage threshold (Anonymous 2011). In this context, the 2018 data indicate that the infestation rates in all three villages where the study was conducted exceeded the economic threshold. According to the 2019 data obtained from the study, the shoot infestation rates in Innaplı and Surtepe were found to be above the economic damage threshold, while in Keskince, it remained below this threshold. The observed differences in infestation rates between the two years are thought to be related to seasonal temperature variations and farmer practices.

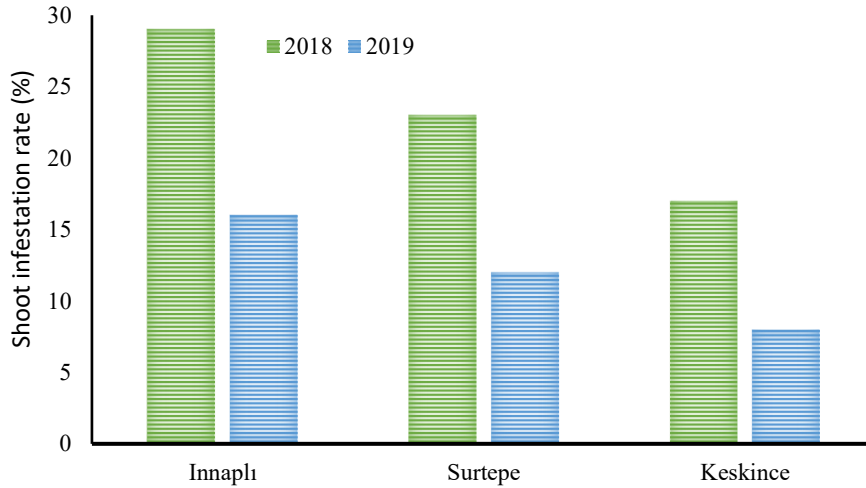


Figure 10. *Kermania pistaciella* shoot infestation rates in pistachio orchards in Middle Euphrates Valley in 2018 and 2019 years.

3.2.2 Determination of the infestation rate of *Kermania pistaciella* in pistachio fruits

The infestation rate of pistachio fruit clusters caused by the pistachio twig borer in the orchards was determined by inspecting a total of 100 clusters in each orchard using the method described in detail in the methodology section. As a result of these inspections, the cluster infestation rate was determined to be 12% in the pistachio orchard in Innaplı, 9% in Surtepe, and 6% in Keskince (Figure 11).

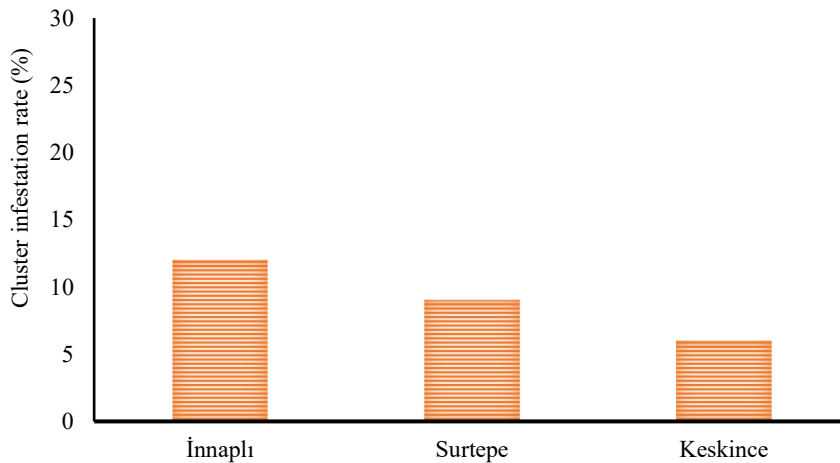


Figure 11. Pistachio cluster infestation rate caused by *Kermania pistaciella* in pistachio orchards in Middle Euphrates Valley in 2019.

4. Discussion

When the data obtained from studies on the population dynamics of *K. pistaciella* in pistachio orchards in the Innaplı, Surtepe, and Keskince villages of the Middle Euphrates Valley were evaluated together, it was determined that the first adult flight of the pest occurred in the last week of March, coinciding with the phenological stage of flower bud formation on the trees. Similarly, in a study conducted by Mart et al. (1995) in the Gaziantep region, the first adult flight of *K. pistaciella* was reported to occur in the first week of April, aligning with the findings of this study. Additionally, in another study conducted by Mart et al. (2003) in the Gaziantep Central, Nizip, and Oğuzeli districts, it was reported that the first adult flight of the pest in Oğuzeli occurred on April 2, demonstrating similarity to this study. Likewise, a study conducted in the Rafsanjan region of Iran reported that the pest's adults emerged at the end of March, consistent with the findings of this study (Basirat 2006). Furthermore, a study by Yıldırım (2014) in Şanlıurfa determined the presence of the pest's

adults in the first week of April, while Yanık et al. (2016) reported that *K. pistaciella* adults began flying in pistachio orchards in Şanlıurfa and Oğuzeli during the last week of March, further supporting the results of this study conducted in the Middle Euphrates Valley.

However, the findings of Küçükarslan (1966) in the Gaziantep region and Güneş (2001) in Şanlıurfa, which determined that the adult flights of *K. pistaciella* occurred in mid-April, differ from the results of this study. Similarly, Mart et al. (1995) reported that the first adult flights of *K. pistaciella* in Gaziantep occurred on April 24, according to their 1992 data, indicating a discrepancy with our findings. Likewise, Abbaszadeh et al. (2006) reported that the pest's adults emerged on April 18 in a study conducted in Iran. When examining the reasons for the differences in the timing of the pest's first adult flights across these studies and the current research, several factors can be considered. The primary reason is thought to be the geographical differences in temperature between the study locations, as colder regions may delay adult flights by 2–3 weeks. Another reason could be variations in the data collected from the same location across different years, which can be attributed to inter-annual differences in seasonal temperatures. Indeed, Yıldırım (2014) reported that the first adult flights of the pest in Şanlıurfa occurred with a one-week shift between two consecutive years, supporting this idea. Based on the results of all these studies, it can be concluded that the ecological conditions, which vary from year to year, may have different impacts on the pest's population dynamics.

In all three villages where the study was conducted, the adult population was observed to peak in the second half of April (20.04.2019). It was determined that the pest's presence in nature lasted for seven weeks in all three villages, with the adult population ending by mid-May. During the sampling period, the population density of the pest showed a continuous increase in all three villages from March 30 to April 20, after which the weekly inspections revealed a gradual decline in the pest population (Figures 4, 6 and 7).

During weekly trap inspections in pistachio orchards located in Innaplı, Surtepe, and Keskince villages, it was determined that the pest reached its peak population on April 20, with 1 263, 977, and 513 adults trap⁻¹, respectively. By this time, pistachio tree leaves had reached their normal size, and the fruits had grown to the size of wheat grains. The last adult flight in all three orchards was observed on May 11. On this date, pistachio fruits had reached the size of chickpeas. During subsequent weekly inspections, it was observed that no adults of *K. pistaciella* were captured in sexual pheromone traps at any of the three orchards.

When the data obtained from population studies of *K. pistaciella* in Innaplı, Surtepe, and Keskince are evaluated together, it was found that the pest population reached its peak on April 20. Consistent with the findings of this study, Mart et al. (2003) reported that the pest population similarly peaked on April 20 in 2001 in Gaziantep's Central district, Nizip, and Oğuzeli. Similarly, Abbaszadeh et al. (2006) reported that the pest population peaked on April 20 in Iran, fully aligning with the results of this study.

In a study conducted in the Rafsanjan region of Iran, it was determined that the pest population peaked between April 13 and 18 (Basirat 2006). However, in another study conducted in the Isfahan region of Iran, it was reported that the pest population peaked on April 28 (Zamani et al. 2012). The approximately one-week difference in peak periods reported by Basirat (2006) and Zamani et al. (2012) compared to this study can be attributed to differences in ecological conditions in those years and locations. Although adults emerged at the end of March in Basirat's (2006) study, similar to this study, the pest population peaked a week later, indicating that factors other than temperature, such as humidity and other environmental conditions, may also influence the development of adult populations.

Another finding derived from the data obtained in all three villages in this study is that the last flight of the pest occurred in the first half of May. Consistent with the results of this study, Küçükarslan (1966) reported that the adult flight of *K. pistaciella* ended in mid-May in the Gaziantep region. Similarly, Abbaszadeh et al. (2006) reported that the pest's adults in the Rafsanjan region of Iran withdrew from the field in the second half of May. Zamani et al. (2012) stated that the adults of the pest were no longer observed in the field in the Isfahan region of Iran after May 19. Likewise, studies conducted by Güneş (2001) in the Şanlıurfa Central and Viranşehir districts and by Yanık et al. (2016) in Şanlıurfa and Oğuzeli also reported that the pest population ended in early May, further supporting the results of this study. All the above studies indicate that the last adult flight of the pest coincides with mid-May.

Another parameter obtained from the population studies conducted in the three villages is the active period during which the pest's adults remained in the field. This study determined that the pest remained active in the field for seven weeks. In this regard, the findings of Zamani et al. (2012), who reported that pistachio twig borer adults remained in the field for six to seven weeks in the Isfahan region of Iran, are consistent with the results of this study. Küçükarslan (1966) reported that the adults remained in the field for 5-19 days in the Gaziantep region. Güneş (2001) found that the adults stayed in the field for approximately four weeks in the Şanlıurfa Central and Viranşehir districts. Abbaszadeh et al. (2006) reported that the pest remained in the field for about five weeks in Iran, while Yanık et al. (2016) reported that the adults were active in the field for approximately four to five weeks in Şanlıurfa and Oğuzeli. The differences reported in these studies can be attributed to the variations in ecological conditions in the years and locations where the studies were conducted.

This study found that during the peak period of the population in Innanlı, Surtepe, and Keskince, 1 263, 977, and 513 adults trap⁻¹ were captured, respectively (Table 5). Yanık et al. (2016) reported that during the peak period, 1 106 and 857 adults trap⁻¹ were captured in the Birecik district, while 377 and 300 adults trap⁻¹ were captured in the Oğuzeli district. Yıldırım (2014) reported that during the peak period in Bozova Central in 2011, 212.67 adults trap⁻¹ were captured, while in Bozova Bağlıca, 218.33 adults trap⁻¹ were recorded. During the 2012 peak period, 854 adults trap⁻¹ were captured in Kızlar, 265 in Bozova Central, 228 in Bozova Bağlıca, and 282.66 adults trap⁻¹ in other locations. Compared to other studies in literature, the higher number of adults captured per trap in this study may be attributed to ecological conditions that vary from year to year and to chemical control measures applied by farmers against different pests.

According to the data obtained from the studies conducted to determine the infestation rates of the pest in twigs and clusters, it was found that the infestation rates of *K. pistaciella* were higher in Innanlı compared to Surtepe and Keskince. Similarly, infestation rates were higher in Surtepe compared to Keskince. It was determined that the infestation rates in twigs were generally above the economic threshold and that there was a parallel relationship between the infestation rates in twigs and clusters. Indeed, Mamay et al. (2022) reported infestation rates ranging from a minimum of 2% to a maximum of 70% in pistachio orchards across 25 locations in Şanlıurfa's Birecik, Bozova, Ceylanpınar, Eyyübiye, Halfeti, Haliliye, Hilvan, and Karaköprü districts during 2019 and 2020, further supporting the results of this study. Küçükarslan (1966) conducted a study in the Gaziantep region and noted that *K. pistaciella* caused four significant types of damage to pistachios: the formation of blind clusters, thinning of grains in clusters, shedding of buds, and damage within twigs by larvae.

In conclusion, it was determined that the pest formed a high population in pistachio orchards in the Middle Euphrates Valley and caused infestation rates exceeding the economic damage threshold. By implementing environmentally friendly biotechnical control methods, such as mass trapping, which must be applied by all producers, the pest population can be reduced resulting the less damage.

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Conflicts of Interest: The authors declare that there is no conflict of interest among them. This study constitutes a part of the first author's master's thesis.

Ethical Approval Statement: Since this study does not involve any research on human or animal subjects, ethical approval was not required.

References

- Abbaszadeh G, Seiedoleslami H, Semih MA, Hatami B (2006). Bioecology of pistachio twig borer moth *Kermania pistaciella* Amsel, in Rafsanjan and Isfahan-Iran. *Communications in Agricultural and Applied Biological Sciences* 71(2b), 563-570
- Açar I (2016). Antepfıstığı yetiştiriciliği. *Agromedya* 24: 58-64.
- Anonymous (2008). T.C. Tarım Orman ve Köy İşleri Bakanlığı Tarımsal Araştırmalar Genel Müdürlüğü, Zirai Mücadele Teknik Talimatları. 5: 206-208
- Anonymous (2011). Antepfıstığı Entegre Mücadele Teknik Talimatı. Tarımsal Araştırmalar ve Politikalar Genel Müdürlüğü, s. 29, Ankara.
- Babadoğan G (2007). Antep Fıstığı, T.C. Başbakanlık Dış Ticaret Müsteşarlığı İhracatı Geliştirme Etüd Merkezi.
- Basirat M (2006). Determination of heat requirements for pistachio twig borer moth, *Kermania pistaciella*. *Acta Horticulturae* 726, 519-523. <https://doi.org/10.17660/ActaHortic.2006.726.86>
- Basirat M, Mehrnejad MR (2019). Population density of the pistachio twig borer moth, *Kermania pistaciella* Amsel on pistachio cultivars. *Applied Entomology and Phytopathology* 86(2), 121-132.
- Bayram M (2011). Comparison of unsplit inshell and shelled kernel of the pistachio nuts, *Journal of Food Engineering* 107, 374-378. <https://doi.org/10.1016/j.jfoodeng.2011.07.001>
- Bellomo MG, Fallico B (2007). Anthocyanins, chlorophylls and xanthophylls in pistachio nuts (*Pistacia vera*) of different geographic origin, *Journal of Food Composition and Analysis* 20, 352-359. <https://doi.org/10.1016/j.jfca.2006.04.002>
- Bolu H (2002). Investigations on the fauna of insects and mites in pistachio areas in South Eastern Anatolia Region of Türkiye. *Turkish Journal of Entomology* 26 (3), 197-208.
- Bolu H (2020). Population development of twig borer moth, *Kermania pistaciella* (Lepidoptera: Oinophilidae) and its pupae parasitoid *Microchelonus fissilis* (Hymenoptera: Braconidae) on pistachio in Türkiye. *International Journal of Innovative Engineering Applications* 4(2), 91-95. <https://doi.org/10.46460/ijiea.828233>
- Davatchi GA (1956). Sur quelques insectes nuisibles au pistachier en Iran. *Revue de Pathologie Végétale et D'etomologie Agricole de France* 35, 17-26.
- Fakhri N, Abbasipour H (2019). Population fluctuations of the pistachio twig borer, *Kermania pistaciella* Amsel, 1964 (Lep.: Oinophylidae) using delta pheromone trap. *Acta agriculturae Slovenica* 114(1), 13-20. <https://doi.org/10.14720/aas.2019.114.1.2>
- FAO (2024). Crops and livestock products/Pistachio. <https://www.fao.org/faostat/en/#data/OCL> (access date: 03.03.2025)
- Gül Yavuz G (2011). Sert Kabuklu Meyveler/ Antep Fıstığı. TEPGE BAKIŞ, Tarımsal Ekonomi Ve Politika Geliştirme Enstitüsü, Aralık 2011 / ISSN: 1303-8346 / Nüsha: 5, Ankara.
- Günaydin T (1978). Güneydoğu Anadolu Bölgesi'nde Antepfıstıklarında Zarar Yapan Böcek Türleri, Tanımları, Yayılışları ve Ekonomik Önemleri Üzerinde Araştırmalar. Yayınlanmamış Uzmanlık Tezi Diyarbakır Zirai Mücadele Enstitüsü, Diyarbakır. 106.
- Güneş A (2001). Şanlıurfa İli Antepfıstığı Alanlarında *Kermania pistaciella* Amsel'nin biyolojisi ve zarar durumu. Yüksek Lisans Tezi. Harran Üniversitesi, Şanlıurfa.
- Hormaza JL, Wünsch A (2007). Pistachio. In Fruits and nuts (pp. 243-251), Springer, Berlin, Heidelberg.
- Kaplan C, Çiftçi MC, Çakmak S (2018). Insect pests in pistachio producing areas of Türkiye. International Congress on Mathematic, Engineering and Natural Sciences-IV, 11-13 August 2018, Kiev, Ukraine, pp.8.

- Karuserci B (2020). Antepfıstığının kültür tarihi. <https://arastirma.tarimorman.gov.tr/afistik/Belgeler/AYRILMI%C5%9E%20MAKALELER/99-ANTEPFISTI%C4%9EININ%20K%C3%9CLT%C3%9CR%20TAR%C4%B0H%C4%B0%202020.pdf> (access date: 03.03.2025)
- Khoja S, Mozaik MF, Azar Y, Hoka K (2009). Survey for the most important insect pests of pistachio in Aleppo Governorate (Syria). 5th International Symposium on Pistachios and Almonds, ISHS, Şanlıurfa, Türkiye, s.96
- Kubat Şengel D (2020). Determination of population development and infestation rate of *Kermania pistaciella* in pistachio orchards in the Euphrates Valley of Birecik (Şanlıurfa) district, MSc Thesis, Harran University, Şanlıurfa.
- Küçükarslan N (1966). Antepfıstıklarında zarar yapan fıstık dal güvesi (*Kermania pistaciella* Amsel, Lepidoptera, Oinophilidae)'nin biyolojisi ve savaşı üzerinde incelemeler. Sabri AŞ. Basımevi, İstanbul, s.64.
- Mamay M (2018). Important parameters in mechanical management of carob moth [*Apomyelois* (= *Ectomyelois*) *ceratoniae* zeller (lep.: pyralidae)] in pomegranate orchards: determination of overwintering population density and infestation rate. *Fresenius Environmental Bulletin* 27(12B), 9542-9548.
- Mamay M, Ünlü L (2013) Şanlıurfa ili nar bahçelerinde güvesi, *Apomyelois ceratoniae* Zell. (Lepidoptera: Pyralidae)'nin ergin popülasyon gelişimi ve zarar oranının belirlenmesi. *Türkiye Entomoloji Bülteni* 3(3), 121-131.
- Mamay M, Yanık E, Doğramacı M (2014). Phenology and damage of *Anarsia lineatella* Zell. (Lepidoptera: Gelechiidae) in peach, apricot and nectarine orchards under semi-arid conditions. *Phytoparasitica* 42, 641-649. <https://doi.org/10.1007/s12600-014-0405-6>
- Mamay M, Şimşek E (2017). Harmful and beneficial insect biodiversity in pistachio orchards (*Pistacia vera* L.) in Southeastern Anatolia Region of Türkiye. Symposium on EuroAsian Biodiversity (SEAB-2017), 5-8 July 2017, Minsk, Belarus, pp. 32.
- Mamay M, Sönmez C, Li Y, Mutlu Ç, Akhtar I, Bibi R, Alfarraj S, Ansari MJ, Vyhnanek T (2022). Infestation rate and cardinal directional preference of pistachio twig borer [*Kermania pistaciella* Amsel (Lepidoptera: Tineidae)]. *Journal of King Saud University-Science* 34(4), 102025. <https://doi.org/10.1016/j.jksus.2022.102025>
- Mamay M, Yanık E (2013). Determination of population development and infestation rates of codling moth [*Cydia pomonella* (L.) (Lepidoptera: Tortricidae)] by using different sampling methods in Şanlıurfa province. *Journal of Agricultural Sciences* 19(2), 113-120. <https://doi.org/10.1501/Tarimbil.0000001235>
- Mart C, Yiğit A, Çelik MY (1995). Biological observations and chemical control of pistachio twig borer, *Kermania pistaciella*, injurious in pistachio orchards in Türkiye. *Acta Horticulturae* 419, 373-378.
- Mart C, Karadağ S, Aslan, MM, Nazife E (2003). Antepfıstığı alanlarında entegre mücadeleye veri tabanı oluşturacak bazı konularda araştırmalar. TÜBİTAK Tarp-2076 Nolu proje raporu, 315 s.
- Mehrnejad MR (2001). The current status of pistachio pests in Iran. *Cahiers Options Méditerranéennes* 56(1), 315-322.
- Mehrnejad MR (2002). The natural parasitism ratio of the pistachio twig borer moth, *Kermania pistaciella*, in Iran. *Acta Horticulturae* 591, 541-544. <https://doi.org/10.17660/ActaHortic.2002.591.83>
- Mehrnejad MR (2003). The influence of host species on some biological and behavioural aspects of *Dibrachys boarmiae* (Hymenoptera: Pteromalidae), Parasitoid of *Kermania pistaciella* (Lepidoptera: Tineidae). *Biocontrol Science and Technology* 13: 219-229. <https://doi.org/10.1080/0958315021000073484>
- Mehrnejad MR, Basirat M (2009). Parasitoid complex of the pistachio twig borer moth, *Kermania pistaciella*, in Iran. *Biocontrol Science and Technology* 19(5), 499-510. <https://doi.org/10.1080/09583150902887610>

- Mehrnejad MR (2020). Arthropod pests of pistachios, their natural enemies and management. *Plant Protection Science* 56, 231–260. <https://doi.org/10.17221/63/2019-PPS>.
- Mourikis PA, Tsourgianni A, Chitzanidis A (1998). Pistachio nut insect pests and means of control in Greece. *Acta Horticulturae* 470, 604-611. <https://doi.org/10.17660/ActaHortic.1998.470.85>
- OriginLab (2024). OriginPro, Graphing for science and engineering. <https://www.originlab.com/> (access date: 03.03.2025).
- Özdemir S (2024). Efficacy of combinations of anionic surfactant and some insecticides in control of pistachio twig borer [*Kermania pistaciella* (Lepidoptera: Tineidae)]. MSc Thesis, Harran University, Şanlıurfa.
- Özgen I, Bolu H, Beyarslan A (2012). *Chelonus flavipalpis* Szépligeti, 1896 and *Mirax rufilabris* Haliday, 1833 (Hymenoptera: Braconidae): two new larva-pupa parasitoids of Pistachio twig borer *Kermania pistaciella* Amsel, 1964 (Lepidoptera: Oinophilidae) with the parasitization ratios from Türkiye. *Munis Entomology & Zoology* 7, 238-242.
- Özgen I, Mamay M, Yanık E (2022). Release of the lady beetle (*Oenopia conglobata* L.) to control the common pistachio psylla. *Biological Control* 171, 104940. <https://doi.org/10.1016/j.biocontrol.2022.104940>
- Sabuncu Y, Mamay M, Özgen I (2021). Overwintering insect (Arthropoda: Insecta) biodiversity in pistachio orchards of the Middle Euphrates Valley, Türkiye. *Harran Tarım ve Gıda Bilimleri Dergisi* 25, 185-192. <https://doi.org/10.29050/harranziraat.884529>.
- Sönmez C, Mamay M (2022). Twig traps: a sustainable and eco-friendly management option for pistachio bark beetle [*Hylesinus* (= *Chaetoptelius*) *vestitus* (Mulsant & Rey, 1860) (Coleoptera: Scolytidae)]. *Journal of Plant Diseases and Protection* 129(5), 1181-1188. <https://doi.org/10.1007/s41348-022-00637-0>
- Sürücü A, Acar I, Demirkiran AR, Farooq S, Gokmen V (2020). Variations in nutrient uptake, yield and nut quality of different pistachio cultivars grafted on *Pistacia khinjuk* rootstock. *Scientia Horticulturae* 260, 108913.
- Şimşek A (2012). Determination of the insect fauna in pistachio (*Pistacia vera* L.) areas in Diyarbakir province. MSc Thesis, Dicle University, Diyarbakır.
- Tekin H, Arpacı S, Atlı S, Açar I, Yaman A, Yükciken Y Karadağ S (2001). Antep Fıstığı Yetiştiriciliği. Antep Fıstığı Araştırma Enstitüsü Müdürlüğü Yayınları, Yayın No: 13, s.12, Gaziantep.
- Tezerji ZS (2009). Determination of damages of pistachio twig borer moth *Kermania pistaciella* amsel, to fruit clusters of pistachio trees. In V. International Symposium on Pistachios and Almonds, 25 November 2011, Şanlıurfa, Türkiye, pp. 701-707.
- Tezerji ZS (2011). Determination of damages of pistachio twig borer moth *Kermania Pistaciella* Amsel, to fruit clusters of pistachio trees. *ISHS Acta Horticulturae* 912, 701-708. <https://doi.org/10.17660/ActaHortic.2011.912.105>
- Tomaino A, Martorana M, Arcoraci T, Monteleone D, Giovinazzo C, Saija A (2010). Antioxidant activity and phenolic profile of pistachio (*Pistacia vera* L., variety Bronte) seeds and skins. *Biochimie* 92, 1115-1122. <https://doi.org/10.1016/j.biochi.2010.03.027>
- Tsantili E, Takidelli C, Christopoulou MV, Lambrineab E, Rouskasc D, Roussosa PA (2010). Physical, compositional and sensory differences in nuts among pistachio (*Pistacia vera* L.) varieties, *Scientia Horticulturae* 125, 562-568. <https://doi.org/10.1016/j.scienta.2010.04.039>
- TÜİK (2019). İstatistik veri portal. <https://data.tuik.gov.tr/Bulten/Index?p=Bitkisel-Uretim-Istatistikleri-2019-30685> (access date: 03.03.2025)
- TÜİK (2024). İstatistik veri portal. <https://data.tuik.gov.tr/Bulten/Index?p=Bitkisel-Uretim-Istatistikleri-2024-53447> (access date: 03.03.2025)

- Yanık E (1997). Şanlıurfa İlinde Saptanan Antepfıstığı Zararlıları, Popülasyon Gelişmeleri ve Zarar Durumları. Yüksek Lisans. Harran Üniversitesi, Şanlıurfa.
- Yanık E, Yücel A (2001). The pistachio (*Pistacia vera* L.) pests, their population development and damage state in Şanlıurfa province. *Cahiers Options Mediterraneenes* 56 (1), 301-309.
- Yanık E, Karadağ S, Ünlü L, Sırt A, Evelekler H, Sinangil F (2016). Determination of the efficiency of sex pheromone synthesized in Türkiye of pistachio twig borer, *Kermania pistaciella* Amsel (Lepidoptera: Oenophilidae). Türkiye 6th Plant Protection Congress with International Participation, 5-8 September 2016, Konya, Türkiye, p.174.
- Yıldırım Y (2014). Efficiency of pheromone mass-trapping method on pistachio twig borer (*Kermania pistaciella* Amsel (Lepidoptera:Tineidae)). MSc Thesis, Harran University, Şanlıurfa.
- Zamani Z, Khajehali J, Sabrazalian MR (2012). Influence of trap type, trapping location and cardinal direction on the capture of the pistachio twig borer moth, *Kermania pistaciella* Amsel. (Lepidoptera: Tineidae)'in Isfahan. *Plant Pest Research* 2(2), 59-61.



Relationships between Tillering, Grain Yield and Yield Components in Durum Wheat Genotypes

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HIGHLIGHTS

- New lines and varieties can be developed by following the hybrid combinations obtained.
- With subsequent studies, optimum fertile tiller numbers can be revealed, and yield can be increased by the sparse planting method.

Abstract

Grain yield in wheat is influenced by genetically determined agronomic traits-such as tillering capacity, grain weight, and grain number per spike-as well as biotic, abiotic, and management factors. This study was conducted under irrigated conditions during the 2020–2021 growing season at Karamanoğlu Mehmetbey University using a Randomized Complete Block Design with two replications. The plant material included three registered cultivars, two landraces, and their F₁ hybrids. Traits assessed included fertile tiller number, stem height, spike length, grain number per main spike, main spike yield, tiller yield, yield per tiller, single-plant yield, and days to spike formation. Hybrids such as Ç-1252/AR14 and Poyraz/Kızıltan 91 performed well across multiple yield traits, highlighting the potential of cultivar-landrace crosses for developing high-yielding lines. Correlation analysis revealed strong associations between fertile tiller number and both tiller yield and single-plant yield ($r=0.84$), and a moderate correlation with grain number per spike ($r=0.52$) and spike yield ($r=0.59$). Yield per tiller showed a slightly stronger correlation with single-plant yield ($r=0.80$) than did main spike yield ($r=0.78$). Additionally, the stability value of grain yield per tiller (0.57) exceeded that of grain yield from the main spike (0.40). The results suggest that regulating tiller number by adjusting planting density, especially through single-plant sowing, may be a viable strategy to improve grain yield.

Keywords: Durum wheat; tillering capacity; single plant; yield

1. Introduction

As one of the most farmed crops in the world wheat (*Triticum spp.*) is grown under both rain-fed and irrigation conditions. Wheat, as a staple cereal crop, plays an important role in providing food energy and nutrition globally, meeting more than 60% of the total daily protein and calorie requirements (Sodhaparmar et al. 2024). Durum wheat (*Triticum durum Desf.*) serves as the primary raw material for several food products, including pasta, bulgur, couscous and noodles. Additionally, it has significant value as a feed source for livestock, contributing to animal production, which is essential for human nutrition. With the global

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population continuing to grow, the importance of 'food safety and nutrition' has risen significantly. From the perspective of added value, wheat's ability to be cultivated under both rainfed and irrigated conditions enhances its strategic importance.

Wheat grain yield is a genetically controlled trait (Aydoğan et al. 2010) influenced by various environmental factors, including the number of grains per spike (Arduni et al. 2018), single spike yield (Gülmezoğlu and Tolay 2016), the number of fertile tillers (Verma et al. 1998), tiller yield (Elhani et al. 2007), days to spike (Abinasa and Ayana (2011), and plant height (Khan et al. 2013). While these traits are shaped by environmental conditions, they remain under genetic control (Aydoğan et al. 2010). Additionally, ecological factors, such as soil moisture (Geçit and Çakır 2006) and soil temperature (He et al. 2017), as well as agronomic practices, including pre-planting preparations (Eser and Adak 1998), sowing time (Arduni et al. 2018), seed density (Taner 2022), fertilization (Gökmen et al. 2008; Akman and Topal, 2010), and sowing depth (Kühling et al. 2017) significantly impact yield. Biotic factors, such as diseases (Öztürk et al. 2018) and pests (Zhang et al. 2022), also play a critical role.

The primary determinants of grain yield in wheat include the number of fertile tillers, spike length, grain count per spike, yield per spike, thousand-grain weight (Taner 2022), and plant density per unit area. Herein, the relationships between tillering capacity, grain yield, and yield components were examined in genotypes comprising local varieties, registered modern varieties, and F₁ hybrids derived from these genotypes, cultivated in the Ermenek district of Karaman province.

2. Materials and Methods

In breeding studies, when hybridization is conducted under field conditions, environmental factors may limit the production of hybrid seeds. Consequently, the F₁ seeds obtained were sufficient only for two replicate experiments. In conducting research, the number of replications is determined by considering factors such as the number and quality of materials available. Numerous studies on different plant species, have conducted experiments with two replications (Kan and Sade, 2002; Bozdağ and Soyly, 2019; Katiyar et al. 2021; Çat 2022). Similarly, this study was conducted with two replications in a randomized block design at the Karamanoğlu Mehmetbey University Campus research area during the 2020–2021 production season. To maximize the tillering capacity of the plants, sowing was performed sparsely (20 × 20 cm spacing) on 28 October 2020, with ten plants per plot. The study utilized three registered durum wheat varieties, two local varieties, and ten hybrid combinations (F₁ stage) derived from these varieties. DAP mineral fertilizer was applied at a rate corresponding to 10 kg da⁻¹ of pure phosphorus (P) at planting, providing 3.9 kg da⁻¹ of pure nitrogen (N) simultaneously. The remaining nitrogen was applied as urea in split doses with irrigation water on March 15, 2021, and April 27, 2021, bringing the total nitrogen application to 12 kg da⁻¹. The plants were irrigated using drip irrigation immediately after sowing and during the Zadoks 41, Zadoks 60, and Zadoks 75 growth stages (Zadoks et al 1974). Harvest was carried out on 25–26 June 2021.

Plot Values: The average of the measurements and weights obtained from nine of the ten plants in each plot was used as plot values.

Observations and Measurements are given below.

2.1. Number of Fertile Tillers per Plant (count)

The fertile tillers of each plant were counted to evaluate the number of fertile tillers per plant.

2.2. Main Stem Length (cm)

The height of the main stem was measured from the soil surface to the top spikelet, excluding the awns.

2.3. Main Spike Length (cm)

The spike length was measured as the distance from the lowest node on the spike axis to the tip of the uppermost spikelet, excluding the awns.

2.4. *Number of Grains in the Main Spike (count)*

Grains from each spike were threshed separately, counted, averaged, and recorded as the number of grains per spike.

2.5. *Main Spike Yield (g)*

Grains from threshing the main spike were weighed individually, averaged, and recorded in grams (g).

2.6. *Yield of Other Tillers (Except for the main stem, other stems = tillers) (g)*

The yield of the tillers was determined by subtracting the weight of the main spike from the total individual plant yield obtained by weighing the grains of the whole plant.

2.7. *Yield per Tiller (g)*

The tillers yield of the other than the main stem was divided by the number of fertile tillers to obtain the yield per tiller.

2.8. *Single Plant Yield (g)*

Individual plant yield was determined by weighing the threshed grain from each harvested plant.

2.9. *Days to Heading (day)*

The date when 50% of the plants protruded from the flag leaf was recorded as the spike date. The number of days to spike was calculated based on January 1 as the starting date.

2.10. *Statistical Analysis*

The statistical analyses used the 'Agricolae', 'FactoMineR', and 'Factoextra' packages in the R Studio version 4.3.2 (Kassambara 2017). Differences between means subjected to variance analysis were tested using Duncan's multiple comparison method ($p \leq 0.05$). Regression graphs were plotted in Microsoft Excel.

3. Results and Discussion

Statistical analysis showed that the number of fertile tillers (NTF), yield of tillers (OTY), average yield per tiller (TY) and single plant grain yield (SPY) were not statistically significant. In contrast, main stem height (MSH), main spike length (MSL), number of grains in the main spike (NGMS), main spike yield (MSY) and number of days to spike (NDY) were found to be statistically significant. Although considerable variation was observed among genotypes in traits such as OTY and SPY examined in the study, these differences were not found to be statistically significant. This may be attributed to inconsistencies in the performance of certain genotypes across replications. As a result, some differences that may be biologically meaningful were not supported by statistical significance (Table 1).

3.1. *Fertile Tiller Number (NTF)*

The average number of fertile tillers was determined to be 13.49. Genotypes coded as G8, G1 (Ç-1252), G14, G6, G9, G13, G11, and G4 (AR 14) produced a number of fertile tillers above the average. The lowest number of fertile tillers was observed in genotype G3 (Poyraz), with 8.60, while the highest was recorded in genotype G8 (Ç-1252/Kızıltan 91), with 16.06 (Table 1). All of these, except G1, were F_1 genotypes. In other words, F_1 hybrids were generally above average. In a previous study, the number of fertile tillers varied between 6.78 and 28.06 depending on the genotype (Soylu and Sade 2003), and the number of fertile tillers per unit area was also found to vary (Geçit and Çakır 2006). Although the number of tillers in wheat is under genetic control, cultivation techniques significantly influence this trait. For instance, as the sowing density decreases, meaning fewer plants per unit area, the number of tillers per plant increases (Taner 2022).

Table 1. Average values of the genotypes used in the study in terms of the characteristics examined.

GN	Genotype	Status	NFT (count)	MSH (cm)	MSL (cm)	NGMS (count)	MSY (g)	OTY (g)	TY (g)	SPY (g)	NDH (day)
G1	Ç-1252	variety	15.60±1.40	97.23±0.37de	13.15±1.99a	57.67±2.83ab	3.39±0.05ac	27.58±2.13	1.77±0.02	30.97±2.07	130.0±0.00bc
G2	Kızıltan 91	variety	12.25±0.95	91.53±1.63e	10.70±0.09b	56.15±1.45ac	3.32±0.15ac	21.72±2.09	1.77±0.03	25.04±1.94	131.0±0.00ab
G3	Poyraz	variety	8.60±0.60	75.40±0.99g	6.78±0.40e	47.27±7.82ce	2.59±0.49de	13.18±2.45	1.52±0.17	15.77±2.94	127.0±1.00df
G4	AR14	landrace	13.85±1.25	129.00±3.58a	9.70±0.15bd	54.65±2.05d	3.16±0.10ad	24.51±1.93	1.77±0.02	27.67±1.82	132.5±0.501a
G5	KY11	landrace	13.10±0.50	130.26±4.84a	9.60±0.13bd	42.40±0.70e	2.46±0.06e	19.00±2.35	1.46±0.23	21.46±2.41	132.5±0.50a
G6	Ç-1252/AR14	F ₁	14.58±1.2	113.08±5.93bc	9.94±0.31bd	53.67±3.66ad	3.50±0.56a	30.88±1.59	2.14±0.25	34.38±2.16	128.0±0.00de
G7	Ç-1252/KY11	F ₁	12.85±0.65	119.33±0.65b	10.07±0.07bc	49.30±1.60be	2.93±0.24ae	20.63±0.02	1.61±0.07	23.56±0.22	130.5±0.50b
G8	Ç-1252/Kızıltan 91	F ₁	16.06±0.83	95.82±0.48de	10.77±0.04b	58.50±0.61ab	3.46±0.09ab	26.24±2.68	1.63±0.08	29.70±2.77	128.5±0.50cd
G9	Kızıltan 91/AR14	F ₁	14.52±0.18	114.59±0.25bc	10.23±0.04b	53.13±0.42ad	3.44±0.23ab	27.76±1.19	1.91±0.10	31.21±1.42	128.5±0.50cd
G10	Kızıltan 91/KY11	F ₁	12.67±0.11	112.83±5.62bc	10.28±0.260b	47.56±3.11ce	2.96±0.37ae	20.80±1.26	1.64±0.11	23.76±0.88	131.0±0.00ab
G11	KY11/AR14	F ₁	13.95±3.35	130.72±1.68a	9.46±0.18bd	45.70±2.00de	2.77±0.28be	23.06±1.78	1.72±0.28	25.83±1.49	131.0±0.00ab
G12	Poyraz/AR14	F ₁	12.43±1.42	101.74±1.56d	8.23±0.02de	54.83±1.74ad	3.22±0.38ad	25.52±3.34	2.05±0.03	28.74±2.95	125.5±0.50f
G13	Poyraz/Ç-1252	F ₁	13.98±1.87	83.14±3.46f	8.16±0.14de	54.75±3.25ad	2.70±0.47ce	26.71±9.23	1.86±0.41	29.41±9.71	127.0±1.00df
G14	Poyraz/Kızıltan 91	F ₁	15.31±1.93	89.34±3.03ef	9.08±0.15bd	62.13±2.00a	3.53±0.25a	29.98±4.40	1.95±0.04	33.51±4.65	125.5±0.50f
G15	Poyraz/KY11	F ₁	12.65±0.85	109.28±0.19c	8.43±0.23ce	55.40±0.10a	3.13±0.05ae	22.75±3.70	1.77±0.17	25.88±3.64	126.5±0.50ef
	Mean		13.49	106.22	9.64	52.87	3.10	24.02	1.79	27.13	129.00
	CV%		14	4	8	7	9	21	14	19	1
	(p≤0.05)		ns	***	***	**	*	ns	ns	ns	***

NFT, Number of fertile tillers; MSH, Main stem length; MSL, Main spike length, NGMS, Number of grains per main spike; MSY, Main spike yield; OTY, Yield of tillers; TY, Average yield per tiller; SPY, Single-plant yield; NDH, Days to heading. ns, not significant. Values with the same letter indicate no significant difference.

3.2. Main Stem Length (MSH)

The average main stem length was recorded as 106.22 cm. Genotypes coded as G11, G5, G4, G7, G9, G6, G10, G15, and G12 had main stem length above the average. The shortest main stem length, 75.40 cm, was observed in genotype G3, while the longest, 130.26 cm, was recorded in genotype G5 (Table 1). The landrace genotypes with the highest plant height values, significantly exceeding the average, were AR14 and KY11. The hybrid derived from these two genotypes was the KY11/AR14 combination. Variations in plant length among genotypes have been reported in the literature (Kaya and Şanlı 2009; Taner and Sade 2012). Landrace genotypes are generally tall (Çakır 2024). In this study, both local genotypes exhibited tall stature, and their hybrids also produced tall plants (Table 1). It is well established that tallness is generally dominant over shortness in wheat. The observed variation in plant height in this study may be attributed to the influence of non-additive genetic effects (Göçmen Akçacık 2006).

3.3. Main Spike Length (MSL)

The average main spike length of the main stems was recorded as 9.64 cm. Genotypes coded as G1, G8, G2, G10, G9, G7, G6, and G4 had main spike lengths above the average. The longest main spike length was observed in genotype G1 at 13.15 cm, while the shortest was recorded in genotype G3 at 6.78 cm (Table 1). The statistically significant differences in main spike length among genotypes align with the findings of Kaya and Şanlı (2009), Atak et al. (2021), and Kahraman and Gökmen (2022). The differences in spike length observed among genetically diverse cultivars and their hybrids (Table 1) may be attributed to the genetic interactions involving two or more genes (Sharma et al. 2003).

3.4. Number of Grains in the Main Spike (NGMS)

The average number of grains in the main spike was 52.87. Genotypes coded as G14, G8, G1, G2, G15, G12, G13, G4, G6, and G9 had higher-than-average grain counts. The lowest number of grains in the main spike was recorded in genotype G5, with 42.40, while the highest was observed in genotype G14, with 62.13 (Table 1). The differences in the number of grains in the main spike among genotypes were statistically significant, consistent with the findings of Geçit and Çakır (2006), Koç and Çiftçi Aydoğan (2022) and Kahraman and Gökmen (2022). An examination of the number of grains per spike reveals differences between registered and local varieties. However, their hybrids exhibit higher grain numbers (Table 1), which is thought to be a result of heterosis (Özberk and Kırtok 2002).

3.5. Main Spike Yield (MSY)

The average yield of the main spike was measured as 3.10 g. Genotypes coded as G14, G6, G8, G9, G1, G2, G12, G4, and G15 had yields above the average. The highest main spike yield was observed in genotype G14, with 3.53 g, while the lowest was recorded in genotype G5, with 2.46 g (Table 1). In terms of main spike yield, the varieties Ç-1252 and Kızıltan 91, along with the landrace genotype AR14 and their hybrid combinations, exhibited higher values. The main spike yield differences among genotypes were statistically significant, consistent with the findings of Geçit and Çakır (2006) and Pampana et al. (2016). Spike yield is influenced by both the number and the weight of grains. Grain weight differed among the varieties and their hybrids (Table 1). These variations may be attributed to differences in the general combining abilities of the varieties and the expression of heterosis in their hybrids (Taner and Sade 2012).

3.6. Yield of Other Tillers (OTY) (Except for the main stem, other stems = tillers)

The average yield of tillers was calculated as 24.02 g. The genotypes with the highest values above the average were, in descending order, G6, G14, G9, G1, G13, G8, G12, and G4. The highest yield for this trait was recorded in genotype G6, with 30.88 g, while the lowest was observed in genotype G3, with 13.18 g (Table 1). Similarly, Elhani et al. (2007) reported significant differences among genotypes in tiller yields, consistent with the findings of this study. The variety Ç-1252 and landrace genotype AR14 and their hybrid combinations, exhibited higher values (Table 1).

3.7. Yield per Tiller (TY)

The average yield per tiller was 1.79 g. The genotypes with yields above the mean all of which were F₁ genotypes were, in descending order, G6, G12, G14, G9, and G13. The highest yield per tiller was recorded in genotype G6 (2.14 g), whereas the lowest yield was observed in genotype G5, which was a landrace genotype, at 1.46 g (Table 1).

3.8. Single Plant Yield (SPY)

Single plant yield is determined by the number of grains in the spike and the thousand grain weight, making it a critical factor positively influencing overall grain yield (Yıldırım et al., 2005). The average single plant yield was recorded as 27.13 g. The genotypes with the highest single plant yield values above the average, listed in descending order, were G6, G14, G9, G1, G8, G13, and G4. The highest single plant yield was observed in genotype G6, while the lowest was recorded in genotype G3, with 15.77 g (Table 1). These findings regarding single plant yield were statistically insignificant, consistent with the results of an earlier study by Ulukan (1990). With the exception of the Poyraz/KY11 hybrid combination, the Ç-1252 variety, the AR14 landrace genotype, and their hybrid combinations were identified as the prominent genotypes in terms of single plant yield (Table 1).

3.9. Number of Days to Heading (NDH)

The average number of days to heading was determined to be 129.0 days. Among the genotypes in this study, the ones with symbols G4, G5, G11, G2, G10, G7, and G1 exhibited heading days above the average. These genotypes ranged from the latest to the earliest heading, respectively. Genotypes G4 and G5 had the latest heading days at 132.5 days, while genotypes G14 and G12 shared the earliest spike days at 125.5 days (Table 1). These findings are in line with the results of previous studies conducted by Khan et al. (2013) and Kahraman and Gökmen (2022). In terms of heading time, the latest genotypes were the landrace genotypes AR14 and KY11, followed by hybrids involving KY11 and the varieties Ç-1252 and Kızıltan 91 (Table 1). Due to its spring wheat (Anonymous 2019), the Poyraz variety exhibited earliness in heading time, which was also observed in its hybrids.

The Ç-1252 variety can be evaluated as a parent in breeding studies for its main spike length, grain number per spike, and fertile tiller number. The Kızıltan 91 variety is notable for its grain number per spike, while the Poyraz variety stands out for its short plant height and earliness, making it a potential parent in breeding programs.

When hybrid combinations are analyzed:

- The Ç-1252/AR14 hybrid combination demonstrates significant potential for main spike yield, yield from tillers, yield per tiller, and single plant yield.

- The Ç-1252/Kızıltan 91 hybrid shows promise for fertile tiller number, main spike length, grain number per spike, and main spike yield.

- The Kızıltan 91/AR14 hybrid is notable for its yield from tillers and single plant yield.

- The Poyraz/AR14 hybrid combination excels in yield per tiller and earliness.

- The Poyraz/Ç-1252 hybrid exhibits favorable traits for short stature and earliness.

- The Poyraz/Kızıltan 91 hybrid stands out for increasing fertile tiller number, shortening main stem length, enhancing grain number per main spike, and improving main spike yield, yield from tillers, yield per tiller, single plant yield, and earliness.

- The Poyraz/KY11 hybrid combination can be monitored for its potential in earliness traits.

These hybrid combinations represent valuable genetic resources for the improvement of targeted traits in breeding programs.

3.9. Correlation Values of Relationships between Characteristics

The correlation coefficient is a measure of the relationship between two variables, specifically the extent to which they change together. In other words, correlation represents the average strength of the relationship between two variables (Yurtsever 1984). Numerous researchers have employed correlation analysis to explore the relationships between yield and its components (Taner 2022; Ali et al. 2024). According to the correlation analysis results, significant positive relationships were observed between the number of fertile tillers and MSL (0.644), NGMS (0.521), MSY (0.599), OTY (0.847), and SPY (0.843). There was a positive relationship between main stem height and NDH (0.647). The number of grains in the main spike was positively correlated with MSY (0.812), OTY (0.691), TY (0.583), and SPY (0.712). The main spike grain yield showed positive correlations with OTY (0.754), TY (0.657), and SPY (0.784). There was a negative relationship between the single plant yield and NDH (-0.308) and a positive relationship between SPY (0.805) (Figure 1).

In diverse yield environments, the trade-off between the number of spikes per plant and the number of grains per spike has been identified as a pivotal factor influencing yield, particularly in the context of varying tillering potentials (Bastos et al. 2020). Moreover, a positive and statistically significant correlation has been established between grain yield and various traits, including the number of grains per spike and single spike yield (Kahraman and Gökmen 2022).

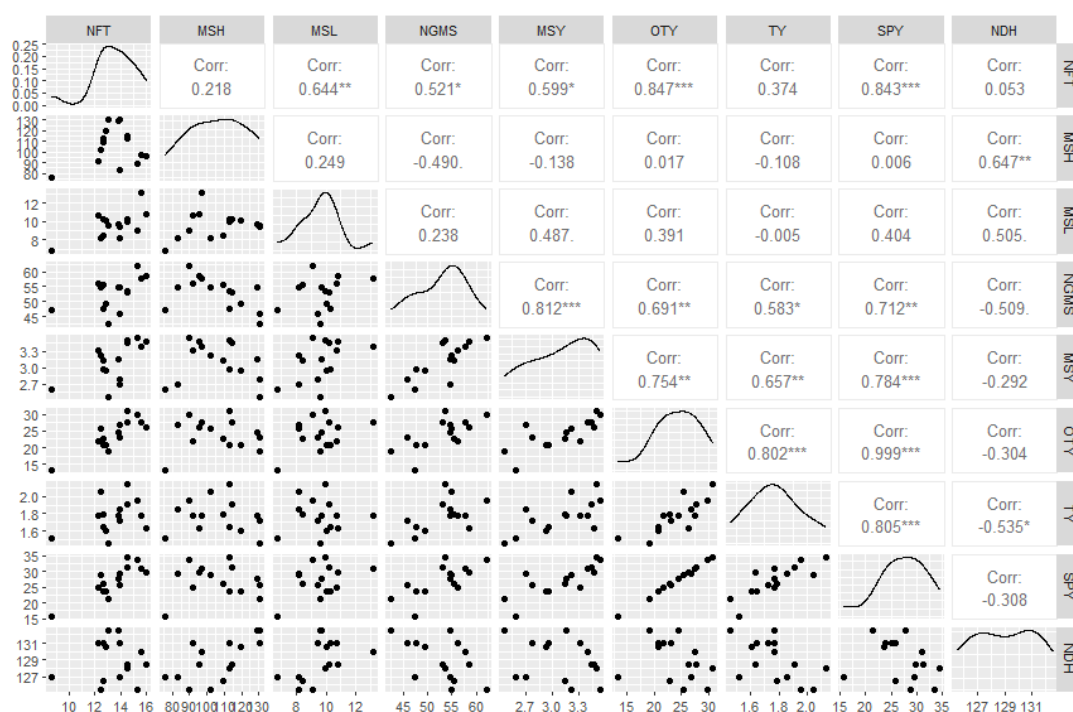


Figure 1. Correlation values of the examined features

Moderately positive correlations were observed between the number of fertile tillers and main spike length, as well as between the number of grains per main spike. Highly positive correlations were noted between the number of fertile tillers and the yield of tillers, along with single-plant yield. Notably, the correlation coefficient between grain yield per tiller and single-plant yield was higher than the correlation coefficient between main spike yield and single-plant yield.

3.10. Regression graph of single-plant yield, main stem spike yield, and yield per tiller

Grain yield is influenced by several factors, primarily the number of grains per spike, the grain weight within the spike, and spike yield. Additionally, the number of plants per unit area is a critical determinant of grain yield.

When evaluating the regression graphs illustrating the relationship between single plant yield, main stem spike yield, and yield per tiller, it was observed that the coefficient of determination for grain yield per tiller

($R^2=0.57$) was higher than that of the main stem spike yield ($R^2=0.40$) (Figure 2). This indicates that grain yield can be increased by maintaining the number of tillers at an optimal level through proper planting density in sparse sowing systems. In support of this, a previous study reported higher grain yields at a sparse sowing density of 5×5 cm compared to other sowing methods such as 5×10 cm, 10×10 cm, and traditional planting with 20 cm row spacing (Taner 2022). Regression analysis also indicated that the coefficient of determination for grain yield per tiller was higher than that for grain yield from the main spike.

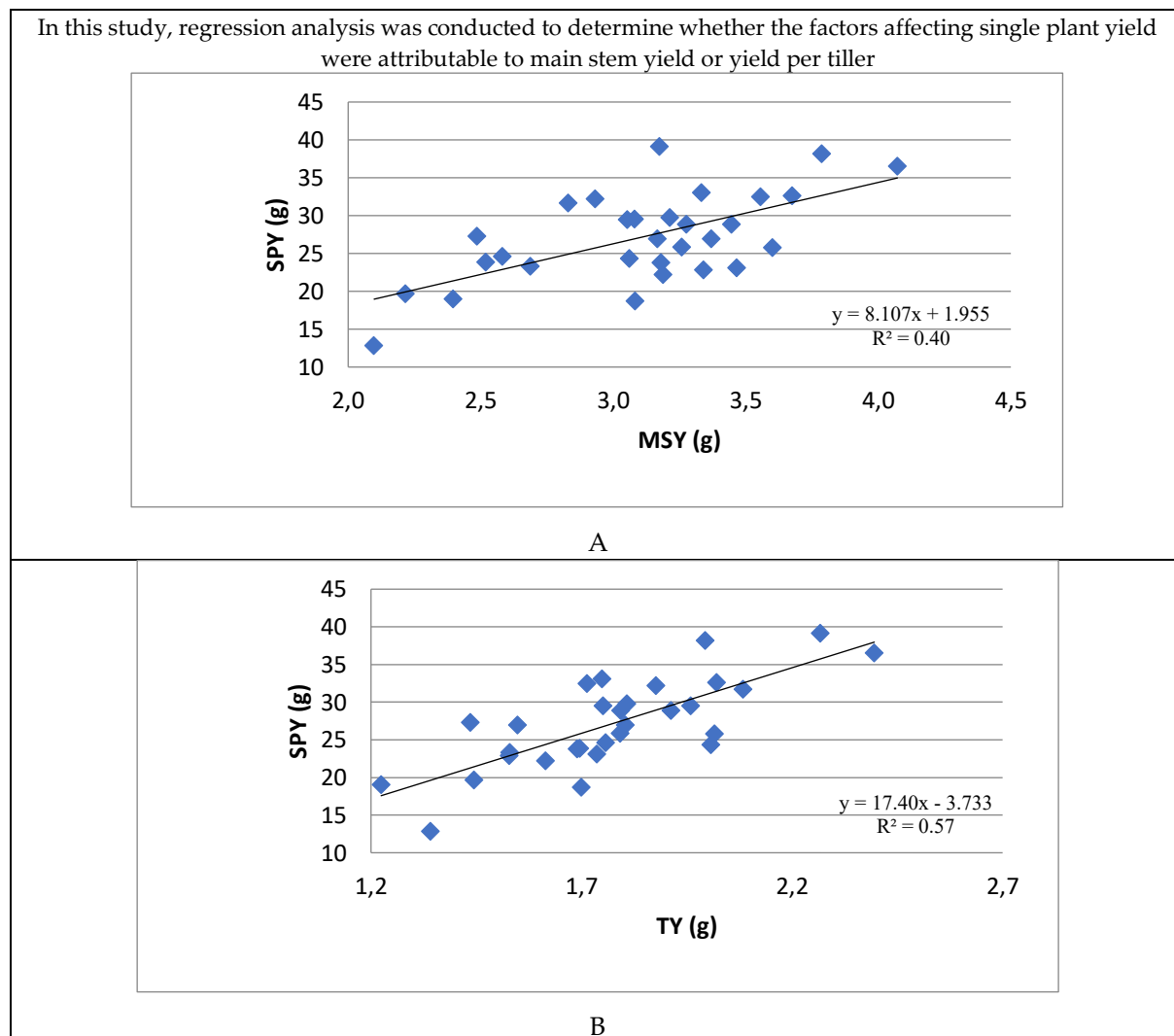


Figure 2. Regression graph of single plant-yield, main stem spike yield, and yield per tiller spike (Figure 2a. Regression graph of yield of single plant and yield of spike belonging to main stem; Figure 2b. Regression graph of yield per tiller with yield of single plant)

4. Conclusions

As in the findings of the hybrid combinations of Ç-1252/AR14 and Poyraz/Kızıltan 91, new promising lines or varieties can be developed in terms of yield and yield components from crossbreedings of registered varieties among themselves or landraces in future studies.

While high significance was found between the number of fertile tillers and main spike length (0.64), yield of other tillers (0.84), single plant yield (0.84), a moderate significance was found between the number of grains in the main spike (0.52) and main spike yield (0.59). The high correlation coefficient observed between the number of fertile tillers and single plant yield, as well as between the number of fertile tillers and the yield of other tillers, highlights the importance of these traits. Additionally, the correlation coefficient between grain yield per tiller and single plant yield is notably higher than the correlation coefficient between main spike

yield and single plant yield. Furthermore, the determination coefficient for single plant yield and yield per tiller is greater than that for single plant yield and main stem yield. In this study, considering the sparse planting method employed as opposed to traditional row planting, the findings support the hypothesis that achieving a balanced number of tillers under optimal plant density can significantly enhance overall yield.

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References

- Abinasa MA, Ayana GB (2011). Genetic variability, heritability, and trait associations in durum wheat (*Triticum turgidum* L. var. durum) genotypes. *African Journal of Agricultural Research* 6(17), 3972-3979. <https://doi.org/10.5897/AJAR10.880>
- Akman H, Topal A (2010). Makarnalık buğdayda farklı şekillerde üre uygulamasının verim, verim unsurları ve kaliteye etkisi. *Selçuk Tarım ve Gıda Bilimleri Dergisi* 24(3), 41-51.
- Ali A, Momand MJ, Ali M, Rahman SU, Abbas S (2024). Estimation of phenotypic and genotypic correlation analysis in F₃ populations of bread wheat genotypes. *Turkish Journal of Agriculture–Food Science and Technology* 12(6), 905-910. <https://doi.org/10.24925/turjaf.v12i.905-910.6672>
- Anonim (2019). Ege-Güney Marmara Bölgesi makarnalık buğday tescil raporu. T.C. Tarım ve Orman Bakanlığı, Tohumluk Tescil ve Sertifikasyon Merkez Müdürlüğü, Ankara.
- Arduni I, Pellegrino E, Ercoli L (2018). Contribution of main culm and tillers to grain yield of durum wheat: Influence of sowing date and plant traits. *Italian Journal of Agronomy* 13(1115), 235-247.
- Atak M, Kısa Ö, Atış İ (2021) Ekimsıklığının buğday (*Triticum* sp.) genotiplerinin verim ve bazı kalite özelliklerine etkisi. MKU. *Mustafa Kemal Üniversitesi Tarım Bilimleri Dergisi* 26(2): 387-398. <https://doi.org/10.37908/mkutbd.910456>
- Aydoğan S, Şahin M, Akcacık A, Türköz M (2010). İleri makarnalık buğday hatlarının farklı çevrelerde verim ve kalite özellikleri yönünden değerlendirilmesi. *Harran Tarım ve Gıda Bilimleri Dergisi* 14(4), 23-31.
- Bastos LM, Carciochi W, Lollato RP, Jaenisch BR, Rezende CR, Schwalbert R, Prasad PV, Zhang G, Fritz AK, Foster C, Wright Y, Young S, Bradley P, Ciampitti IA (2020). Winter wheat yield response to plant density as a function of yield environment and tillering potential: A review and field studies. *Frontiers in Plant Science* 11, 54. <https://doi.org/10.3389/fpls.2020.00054>
- Bozdağ A, Soylu S (2019). Orta Anadolu Bölgesinde geliştirilen mısır (*Zea mays* L.) hatlarının kombinasyon yeteneklerinin ve melez güçlerinin incelenmesi. *Bahri Dağdaş Araştırma Dergisi* 8(1), 64-72.
- Çakır E (2024). Akdeniz havzasındaki ülkelerden toplanmış yerel makarnalık buğday (*Triticum durum* L.) genotiplerinin Adana koşullarında agro-morfolojik özelliklerinin değerlendirilmesi. *Çukurova Tarım Gıda Bilimleri Dergisi* 39(2), 479-496. <https://doi.org/10.36846/CJAFS.2024.167>
- Çat A (2022). Tescilli makarnalık buğday (*Triticum durum*) çeşitlerinin sarı pas (*Puccinia striiformis* f. sp. *tritici*) hastalığına karşı dayanıklılığının belirlenmesi. *Turkish Journal of Agricultural Engineering Research* 9(2), 136-143.

- Elhani S, Martos V, Rharrabti Y, Royo C, Garcí'a del Moral LF (2007). Contribution of main stem and tillers to durum wheat (*Triticum turgidum* L. var. durum) grain yield and its components grown in Mediterranean environments. *Field Crops Research* 103, 25–35. <https://doi.org/10.1016/j.fcr.2007.05.008>
- Eser D, Adak S (1998). Orta Anadolu koşullarında farklı toprak işleme, mercimek–buğdayve nadas–buğday ekim nöbeti sistemlerinde mercimek ve buğdayda kök uzunluğu yoğunluğu ile toprakta infiltrasyon ölçümleri. *Turkish Journal of Agriculture and Forestry* 22, 483–489.
- Geçit HH, Çakır E (2006). Makarnalık Buğdayda (*Triticum durum* L.) Sulama ve Azotlu Gübrelemenin Verim ve Bazı Verim Öğeleri Üzerine Etkisi. *Tarım Bilimleri Dergisi* 12 (3), 259-266. https://doi.org/10.1501/Tarimbil_0000000461
- Göçmen Akçacık A (2006). Ekmeklik buğdayda verim ve kalite özellikleri yönüyle uygun anaçların, kombinasyon yeteneklerinin ve kalıtım parametrelerinin çoklu dizi (Line X Tester) yöntemi ile belirlenmesi. Doktora Tezi. Selçuk Üniversitesi (Yayınlanmamış), Türkiye.
- Gökmen F, Zengin M, Arısoy RZ, Taner S, Gezgin S, Çakmak İ (2008). Amonyum nitrat ve entec gübrelerinin çinkosuz ve çinkolu bloklarda yetiştirilen makarnalık buğdayın verim ve verim unsurlarına etkileri. *Ülkesel Tahıl Sempozyumu*, 2-5 Haziran 2008, Konya; 536-551.
- Gülmezoğlu N, Tolay İ (2016). Eskişehir kuru koşullarında ekmeklik ve makarnalık buğday çeşitlerinin bazı verim unsurları, verim ve kalite özelliklerinin karşılaştırılması. *Tarım Bilimleri Araştırma Dergisi* 9 (1), 05-08.
- He G, Wang Z, Ma X, He H, Cao H, Wang S, Dai J, Luo L, Huang M, Malhi SS (2017). Wheat yield affected by soil temperature and water under mulching in dryland. *Agronomy Journal* 109, 2998-3006. <https://doi.org/10.2134/agronj2017>
- Kahraman ND, Gökmen S (2022). Konya koşullarında makarnalık buğdaylarda bazı fenolojik ve morfolojik özellikler ile verim ve verim unsurlarının belirlenmesi. *Bahri Dağdaş Bitkisel Araştırma Dergisi* 11 (1), 40-48.
- Kan A, Sade B (2002). Ekmeklik buğdaylarda (*Triticum aestivum* L.) kalite özelliklerinin kombinasyon yeteneği, melez gücü ve kalıtımı. *Selçuk Üniversitesi Ziraat Fakültesi Dergisi* 16 (29), 12-18.
- Kassambara A (2017). Practical guide to principal component methods in R: PCA, M (CA), FAMD, MFA, HCPC, factoextra (Vol. 2). Sthda; <https://bafr.shinyapps.io/BAFR/>. (access date: 05.03.2024).
- Katiyar A, Sharma A, Singh S, Srivastava A, Vishwakarma SR (2021). Combining ability analysis for yield traits in barley (*Hordeum vulgare* L.). *Electronic Journal of Plant Breeding* 12(2), 583-588. <https://doi.org/10.37992/2021.1202.082>
- Kaya M, Şanlı A (2009). Bazı ekmeklik (*Triticum aestivum* L.) ve makarnalık (*Triticum durum* L.) buğday çeşitlerinin Isparta ekolojik koşullarında verim ve bazı verim öğelerinin belirlenmesi. *Bitkisel Araştırma Dergisi* 2, 27-34.
- Khan AA, Alam MA, Alam MK, Alam MJ, Sarker ZI (2013). Correlation and path analysis of durum wheat (*Triticum turgidum* L. var. Durum). *Bangladesh Journal of Agricultural Research* 38(3), 515-521.
- Koç S, Çifci Aydoğan E (2022). Ekmeklik buğday (*Triticum aestivum* L.) hat ve çeşitlerinin farklı çevrelerde bazı tarımsal özellikler yönünden incelenmesi. *Bursa Uludağ Üniversitesi Ziraat Fakültesi Dergisi* 36(1), 103-118. <https://doi.org/10.20479/bursauludagziraat.986091>
- Kühling I, Redozubovc D, Brollb G, Trautza D (2017). Impact of tillage, seeding rate and seeding depth on soil moisture and dryland spring wheat yield in Western Siberia. *Soil & Tillage Research* 170, 43–52. <http://dx.doi.org/10.1016/j.still.2017.02.009>
- Pampana S, Masoni A, Arduini I (2016). Grain yield of durum wheat as affected by waterlogging at tillering. *Cereal Research Communications* 44(4), 706-716. <https://doi.org/10.1556/0806.44.2016.026>
- Sharma SN, Sain RS, Sharma RK (2003). Genetics of spike length in durum wheat. *Euphytica* 130, 155–161.

- Sodhaparmar HR, Patel NJ, Bedse TJ (2024). Biochemical characterization of wheat and their antinutritional composition. *International Journal of Advanced Biochemistry Research* SP-8(1), 87-93. <https://doi.org/10.33545/26174693.2024.v8.i1Sb.290>
- Soylu S, Sade B (2003). Makarnalık buğdaylarda (*Triticum durum* L.) bitki boyu, hasat indeksi ve bunlara etkili faktörlerin kombinasyon yeteneği ve kalıtımı. *Anadolu, Journal of Aegean Agricultural Research Institute* 13 (1), 75-90.
- Taner S, Sade B (2012). Kuru şartlarda 5x5 yarım diallel ekmeklik buğday melez popülasyonunda kombinasyon yetenekleri ve heterosis değerlerinin incelenmesi. *Selçuk Tarım ve Gıda Bilimleri Dergisi* 26(4), 1-10.
- Taner S (2022). Ekim şekline göre tohum sıklıklarının yağışa bağımlı şartlarda buğday tane verimi ve bazı verim unsurlarına etkisi. *Bahri Dağdaş Bitkisel Araştırma Dergisi* 11(2), 165-172.
- Ulukan H (1990). Sıra arası açıklığı ve sıra üzeri sıklığının buğdayda ilk gelişme, kardeşlenme verim ve verim ögelerine etkisi. Yüksek Lisans Tezi. Ankara Üniversitesi (Basılmamış), Ankara.
- Özberk İ, Kırtok Y (2002). Makarnalık buğdayda bazı kantitatif karakterlerdeki genetik varyasyon ve kalıtımın araştırılması. *Anadolu, Journal of Aegean Agricultural Research Institute* 12 (1), 192 - 209.
- Öztürk İ, Kahraman T, Avcı R, Girgin VÇ, Çiftçigil TH, Seidi M, Tülek A, Akın K, Tuna B (2018). Ekmeklik buğday (*Triticum aestivum* L.) genotiplerinde çevre koşullarının agronomik karakterler ve biyotik stres faktörlerine etkisi. *Bahri Dağdaş Bitkisel Araştırma Dergisi* 7(1), 14-22.
- Verma SR, Yunus M, Sethi SK (1998). Breeding for yield and quality in durum wheat. *Euphytica* 100, 15-18.
- Yıldırım A, Sakin MA, Gökmen S (2005). Tokat Kazova koşullarında bazı ekmeklik buğday çeşit ve hatlarının verim ve verim unsurları yönünden değerlendirilmesi. *TGOÜ Ziraat Fakültesi Dergisi* 22(1), 63-72.
- Yurtsever N (1984). Deneyisel istatistik metotlar, T.C. Tarım Orman ve Köyişleri Bakanlığı Köy Hizmetleri Genel Müdürlüğü Yayınları, Ankara. Sayfa 171.
- Zhang Q, Men X, Hui C, Ge F, Ouyang F (2022). Wheat yield losses from pests and pathogens in China. *Agriculture, Ecosystems and Environment* 326, 107821. <https://doi.org/10.1016/j.agee.2021.107821>
- Zadoks JC, Chang TT, Konzak CF (1974). A decimal code for growth stages of cereals. *Weed Research* 14, 415-421.



Genetic Variation Analysis of Selected Grape (*Vitis vinifera* L.) Accessions Through SCoT Markers

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HIGHLIGHTS

- In this study, 45 grape genotypes were used as plant material.
- SCoT markers can be successfully used, either alone or in combination with other existing DNA markers, to study interspecific or intraspecific genetic variation.
- The molecular identification and conservation of local grape varieties are highly important for sustainable agricultural practices.

Abstract

Molecular techniques such as ISSR, RAPD, SCoT, and SSR are widely used to identify genetic polymorphism, reveal genetic structures, and analyze inter-varietal relationships in grape cultivars. In this context, the aim of our study was to reveal the genetic diversity of some local grape (*Vitis vinifera*) genotypes cultivated or naturally found in the Divriği district of Sivas province, contribute to the sustainable conservation of natural genetic resources, and determine the agricultural production potential of these genotypes. Additionally, the potential use of Start Codon Targeted (SCoT) markers in evaluating the diversity among different grape genotypes was investigated. Plant materials were collected from vineyards, and DNA was isolated from fresh leaves using the CTAB method. A total of 36 SCoT markers were screened in the samples, and 12 markers with the highest polymorphism rate were selected for analysis. In this study, a total of 119 bands were obtained from the 12 SCoT primers used to determine the genetic relationships among the grape genotypes. Among these, 83 bands were polymorphic, resulting in a polymorphism rate of 69.74%. The molecular data obtained allowed for the construction of a dendrogram (phylogenetic tree) grouping the analyzed grape genotypes according to their similarity indices. According to the UPGMA dendrogram and the correlation matrix generated from the SCoT molecular data, the lowest genetic similarity (0.382) was observed between genotypes G6 and G38, while the highest similarity (0.786) was found between genotypes G37 and G39. In conclusion, it was demonstrated that SCoT markers can be effectively used to assess genetic variation and establish similarity indices among grape genotypes. This molecular approach provides a robust basis for advanced genetic research and future breeding programs.

Keywords: *Vitis vinifera* L.; genetic diversity; molecular marker.

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1. Introduction

Grapes, which hold an important place in both our kitchens and traditional medicine, are a perennial fruit species belonging to the *Vitaceae* family (Braidot et al. 2008). Grape varieties are rich in phenolic compounds, flavonoids, vitamins, minerals, and organic acids (Lebon et al. 2008). Thanks to these chemical components, grapes exhibit strong antioxidant, antimicrobial, anti-inflammatory, and anticancer properties. In addition to being consumed fresh or dried, grapes are widely used in various forms such as juice, vinegar, molasses, wine, and cosmetic products (Pellegrino et al. 2005). Derivative products like grape seed extract also hold commercial value as functional foods and natural health supplements. *Vitis vinifera* L., due to its high economic value, nutritional content, and medicinal effects, is one of the most widely cultivated fruit species globally. Due to its broad geographical distribution and ability to adapt to different environmental conditions, grape species exhibit a high level of genetic diversity (Franks et al. 1998; Goufo et al. 2020). Although the Sivas province, particularly the districts of Zara, Divriği, and İmranlı, shows limited suitability for large-scale viticulture, local grape varieties naturally or traditionally grown in these areas still exist (Trouillas et al. 2011). These varieties differ morphologically and biochemically depending on the ecological conditions of the region (Martínez et al. 2006). This presents significant potential for the conservation and evaluation of local genetic resources. Local grape varieties are generally preferred for their more intense aroma profiles and region-specific taste characteristics, often tied to traditional production and consumption practices. This diversity, defined as genetic polymorphism, is critically important for the sustainability, environmental adaptation, and breeding of the species (This et al. 2006; Riaz et al. 2018). Genetic polymorphism enables grape varieties to develop tolerance to different climate and soil conditions, and resistance to pests and diseases. The genetic diversity demonstrated by local varieties grown especially in arid and semi-arid regions enhances the adaptability of these plants (Aradhya et al. 2003; Nicolas et al. 2016).

Genetic diversity directly affects the quality traits of grape fruits. Compounds such as tannins, resveratrol, and anthocyanins may vary among genotypes (Aradhya et al. 2013). These differences directly influence many traits such as fruit quality, shelf life, processability, and commercial value. Therefore, genetic polymorphism plays a fundamental role in determining the quality standards of grapes for both fresh consumption and industrial processing (Zdunić et al. 2013). The primary goals of grape breeding programs include improving yield, resistance to diseases and pests, fruit quality, aroma profile, and tolerance to stress conditions. Genetic polymorphism enables the selection and improvement of such traits. Identifying genetically distinct individuals is crucial for determining superior lines in breeding studies (Ekhvaia et al. 2014; Kaya et al. 2023). Molecular techniques such as ISSR, RAPD, SCoT, and SSR are commonly used to determine genetic polymorphism in grape varieties, to reveal genetic structures, and to analyze relationships between different varieties (Korbin et al. 2002; Almadanim et al. 2007). These techniques allow for more precise and reliable variety identification and classification. These molecular marker techniques have a wide range of applications including classification of grape genotypes, understanding population structure, calculating genetic distance, and selecting superior individuals in breeding programs. Thus, scientifically-based strategies can be developed for the conservation of local varieties and sustainable agricultural production (Souframanien and Gopalakrishna 2004; Collard and Mackill 2009; Poyraz 2016). The aim of this study is to determine the genetic polymorphism among different grape genotypes collected from vineyards in the Divriği district of Sivas province and to reveal the existing genetic diversity. The findings are expected to contribute to the conservation of grape genetic resources in the region and to future breeding efforts.

2. Materials and Methods

Fresh leaves were collected from 45 different grape samples belonging to the *Vitis vinifera* L., germplasm, cultivated in farmer gardens in the Divriği district of Sivas. Information related to the grape samples is presented in Table 1.

Table 1. Data of grape genotypes characterised.

Genotype Code	Fruit Skin Color	Taxonomy	Province	Collected Location	Longitude	Latitude	Altitude (m)
G1	Yellow	<i>Vitis vinifera</i> L.	Divriği	Sivas	39°22'39.7"N	38°06'53.1"E	1150
G2	Red	<i>Vitis vinifera</i> L.	Divriği	Sivas	39°22'39.7"N	38°06'53.1"E	1150
G3	Yellow	<i>Vitis vinifera</i> L.	Divriği	Sivas	39°22'39.7"N	38°06'53.1"E	1150
G4	Colourful	<i>Vitis vinifera</i> L.	Divriği	Sivas	39°22'39.7"N	38°06'53.1"E	1150
G5	Yellow	<i>Vitis vinifera</i> L.	Divriği	Sivas	39°22'39.7"N	38°06'53.1"E	1150
G6	Black	<i>Vitis vinifera</i> L.	Divriği	Sivas	39°22'39.7"N	38°06'53.1"E	1150
G7	Colourful	<i>Vitis vinifera</i> L.	Divriği	Sivas	39°22'39.7"N	38°06'53.1"E	1150
G8	Red	<i>Vitis vinifera</i> L.	Divriği	Sivas	39°22'39.7"N	38°06'53.1"E	1150
G9	Red	<i>Vitis vinifera</i> L.	Divriği	Sivas	39°22'39.7"N	38°06'53.1"E	1150
G10	Red	<i>Vitis vinifera</i> L.	Divriği	Sivas	39°22'39.7"N	38°06'53.1"E	1150
G11	Red	<i>Vitis vinifera</i> L.	Divriği	Sivas	39°22'39.7"N	38°06'53.1"E	1150
G12	Red	<i>Vitis vinifera</i> L.	Divriği	Sivas	39°22'39.7"N	38°06'53.1"E	1150
G13	Red	<i>Vitis vinifera</i> L.	Divriği	Sivas	39°22'39.7"N	38°06'53.1"E	1150
G14	Black	<i>Vitis vinifera</i> L.	Divriği	Sivas	39°22'39.7"N	38°06'53.1"E	1150
G15	Black	<i>Vitis vinifera</i> L.	Divriği	Sivas	39°22'39.7"N	38°06'53.1"E	1150
G16	Black	<i>Vitis vinifera</i> L.	Divriği	Sivas	39°22'39.7"N	38°06'53.1"E	1150
G17	Black	<i>Vitis vinifera</i> L.	Divriği	Sivas	39°22'39.7"N	38°06'53.1"E	1150
G18	Black	<i>Vitis vinifera</i> L.	Divriği	Sivas	39°22'39.7"N	38°06'53.1"E	1150
G19	Black	<i>Vitis vinifera</i> L.	Divriği	Sivas	39°22'39.7"N	38°06'53.1"E	1150
G20	Black	<i>Vitis vinifera</i> L.	Divriği	Sivas	39°22'39.7"N	38°06'53.1"E	1150
G21	Black	<i>Vitis vinifera</i> L.	Divriği	Sivas	39°22'39.7"N	38°06'53.1"E	1150
G22	Black	<i>Vitis vinifera</i> L.	Divriği	Sivas	39°22'39.7"N	38°06'53.1"E	1150
G23	Black	<i>Vitis vinifera</i> L.	Divriği	Sivas	39°22'39.7"N	38°06'53.1"E	1150
G24	Yellow	<i>Vitis vinifera</i> L.	Divriği	Sivas	39°22'39.7"N	38°06'53.1"E	1150
G25	Yellow	<i>Vitis vinifera</i> L.	Divriği	Sivas	39°22'39.7"N	38°06'53.1"E	1150
G26	Yellow	<i>Vitis vinifera</i> L.	Divriği	Sivas	39°22'39.7"N	38°06'53.1"E	1150
G27	Red	<i>Vitis vinifera</i> L.	Divriği	Sivas	39°22'39.7"N	38°06'53.1"E	1150
G28	Red	<i>Vitis vinifera</i> L.	Divriği	Sivas	39°22'39.7"N	38°06'53.1"E	1150
G29	Red	<i>Vitis vinifera</i> L.	Divriği	Sivas	39°22'39.7"N	38°06'53.1"E	1150
G30	Red	<i>Vitis vinifera</i> L.	Divriği	Sivas	39°22'39.7"N	38°06'53.1"E	1150
G31	Black	<i>Vitis vinifera</i> L.	Divriği	Sivas	39°22'39.7"N	38°06'53.1"E	1150
G32	Black	<i>Vitis vinifera</i> L.	Divriği	Sivas	39°22'39.7"N	38°06'53.1"E	1150
G33	Black	<i>Vitis vinifera</i> L.	Divriği	Sivas	39°22'39.7"N	38°06'53.1"E	1150
G34	Black	<i>Vitis vinifera</i> L.	Divriği	Sivas	39°22'39.7"N	38°06'53.1"E	1150
G35	Black	<i>Vitis vinifera</i> L.	Divriği	Sivas	39°22'39.7"N	38°06'53.1"E	1150
G36	Black	<i>Vitis vinifera</i> L.	Divriği	Sivas	39°22'39.7"N	38°06'53.1"E	1150
G37	Black	<i>Vitis vinifera</i> L.	Divriği	Sivas	39°22'39.7"N	38°06'53.1"E	1150
G38	Black	<i>Vitis vinifera</i> L.	Divriği	Sivas	39°22'39.7"N	38°06'53.1"E	1150
G39	Black	<i>Vitis vinifera</i> L.	Divriği	Sivas	39°22'39.7"N	38°06'53.1"E	1150
G40	Red	<i>Vitis vinifera</i> L.	Divriği	Sivas	39°22'39.7"N	38°06'53.1"E	1150
G41	Red	<i>Vitis vinifera</i> L.	Divriği	Sivas	39°22'39.7"N	38°06'53.1"E	1150
G42	Red	<i>Vitis vinifera</i> L.	Divriği	Sivas	39°22'39.7"N	38°06'53.1"E	1150
G43	Colourful	<i>Vitis vinifera</i> L.	Divriği	Sivas	39°22'39.7"N	38°06'53.1"E	1150
G44	Colourful	<i>Vitis vinifera</i> L.	Divriği	Sivas	39°22'39.7"N	38°06'53.1"E	1150
G45	Colourful	<i>Vitis vinifera</i> L.	Divriği	Sivas	39°22'39.7"N	38°06'53.1"E	1150

2.1. Genomic DNA Isolation and PCR

DNA extraction from grape samples was performed based on the CTAB protocol described by Doyle and Doyle (1990). The concentrations of stock DNA were measured using a MaestroNano Pro spectrophotometer (MN913A, MaestroGen), and the DNA stocks were diluted to a final concentration of 5 ng/μL. The selected SCoT primers, PCR reaction mixture content and PCR cycling conditions used for PCR amplifications are presented in Table 2. For electrophoresis of the PCR products, a 2% agarose gel prepared in Tris-borate-EDTA (TBE) buffer was used. DNA bands were subsequently visualized under UV light. A total of 36 SCoT primers were screened and 12 primers that exhibited polymorphic patterns were selected for further analysis (Table 2).

Table 2. SCoT primers used for PCR amplification.

SCoT Primers Code	DNA Sequences (5'-3')	T _m °C	PCR Reaction Mixture Content	PCR Amplification
SCoT 2	CAACAATGGCTACCACCC	56	4 μL DNA (20 ng) 1 μL primer 10 μL PCR master mix (Eco Tech, Cat No: ET5) 10 μL dH ₂ O	94 °C - 3 min 94 °C - 1 min 56–61 °C 1 min 72 °C - 1 min 72 °C - 8 min 35 cycles
SCoT 12	ACGACATGGCGACCAACG	58		
SCoT 18	ACCATGGCTACCACCGCC	61		
SCoT 19	ACCATGGCTACCACCGGC	61		
SCoT 20	ACCATGGCTACCACCGCG	61		
SCoT 21	ACGACATGGCGACCCACA	58		
SCoT 22	AACCATGGCTACCACCAC	56		
SCoT 23	CACCATGGCTACCACCAG	58		
SCoT 26	ACCATGGCTACCACCGTC	58		
SCoT 28	CCATGGCTACCACCGCCA	61		
SCoT 32	CCATGGCTACCACCGCAC	61		
SCoT 33	CCATGGCTACCACCGCAG	61		

2.2. Statistical Analysis

The bands obtained from the PCR analysis were scored as 1 for presence and 0 for absence. A dendrogram based on Jaccard's similarity coefficient was generated using the UPGMA (Unweighted Pair Group Method with Arithmetic Mean) algorithm in the MVSP 3.22 software (Kovach 2007). The application of MVSP 3.22 to the SCoT molecular data enabled the generation of a genetic similarity matrix. In addition, principal component analysis (PCA) was performed among grape populations using the MVSP 3.22 software.

3. Results and Discussion

The gel images of PCR results for the primers, which produced the most polymorphic bands, are shown in Figure 1 are shown. A total of 14, 11, 10, and 13 polymorphic bands were obtained from the primers SCoT-12, SCoT-21, SCoT-28, and SCoT-32, respectively, while the lowest number of bands (6) was obtained from the primer SCoT-26. In polymorphism analysis, the number of bands is a highly important indicator in the assessment of genetic diversity. Whether the number of bands is high or low reflects how informative and sensitive the molecular marker used (e.g., SCoT, ISSR, RAPD) is. As the number of bands increases, the resolution, accuracy, and reliability of genetic polymorphism analyses also improve. This directly affects the quality of scientific research and the success of applied agricultural and breeding programs. A primer or marker that produces a high number of polymorphic bands can reveal genetic differences more precisely. Therefore, such markers are more preferred in breeding programs and in the conservation of genetic resources (Pan ve ark. 2024).

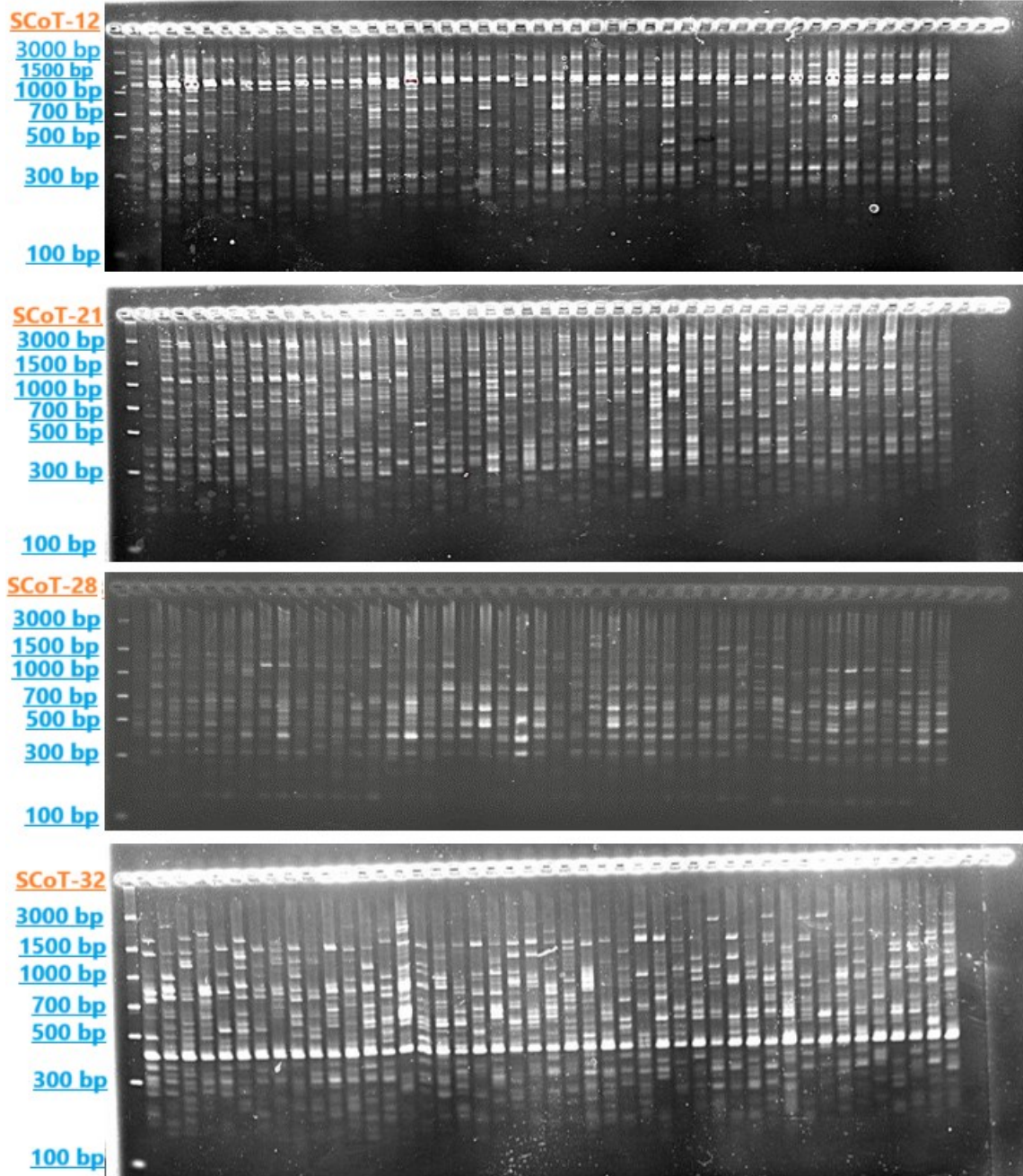


Figure 1. Gel image of bands amplified with SCoT 12, SCoT 21, SCoT 28 and SCoT 32 primers: M: generuler.

In this study, a total of 119 bands were obtained from 12 SCoT primers used to determine the genetic relationships among grape samples. Among these, 83 bands were polymorphic, resulting in a polymorphism rate of 69.74%. According to the UPGMA dendrogram and the correlation matrix generated from the SCoT molecular data, the lowest similarity (0.382) was observed between samples G6 and G38, while the highest similarity (0.786) was observed between samples G37 and G39 (Figure 2, Table 3).

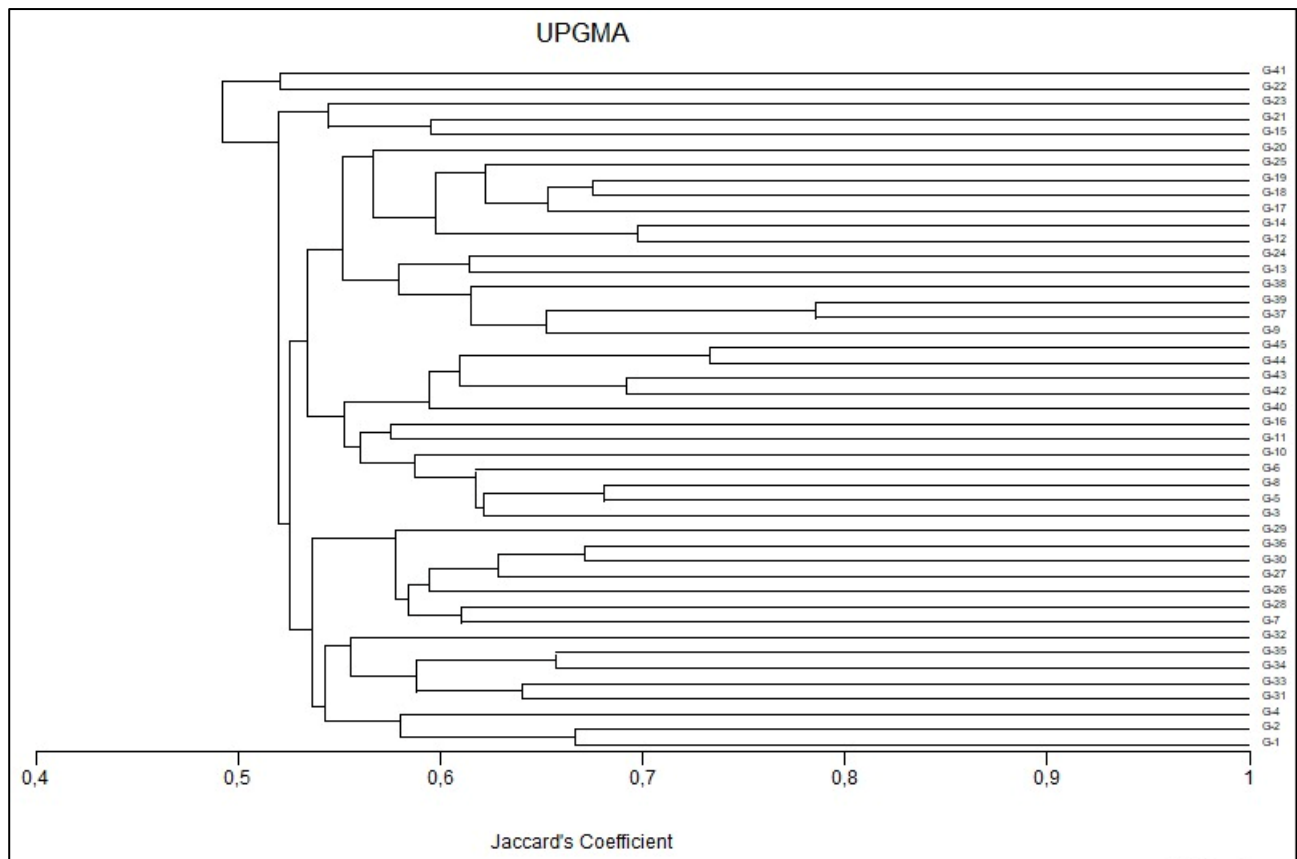


Figure 2. UPGMA dendrogram of genetic similarity between SCoT markers and 45 grape genotypes.

Table 3. Pairwise genetic distance matrix obtained from 12 SCoT primers.

[illegible]

Based on the SCoT molecular data, a PCA image shown in Figure 3 was obtained using the MVSP 3.22 software. The UPGMA dendrogram and the PCA analysis were consistent with each other. Genotypes that are genetically similar were positioned close to one another in the PCA plot. PCA is an effective dimensionality reduction method for multivariate data sets (Mishra et al. 2017). Numerous similar studies have been conducted by researchers to determine the genetic diversity of different grape genotypes. Guo et al. (2012) selected 17 informative primers from 36 SCoT primers to evaluate the genetic relationships among 64 grape varieties. A total of 131 bands were obtained, of which 93.1% were polymorphic; the average polymorphism information content (PIC) value was calculated as 0.82. Ibrahim et al. (2016) genotyped the leaves of seven grape varieties differing in agronomic and morphological traits using Start-Codon Targeted (SCoT) and Simple Sequence Repeats (SSR) markers. A total of 24 SCoT primers produced 362 bands with a 77.10% polymorphism rate and an average PIC value of 0.04. Yue et al. (2019) reported that 36 SCoT primers generated a large number of polymorphic bands, and the amplification results showed clear and distinct bands. The amplification efficiency and polymorphism rate were both determined to be 100%. A total of 221 bands were obtained from the 36 primers, of which 175 were polymorphic. The average polymorphism rate was 80.3%,

and the average genetic similarity coefficient was found to be 0.916. UPGMA cluster analysis of 51 materials showed that the materials were grouped into three clusters when the genetic distance reached 0.856. Tamimi et al. (2023) conducted a study on 123 plants from 25 table grape cultivars using SCoT markers. A total of 48 SCoT bands were obtained from all the studied samples, and only one private band was observed in two cultivars. A low to moderate level of genetic polymorphism was detected in the populations; however, AMOVA (Analysis of Molecular Variance) results indicated that the cultivars differed significantly in their genetic content.

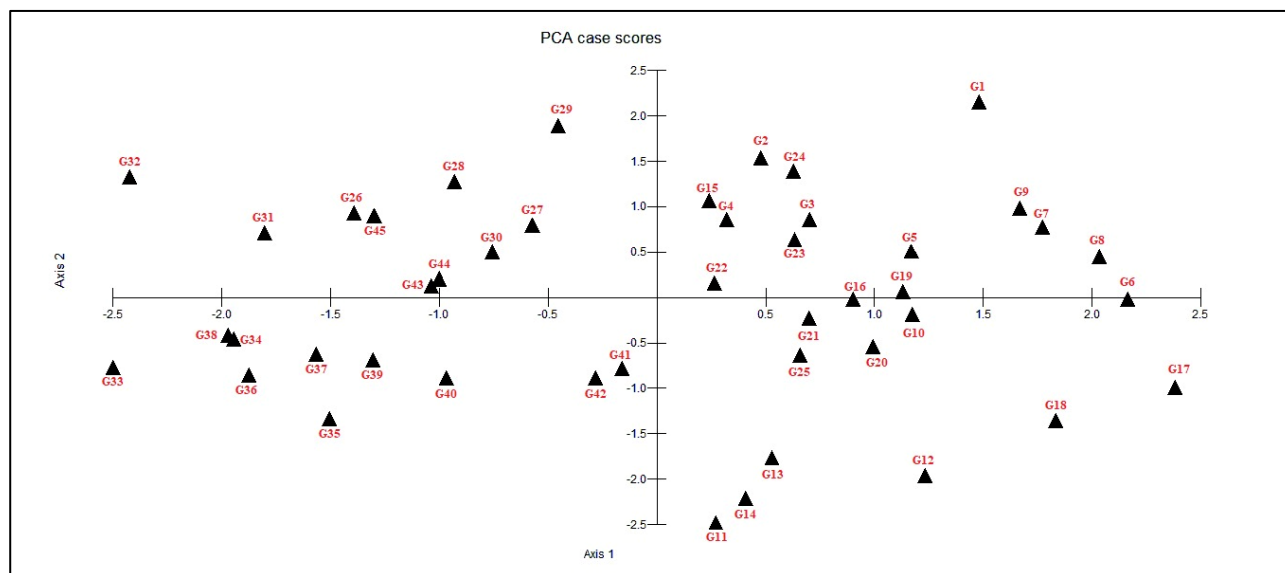


Figure 3. According to SCoT markers principal component analyses of 45 grape genotypes using MVSP 3.22 software

In their study evaluating the genetic diversity of three different grape cultivars, Hameed et al (2020) reported that RAPD primers produced the highest polymorphism rate (67%). This rate was determined as 36% for ISSR primers and 44% for SCoT primers. Each of the three marker systems generated similar dendrograms (phylogenetic trees). However, the genetic distances obtained with RAPD were higher compared to those obtained with SCoT and ISSR. Igwe et al (2022), in their study, reported 326 bands from SCoT primers, with a polymorphism information content (PIC) value of 0.9421. In the study by Bashandy et al (2020), molecular analyses were conducted using Start Codon Targeted (SCoT) and Inter-Simple Sequence Repeats (ISSR) markers. The detected polymorphism rate was 68.38% for SCoT and 41.84% for ISSR. The PIC value was 0.29 for SCoT and 0.19 for ISSR, making SCoT markers more informative. On the other hand, the dendrogram obtained using ISSR markers demonstrated a better clustering pattern compared to that of the SCoT markers. Kajkolah et al (2023) analyzed 178 cultivated *Vitis vinifera* grape accessions to assess genetic diversity and population structure using Start Codon Targeted (SCoT) molecular markers. A total of 35 alleles were detected, indicating that populations exhibited varying levels of genetic variation from low to high. Population genetic analyses revealed that the studied populations differed significantly in genetic content and exhibited a high degree of genetic admixture. When the results of the literature review are compared with our study, it is concluded that similar findings were obtained. Moreover, it was determined that SCoT markers are widely preferred and provide reliable results in the determination of genetic diversity in grape species.

4. Conclusions

The conservation of genetically rich species is critically important for ensuring ecosystem sustainability and meeting future agricultural production needs. Therefore, the molecular identification and preservation of local grape varieties is a necessary and fundamental step for sustainable agricultural practices. In our study, variations among 45 grape genotypes were detected using SCoT markers. Genotypes that are genetically close or distant from each other were clearly identified based on the data from the correlation matrix. Moreover, the genetic variation within the population was distributed homogeneously in both the UPGMA dendrogram and

the PCA plot, with a polymorphism rate of 69.74%. As a result, it was demonstrated that SCoT markers can be successfully used either alone or in combination with other existing DNA markers for studying inter- and intraspecific genetic variation, and they are effective in distinguishing genetically similar materials.

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Conflicts of Interest: The authors declare no conflict of interest.

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References

- Almadanim MC, Baleiras-Couto MM, Pereira HS, Carneiro LC, Fevereiro P, Eiras-Dias JE, Veloso MM (2007). Genetic diversity of the grapevine (*Vitis vinifera* L.) cultivars most utilized for wine production in Portugal. *Vitis-Geilweilerhof* 46(3), 116.
- Aradhya MK, Dangl GS, Prins BH, Boursiquot JM, Walker MA, Meredith CP, Simon CJ (2003). Genetic structure and differentiation in cultivated grape. *Vitis vinifera* L. *Genetics Research* 81(3), 179-192.
- Aradhya M, Wang Y, Walker MA, Prins BH, Koehmstedt AM, Velasco D, ... Preece JE (2013). Genetic diversity, structure, and patterns of differentiation in the genus *Vitis*. *Plant Systematics and Evolution* 299, 317-330.
- Bashandy T, Kamel S, Ferweez H (2020). Evaluation of yield, fruit quality and molecular diversity for three grape cultivars under new valley conditions. *Journal of Agricultural Chemistry and Biotechnology* 11(7), 229-233.
- Braidot E, Zancani M, Petrusa E, Peresson C, Bertolini A, Patui S, Vianello A (2008). Transport and accumulation of flavonoids in grapevine (*Vitis vinifera* L.). *Plant Signaling & Behavior* 3(9), 626-632.
- Collard BC, Mackill DJ (2009). Start codon targeted (SCoT) polymorphism: a simple, novel DNA marker technique for generating gene-targeted markers in plants. *Plant Molecular Biology Reporter* 27, 86-93.
- Doyle JJ, Doyle JL (1990). Isolation of plant DNA from fresh tissue. *Focus* 12, 13-15.
- Ekhvaia J, Gurushidze M, Blattner FR, Akhalkatsi M (2014). Genetic diversity of *Vitis vinifera* in Georgia: relationships between local cultivars and wild grapevine, *V. vinifera* L. subsp. *sylvestris*. *Genetic Resources and Crop Evolution* 61, 1507-1521.
- Franks T, Gang He D, Thomas M (1998). Regeneration of transgenic shape *Vitis vinifera* L. Sultana plants: genotypic and phenotypic analysis. *Molecular Breeding* 4, 321-333.
- Goufo P, Singh RK, Cortez I (2020). A reference list of phenolic compounds (including stilbenes) in grapevine (*Vitis vinifera* L.) roots, woods, canes, stems, and leaves. *Antioxidants* 9(5), 398.
- Guo DL, Zhang JY, Liu CH (2012). Genetic diversity in some grape varieties revealed by SCoT analyses. *Molecular Biology Reports* 39, 5307-5313.
- Hameed, UKA, Abdelaziz K, El Sherif N (2020). Genetic diversity of grapevine (*Vitis vinifera* L.) cultivars in Al-Madinah Al-Munawara based on molecular markers and morphological traits. *Bangladesh Journal of Plant Taxonomy* 27(1), 113-127.
- Ibrahim SD, Adawy SS, Atia MAM, Alsamman AM, Mokhtar MM (2016). Genetic diversity, variety identification and gene detection in some Egyptian grape varieties by SSR and SCoT markers. *Plant Omics* 9(5).

- Igwe DO, Ihearahu OC, Osano AA, Acquah G, Ude GN (2022). Assessment of genetic diversity of Musa species accessions with variable genomes using ISSR and SCoT markers. *Genetic Resources and Crop Evolution* 69(1), 49-70.
- Kajkolah M, Sheidai M, Koochdar F (2023). Population and landscape genetic studies of indigenous table grapes (*Vitis vinifera* subsp. *vinifera* Hegi). *Genetic Resources and Crop Evolution* 70(8), 2533-2553.
- Kaya HB, Dilli Y, Oncu-Oner T, Ünal A (2023). Exploring genetic diversity and population structure of a large grapevine (*Vitis vinifera* L.) germplasm collection in Türkiye. *Frontiers in Plant Science* 14, 1121811.
- Korbin M, Kuras A, Zurawicz E (2002). Fruit plant germplasm characterisation using molecular markers generated in RAPD and ISSR-PCR. *Cellular and Molecular Biology Letters* 7(2B), 785-794.
- Kovach WL (2007). MVSP-A MultiVariate Statistical Package for Windows, ver. 3.1. Kovach Computing Services, Pentraeth Wales, UK.
- Lebon G, Wojnarowicz G, Holzapfel B, Fontaine F, Vaillant-Gaveau N, Clément C (2008). Sugars and flowering in the grapevine (*Vitis vinifera* L.). *Journal of Experimental Botany* 59(10), 2565-2578.
- Martínez LE, Cavagnaro PF, Masuelli RW, Zuniga M (2006). SSR-based assessment of genetic diversity in South American *Vitis vinifera* varieties. *Plant Science* 170(6), 1036-1044.
- Mishra SP, Sarkar U, Taraphder S, Datta S, Swain D, Saikhom R, Laishram M (2017). Multivariate statistical data analysis—principal component analysis (PCA). *International Journal of Livestock Research* (7), 60–78.
- Nicolas SD, Péros JP, Lacombe T, Launay A, Le Paslier MC, Bérard A, ... Doligez A (2016). Genetic diversity, linkage disequilibrium and power of a large grapevine (*Vitis vinifera* L) diversity panel newly designed for association studies. *BMC Plant Biology* 16, 1-19.
- Pan H, Deng L, Zhu K, Shi D, Wang F, Cui G (2024). Evaluation of genetic diversity and population structure of *Annamocarya sinensis* using SCoT markers. *PloS One* 19(9), e0309283.
- Pellegrino A, Lebon E, Voltz M, Wery J (2005). Relationships between plant and soil water status in vine (*Vitis vinifera* L.). *Plant and Soil* 266, 129-142.
- Poyraz I (2016). Comparison of ITS, RAPD and ISSR from DNA-based genetic diversity techniques. *Comptes Rendus. Biologies* 339(5-6), 171-178.
- Riaz S, De Lorenzis G, Velasco D, Koehmstedt A, Maghradze D, Bobokashvili Z, ... Arroyo-Garcia R (2018). Genetic diversity analysis of cultivated and wild grapevine (*Vitis vinifera* L.) accessions around the Mediterranean basin and Central Asia. *BMC Plant Biology* 18, 1-14.
- Souframanien J, Gopalakrishna T (2004). A comparative analysis of genetic diversity in blackgram genotypes using RAPD and ISSR markers. *Theoretical and Applied Genetics* 109, 1687-1693.
- Tamimi Z, Noormohammadi Z, Farahani F (2023). Genetic structure and SCoT marker-based differentiation of indigenous grape, *Vitis venifera* L. cultivars of Iran. *The Nucleus* 66(1), 95-101.
- This P, Lacombe T, Thomas MR (2006). Historical origins and genetic diversity of wine grapes. *Trends in Genetics* 22(9), 511-519.
- Trouillas FP, Pitt WM, Sosnowski MR, Huang R, Peduto F, Loschiavo A, ... Gubler WD (2011). Taxonomy and DNA phylogeny of Diatrypaceae associated with *Vitis vinifera* and other woody plants in Australia. *Fungal Diversity* 49, 203-223.
- Yue Q, Zhang C, Wang Q, Wang W, Wang J, Wu Y (2019). Analysis on genetic diversity of 51 Grape germplasm resources. *Ciência Rural* 49(11), e20190247.
- Zdunić G, Preece JE, Aradhya M, Velasco D, Koehmstedt A, Dangl GS (2013). Genetic diversity and differentiation within and between cultivated (*Vitis vinifera* L. ssp. *sativa*) and wild (*Vitis vinifera* L. ssp. *sylvestris*) grapes. *Vitis* 52(1), 29-32.



Titanium Dioxide Impact on Growth and Yield Parameters of Sunflower

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HIGHLIGHTS

- Oil ratio of sunflower did not improved.
- Titanium dioxide application had benefit on seed yield.
- Seed application with titanium dioxide had superiority over application to leaves in different growth stages.

Abstract

Nanoparticles have unique properties and are used in fertilizers. Seed priming can improve seed germination and seedling growth. Various nanoparticles are used in seed germination and the growth of various plant species and varieties. This experiment was conducted to investigate the effect of TiO₂ nanoparticles on plant morphology when applied to leaves at different growth stages of sunflower and used as seed priming material. Before the field experiment, the seeds were soaked in 20 mg/L TiO₂ for 8 hours at 21±1 °C. The experiment was laid out in a randomized complete block design using three times replicated doses of 0 (control) and 20 mg L⁻¹ TiO₂ treatments to seeds, and at different growth stages. Plant height reached its highest level with TiO₂ treatments to seeds in both years. The maximum seed yield was observed in TiO₂ treatments for seeds in the first year of the experiment. Results revealed that seed priming with TiO₂ and 20 mg L⁻¹ TiO₂ at the V-4 stage is the most effective stage on sunflower growth.

Keywords: oil crop; nanoparticle; seed priming; growth stages

1. Introduction

Nanoparticles have unique physico-chemical properties, high stability, anticorrosion, and photocatalyst activity, which suggests their application in many areas like cosmetics, cleaning products, transportation, energy, and agriculture (Haghighi and Teixeira da Silva 2014).

In agriculture, nanoparticles are active components in nano-fertilizers (Estrada et al. 2018; Liu and Lal 2015; Prasad et al. 2012; Kolenčik et al. 2022). Liu and Lal (2015) categorised nano-fertilizers as macro-nutrient nano-fertilizers, micro-nutrient nano-fertilizers such as (ZnO, CuO, Fe₂O₃, etc.), nutrient-augmented nanomaterials, and plant growth enhancing materials such as TiO₂ and carbon nanotubes. Nano-fertilizers have a high capability of penetration into plants, and their foliar application to sunflowers, due to their broad leaves and stomata morphology, is a highly efficient way for growth support (Liu and Lal 2015).

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Seed priming under optimum and unfavorable conditions could be used to increase seed germination efficiency and seedling fidelity (Day 2022). With the growing industry, new concepts are being developed (Acharya et al. 2017). Various nanoparticles (NPs) such as silver, aluminum oxide, cerium oxide, titanium dioxide, silicon, iron oxide, zinc oxide, and carbon nanotubes are used in plants. Nanoparticles affect plant growth; toxic or supportive, depending on species, form, and concentration (Haghighi et al. 2014; Prasad et al. 2017).

Plants' hormone levels can be altered by TiO₂ NPs. Tobacco showed increased zeatin riboside and brassinolide after being treated with TiO₂ nanoparticles (Hao et al. 2018). The supportive effect of TiO₂ NPs on plant growth and nutrient uptake has been observed in barley (Marchiol et al. 2016), and wheat (Faraji and Sepehri 2019; Zahra et al. 2019).

Mainly, oilseed-type sunflower cultivation is common in Türkiye, with 899.254 ha (TUIK 2024). Sunflower seeds, a snack type, cover 80.435 ha (TUIK 2024) and are used in several food sectors, where they are consumed as a snack (Day et al. 2008). Snack-type sunflower yield (2490 kg ha⁻¹) is less than that of oilseed sunflower (2610 kg ha⁻¹). Germination is vital for sunflower cultivation. It ensures fast germination and healthy seedlings, which are key to high sunflower yields. Pre-sowing seed treatments speed up field emergence in many oilseed crops (Day 2022; Bouriou et al. 2020; Shrestha et al. 2019).

The research about nano-fertilizers is mainly conducted in laboratories or in greenhouses (Rizwan et al. 2019), and field experiments are not common about nano-fertilizers (Ernst et al. 2023). This experiment was conducted to investigate the impact of TiO₂ nanoparticles on plant morphology when applied to leaves in different growth stages of sunflower and used as seed priming material.

Treatment of seeds with different agents and comparing their efficiency with treatments done at different growth stages is important. Therefore, the study aimed to investigate the impacts of TiO₂ NPs as a pre-sowing agent and as a nano-fertilizer on sunflower.

2. Materials and Methods

The seeds of the sunflower (*Helianthus annuus* L.) cultivar Ahmet Bey were obtained from the Turkish Republic Ministry of Agriculture and Forestry, Variety Registration and Seed Certification Centre. TiO₂ nanoparticles were purchased from a producer (NG Materials) of nanoparticles with a size of 50 nm. The experiment was conducted during the 2022 and 2023 seasons at the experimental fields of the Department of Field Crops, Faculty of Agriculture, Ankara University.

2.1. Soil analysis

To measure the qualitative and quantitative properties of soil, samples from the field were taken before sowing and analyses of soil samples (taken from depths of 0-20 and 20-40 cm) were performed at “the Soil Quality and Fertility Analysis Laboratory” of the Central Forestry Soil, Fertilizer and Water Resources Research Institute, Ankara, Türkiye.

2.2. Experimental design and field management

The experiment was designed as a one-factor randomized complete block design with three replications. Doses of 0 (control) and 20 mg L⁻¹ TiO₂ were applied to seeds and leaves. Prior to the start of the field experiment the seeds were soaked in 20 mg L⁻¹ for 8 hours at 21±1 °C. Leaves were sprayed with TiO₂ at different growth stages of V4, R1, and R4 as determined by Schneiter and Miller (1981). Seeds of sunflower were sown by hand on March 12 and 20, 2022, and 2023, respectively. Mechanical weed control and hand weeding were performed. The plot size was 11.2 m² (4 m × 2.8 m). Every individual plot had 70 cm row space and 30 cm intra-row spacing. Fertilizer (DAP and ammonium sulphate) treatment to the soil was made soon after sowing. The ammonium sulphate was applied twice, and the second application was before the R3 stage. Irrigation was carried out soon after sowing, before and after flowering. The plants were harvested on the 9th of September in 2022 and the 12th of September in 2023. Morphological characteristics like plant height, head

diameter, seed yield per head, 1000 seed weight, hull ratio, seed yield and oil ratio were investigated after the harvest.

Chlorophyll measurements were done with SPAD-502 Plus (Konica Minolta) using five leaves per plant. Ten plants from each replicate were used for sampling.

Oil content was determined using hexane-based extraction. The oil was extracted from 2 g sunflower seed samples using a homogenized 3 hexane: 2 isopropanol (v/v) solution. The extraction was replicated three times (Akyıldız 1968).

2.3. Statistical analysis

The experimental data were subjected to analysis of variance using randomized complete block design with three times replicated, and the post hoc tests were performed with Duncan's Multiple Range Test (MSTAT-C Software, Michigan State University, 1991). Measurements of parameters were observed 10 plants obtained from each replicate. The field experiment was one factorial, completely randomized design. The differences between means were determined using Duncan test at 0.05 and 0.01 depending on the results of variance analysis. Principal component analysis (PCA): correlations were used to evaluate the pattern of similarities using JMP statistical software. The relationship among parameters were indicated with Pearson's correlation coefficient.

3. Results

3.1. Soil and climate properties

The texture of the soil in the research area was clay-loam, alkaline. The soil was containing low organic matter and nitrogen (Table 1). Lime (CaCO_3) was determined between 73.0-82.0 g kg^{-1} . The phosphorus content of soil samples was in the range of 1.2-7.9 mg kg^{-1} . The potassium content of soil samples was 130.0-155.0 mg kg^{-1} (Table 1).

Table 1. Physical and chemical properties of the experimental fields.

Years	Depth (cm)	Soil Texture	Saturation (%)	pH	CaCO_3 (g kg^{-1})	P (mg kg^{-1})	K (mg kg^{-1})	Total N (g kg^{-1})	Organic matter (g kg^{-1})
2022	0-20	Clay-loam	78	7.9	73.0	1.2	153.0	0.90	1.52
	20-40	Clay-loam	62	7.6	74.1	4.2	140.0	0.18	1.55
2023	0-20	Clay-loam	70	7.8	82.0	7.9	155.0	0.60	1.25
	20-40	Clay-loam	60	8.0	79.0	6.5	130.0	0.17	1.14

* Soil analysis laboratory of the Ministry of Agriculture and Forestry

The experiment was carried out in the area of Ankara University, Faculty of Agriculture and Department of Field Crops. Long-term average humidity, average temperature and total precipitation were determined to be 60.41%, 11.94 °C and 395.1 mm per year, respectively (Directorate General of Meteorology, 2024). The average temperature, relative humidity and precipitation of the vegetation period and the long-term average of the meteorological data are shown in Table 2.

3.2. Growth and yield contributing characters

Plant height only showed differences in between years ($p < 0.01$). The highest plant height was observed in 2022 with 175.43 cm (Table 3). The year $\times$ TiO₂ interaction did not affect plant height statistically and the plant height values were observed between 169.13 and 178.63 cm. Head diameter showed statistically significant differences ($p < 0.01$) between 2022 (16.04 cm) and 2023 (20.46 cm). TiO₂ treatments at different growth stages affected head diameter and statistically important differences ($p < 0.01$) were observed. The maximum and minimum head diameters were noted in treatment at V-4 stage with 19.33 cm and treatment at R-2 stage with 17.78 cm (Table 3).

Table 2. Meteorological data of the experimental site.

Months	Temperature (°C)			Precipitation (mm)			Relative Humidity (%)		
	1929- 2022	2022	2023	1929-2022	2022	2023	1929-2022	2022	2023
January	0.2	0.9	3.9	40.6	36.2	4.3	77.4	72.6	66.9
February	1.7	4.0	2.7	35.2	29.6	21.0	72.9	72.6	62.4
May	5.7	2.3	8.2	39.7	42.6	67.2	64.5	59.5	68.2
April	11.2	14.1	11.0	42.9	2.6	38.1	58.6	43.2	62.5
March	16.0	16.6	15.8	52.1	13.4	101.1	57.2	49.6	62.4
June	20.0	20.9	19.9	34.9	97.6	94.8	52.0	58.7	64.7
July	23.4	23.1	25.0	14.3	22.9	1.3	44.5	47.5	40.4
August	23.4	26.2	28.3	12.7	25.7	0.0	43.5	46.0	32.9
September	18.8	20.5	21.0	18.4	3.4	27.0	48.0	42.8	45.7
October	13.2	13.7	15.9	28.0	14.3	2.5	58.8	60.7	51.4
November	7.2	10.0	10.7	31.5	9.5	81.7	69.9	61.7	73.1
December	2.5	6.3	6.9	44.8	22.3	29.1	77.6	78.9	80.3
Total /Average	11.94	13.21	14.1	395.1	320.1	468.1	60.4	57.8	59.2

*Directorate General of Meteorology, Ankara, Türkiye 2023.

Table 3. Impact of TiO₂ treatments on plant height and head diameter.

TiO ₂ treatment	Plant height			Head diameter		
	2022	2023	Mean	2022	2023	Mean
Control	174.73	169.20	171.97	16.03	20.37	18.20 b*
Seed treatment	178.63	170.10	174.37	16.17	19.61	17.89 b
Treatment at V-4 stage	176.57	169.77	173.17	16.60	22.06	19.33 a
Treatment at R-2 stage	172.37	169.27	170.82	15.80	19.76	17.78 b
Treatment at R-4 stage	174.87	169.13	172.00	15.60	20.53	18.06 b
Mean	175.43 A	169.43 B**		16.04 B	20.46 A**	

*, **:Figures having a similar letter(s) are not statistically and significantly different using Duncan's test at $p < 0.05$, $p < 0.01$.

Years $\times$ TiO₂ treatment showed statistically significant interaction ($p < 0.05$) on 1000 seed weight (Table 4). The seed treatment in the first year of the experiment resulted in a maximum seed weight of 1000 seeds of 177.01 mg. The minimum 1000 seed weight was observed with 152.91 mg at R-4 stage treatment in the second year. The hull ratio of the seeds statistically differed between years ($p < 0.01$). The hull ratio in the second year (54.45%) of the experiment is higher than in the first year (46.19%). The hull ratio values were observed between 45.13% and 56.35% (Table 4).

Table 4. Impact of TiO₂ treatments on 1000 seed weight and hull ratio.

TiO ₂ treatment	1000 seed weight (g)			Hull Ratio (%)		
	2022	2023	Mean	2022	2023	Mean
Control	158.81 ab	156.37 b*	157.59	46.96	53.28	50.12
Seed treatment	177.01 a	154.70 b	165.85	46.98	54.61	50.79
Treatment at V-4 Stage	168.64 ab	176.10 a	172.37	46.33	55.67	51.00
Treatment at R-2 stage	154.91 b	169.85 ab	162.38	45.54	56.35	50.95
Treatment at R-4 stage	161.51 ab	152.91 b	157.21	45.13	52.32	48.73
Mean	164.17	161.98		46.19 B	54.45A**	

*, **:Figures having a similar letter(s) are not statistically and significantly different using Duncan's test at $p < 0.05$, $p < 0.01$.

Analysis of variance showed significant differences ($p < 0.01$) among the mean of TiO₂ treatments over years and in between years ($p < 0.05$). The maximum chlorophyll index value were observed in TiO₂ treated seeds with 41.68 SPAD units. TiO₂ treatment at R-2 stage with value of 36.74 SPAD units reflected the minimum chlorophyll index value (Table 5).

The analysis of variance on oil ratio reflected no statistical significant differences in terms of parameters observed in this research. The oil ratio of the cultivar ranged in between 47.97% and 52.83% (Table 5).

Table 5. Impact of TiO₂ treatments on SPAD value and oil ratio.

TiO ₂ treatment	Chlorophyll index (SPAD)			Oil content (%)		
	2022	2023	Mean	2022	2023	Mean
Control	42.93	36.78	39.86 ab**	52.83	49.10	50.97
Seed treatment	45.08	38.27	41.68 a	50.80	47.97	49.39
Treatment at V-4 stage	41.71	37.38	39.54 ab	52.70	48.52	50.61
Treatment at R-2 stage	38.48	35.01	36.74 b	51.67	51.06	51.36
Treatment at R-4 stage	37.23	37.30	37.27 b	51.87	48.90	50.37
Mean	41.28 A	37.18 B*		51.97	49.11	

*, **: Figures having a similar letter(s) are not statistically and significantly different using Duncan's test at $p < 0.05$, $p < 0.01$.

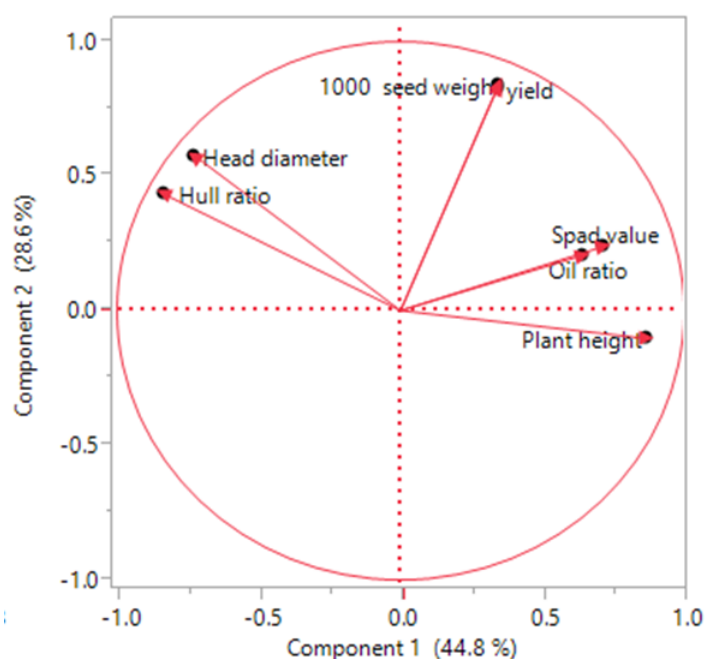
Seed yield represented a statistical difference over TiO₂ treatments at different stages ($p < 0.05$). A comparison among treatments at different stages showed that while TiO₂-treated seeds had the maximum seed yield with 260.47 kg da⁻¹, the control treatment had the minimum seed yield with 218.86 kg da⁻¹ (Table 6).

Table 6. Impact of TiO₂ treatments on the seed yield of sunflower in 2022 and 2023 years.

TiO ₂ treatment	Seed Yield (kg da ⁻¹)		
	2022	2023	Mean
Control	216.32	221.40	218.86 b*
Seed treatment	272.90	218.04	260.47 a
Treatment at V-4 stage	252.14	240.34	246.24 ab
Treatment at R-2 stage	214.82	252.27	233.54 ab
Treatment at R-4 stage	234.16	229.53	231.85 b
Mean	238.07	238.32	

*: Figures having a similar letter(s) are not statistically and significantly different using Duncan's test at $p < 0.05$.

Principal components 1 and 2 PCA results obtained from different parameters of sunflower subjected to TiO₂ under different periods are illustrated in Fig. 1. Component 1 and component 2 were 44.8% and 28.6% in this study, respectively, and their cumulative impact was 73.4% (Fig. 1). 1000 seed weight, yield, spad value, oil ratio and plant height made up 44.8% of the variation. However, head diameter and hull ratio accounted the 28.6% of the variation in PCA.

**Figure 1.** Principal components 1 and 2 obtained from sunflower phenologic parameters subjected to TiO₂ under different periods.

4. Discussion

TiO₂ is known as the newly developed nanoparticle fertilizer. Studies have shown that TiO₂ nanoparticles (NPs) have the ability to alter the hormonal levels of plants during growth. In fact, an increase in zeatin riboside and brassinolide was observed in tobacco plants after the application of TiO₂ NPs to their leaves (Hao et al. 2018). Additionally, the positive impact of TiO₂ NPs on plant growth, microorganism activity, and nutrient uptake has been observed in barley (Marchiol et al. 2016), as well as in wheat (Faraji and Sepehri 2019; Zahra et al. 2019). In the first year of the experiment, the sunflower plants were taller than in the second year. This difference may be due to the higher precipitation levels in March of the second year, which caused late sowing.

Head diameter had the highest level with treatment of TiO₂ at V-4 stage (19.33 cm). This application to new developed real leaves indicates the importance of early application of TiO₂ to sunflower from leaves. 1000 seed weight had the maximum levels from TiO₂ treated seeds in the first year and TiO₂ treatment from leaves at V-4 stage with 177.01 and 176.10 mg respectively.

The positive effect of TiO₂ on the oil content of sunflower was confirmed (Kolenčík et al. 2020), but the oil content in this experiment did not show any benefit from TiO₂. Chlorophyll pigments are the primary components of chloroplasts, playing a crucial role in regulating the rate and process of photosynthesis. Studies indicate that the SPAD value, which is used to measure chlorophyll levels, is closely associated with nitrogen content in plants and is sensitive to environmental stress. Improving results of TiO₂ in sunflower chlorophyll index was observed. The beneficial impact of the TiO₂ attributed to the increased light absorption by chloroplast by upregulated genes due to TiO₂ as reported by Ze et al. (2011), and improved translocation of nitrogen due to TiO₂ (Burke et al. 2014). The improving effect of TiO₂ nanoparticles on chlorophyll was observed in wheat (Satti et al. 2021) and *Dracocephalum moldavica* (Gohari et al. 2020).

Principal component analysis (PCA) is a powerful tool in analyzing relationships. Visualization of data obtained from growth parameters clearly separated hull ratio and head diameter were grouped together and separated from other parameters. One thousand seed weight, spad value and oil ratio were grouped together in the biplot which suggests that these parameters had a positive correlation among themselves. Plant height visualization reflected that it is also separated from other parameters (Fig. 1).

5. Conclusions

This study combines the seed application and foliar application of TiO₂ at different growth stages on field. The results revealed that TiO₂ seed application improved chlorophyll index value along with seed yield in field conditions compared to foliar applications. However, the results showed that oil ratio of sunflower did not improve with TiO₂ applications at any stages. Foliar application has the benefit of using lower amounts of nanoparticles that lead to lower contamination of soil and thus are more sustainable. Results revealed that TiO₂ application to seeds and at V-4 stage is the most effective stages on sunflower growth.

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References

- Acharya D, Mohanta B, Pandey P, Singha M, Nasiri F (2017). Optical and antibacterial properties of synthesised silver nanoparticles. *Micro & Nano Letters* 12(4), 223-226.
- Akyıldız AR (1968). Yemler bilgisi laboratuvar klavuzu. *Ziraat Fakültesi Yayınları*, 358. Uygulama Klavuzu. 122 s. Ankara.
- Bouriou M, Ezzaza K, Bouabid R, Alaoui-Mhamdi M, Bungau S, Bourgeade P, Alaoui-Sossé L, Alaoui-Sossé B, Aleya L (2020). Influence of hydro-and osmo-priming on sunflower seeds to break dormancy and improve crop performance under water stress. *Environmental Science and Pollution Research* 27, 13215-13226.
- Burke DJ, Zhu S, Pablico-Lansigan MP, Hewins CR, Samia ACS (2014) Titanium oxide nanoparticle effects on composition of soil microbial communities and plant performance. *Biology and Fertility of Soils* 50, 1169–1173. <https://doi.org/10.1007/s00374-014-0938-3>
- Day S (2008). Bazı çerezlik ayçiçeği (*Helianthus Annuus* L.) genotiplerinin çimlenmesi üzerine NaCl konsantrasyonlarının etkileri. *Journal of Agricultural Sciences* 14(03), 230-236
- Day S (2022). Impact of seed priming on germination performance of fresh and aged seeds of Canola. *International Journal of Agriculture Environment and Food Sciences* 6(1), 37-40.
- Estrada-Urbina J, Cruz-Alonso A, Santander-González M, Méndez-Albores A, Vázquez-Durán A (2018) Nanoscale zinc oxide particles for improving the physiological and sanitary quality of a Mexican landrace of red maize. *Nanomaterials* 8, 247.
- Ernst D, Kolenčík M, Šebesta M, Ďurišová L, Ďuranová H, Kšíňan S, Illa R, Safarik I, Černý I, Kratošová G, Žitniak Čurná V, Ivanič Porhajašová J, Babošová M, Feng H, Dobročka E, Bujdoš M, Pospiskova KZ, Afzal S, Singh NK, Aydın E (2023). Agronomic investigation of spray dispersion of metal-based nanoparticles on sunflowers in real-world environments. *Plants* 12(9), 1789. <https://doi.org/10.3390/plants12091789>
- Faraji J, Sepehri A (2019). Ameliorative effects of TiO₂ nanoparticles and sodium nitroprusside on seed germination and seedling growth of wheat under PEG-stimulated drought stress. *Journal of Seed Science* 41, 309-317.
- Gohari G, Mohammadi A, Akbari A, Panahirad S, Dadpour MR, Fotopoulos V, Kimura S (2020). Titanium dioxide nanoparticles (TiO₂ NPs) promote growth and ameliorate salinity stress effects on essential oil profile and biochemical attributes of *Dracocephalum moldavica*. *Scientific Reports* 10, 912. <https://doi.org/10.1038/s41598-020-57794-1>
- Hao Y, Yuan W, Ma C, White JC, Zhang Z, Adeel M, Zou T, Rui Y, Xing B (2018). Engineered nanomaterials suppress Turnip mosaic virus infection in tobacco (*Nicotiana benthamiana*). *Environmental Science: Nano* 5(7), 1685-1693.
- Haghighi, M, Teixeira da Silva, JA (2014). The effect of N-TiO₂ on tomato, onion, and radish seed germination. *Journal of Crop Science and Biotechnology* 17, 221–227. <https://doi.org/10.1007/s12892-014-0056-7>
- JMP®, Version <x>. SAS Institute Inc., Cary, NC, 1989–2023.
- Kolenčík M, Ernst D, Urík M, Ďurišová L, Bujdoš M, Šebesta M, Dobročka E, Kšíňan S, Illa R, Qian Y, Feng H, Černý I, Holíšová V, Kratošová G (2020). Foliar application of low concentrations of titanium dioxide and zinc oxide nanoparticles to the common sunflower under field conditions. *Nanomaterials* 10(8), 1619. <https://doi.org/10.3390/nano10081619>
- Kolenčík M, Ernst D, Komár M, Urík M, Šebesta M, Ďurišová L, Bujdoš M, Černý I, Chlpík J, Juriga M, Illa R, Qian Y, Feng H, Kratošová G, Barabaszová KČ, Ducsay L, Aydın E (2022). Effects of foliar application of ZnO nanoparticles on lentil production, stress level and nutritional seed quality under field conditions. *Nanomaterials* 12(3), 310. <https://doi.org/10.3390/nano12030310>

- Liu R, Lal R (2015). Potentials of engineered nanoparticles as fertilizers for increasing agronomic productions. *Science of the Total Environment* 514, 131–139.
- Marchiol L, Mattiello A, Pošćić F, Fellet G, Zavalloni C, Carlino E, Musetti R (2016). Changes in physiological and agronomical parameters of barley (*Hordeum vulgare*) exposed to cerium and titanium dioxide nanoparticles. *International Journal of Environmental Research and Public Health* 13(3), 332.
- MSTAT-C (1991). A software program for the design, management and analysis of agronomic research experiments. Michigan State University, East Lansing.
- Prasad, TNVKV, Sudhakar P, Sreenivasulu Y, Latha P, Munaswamy V, Reddy KR, Sreeprasad TS, Sajanlal PR, Pradeep T (2012). Effect of nanoscale zinc oxide particles on the germination, growth and yield of peanut. *Journal of Plant Nutrition* 35, 905–927.
- Prasad R, Bhattacharyya A, Nguyen QD (2017). Nanotechnology in sustainable agriculture: Recent developments, challenges, and perspectives. *Frontiers in microbiology* 8, 1014.
- Rizwan M, Ali S, Ali B, Adrees M, Arshad M, Hussain A, Rehman MZ, Waris, AA (2019). Zinc and iron oxide nanoparticles improved the plant growth and reduced the oxidative stress and cadmium concentration in wheat. *Chemosphere* 214, 269-277.
- Satti SH, Raja NI, Javed B, Akram A, Mashwani ZuR, et al. (2021). Titanium dioxide nanoparticles elicited agro-morphological and physicochemical modifications in wheat plants to control *Bipolaris sorokiniana* PLOS ONE 16(2), e0246880. <https://doi.org/10.1371/journal.pone.0246880>
- Schneider AA, Miller JF (1981). Description of sunflower growth stages. *Crop Science* 21, 901-903.
- Shrestha A, Pradhan S, Shrestha J, Subedi M (2019). Role of seed priming in improving seed germination and seedling growth of maize (*Zea mays* L.) under rain fed condition. *Journal of Agriculture and Natural Resources* 2(1), 265-273.
- TUIK (2024). Agricultural statistics summary. <https://biruni.tuik.gov.tr/medas/?kn=92&locale=tr> (access date: 20.11.2024).
- Zahra Z, Maqbool T, Arshad M, Badshah MA, Choi HK, Hur J (2019). Changes in fluorescent dissolved organic matter and their association with phyto available phosphorus in soil amended with TiO₂ nanoparticles. *Chemosphere* 227, 17-25.
- Ze Y, Liu C, Wang L, Hong M, Hong F (2011). The regulation of TiO₂ nanoparticles on the expression of light-harvesting complex II and photosynthesis of chloroplasts of *Arabidopsis thaliana*. *Biological Trace Element Research* 143, 1131–1141. <https://doi.org/10.1007/s12011-0>



Risk Assessment in Paddy Rice Cultivation: The Case of Gihanga, Burundi

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HIGHLIGHTS

- Gihanga is located in the Imbo plain, which has rice growing potential.
- Rice is a profitable and easily marketable crop in study area.
- This study revealed that rice farms in Gihanga face various risks that require sustainable strategies.
- The classification of risks according to their severity values was developed using the Kine-Finney method and the results showed the existence of many risks with a severity value above 400.

Abstract

This study was carried out in the Imbo plain of the Gihanga region in Burundi. The primary objective of this research is to analyze the main risks associated with rice production. To achieve the study's objectives, face-to-face surveys were conducted using the KoboCollect application. Once the surveys were completed, a statistical analysis was carried out using SPSS 25, and the Fine-Kinney method has been used to assess the severity of the identified risks. The results reveal that rice cultivation is predominant in Gihanga, with an average production of 3,878.95 kg per enterprise and per year. The average area allocated for rice cultivation was 1.4 hectares. The risks observed in the examined farms, with severity values exceeding 400, include drought, lack of agricultural insurance, plant diseases, inadequate irrigation infrastructure, and limited access to quality inputs. Major challenges identified include difficulties in accessing financial resources, insufficient agricultural oversight, and poor water management. On the other hand, in Imbo, it was found that the semi-intensive production system of small farms neither weakened nor strengthened their competitive advantage. It is imperative to consider agricultural risks when making production decisions, and the formulation of policies aimed at developing the rice sector is strongly recommended.

Keywords: Risk analysis; Fine-Kinney method; agricultural enterprises

1. Introduction

The economy of Burundi is primarily based on agriculture, with the agricultural sector contributing approximately 40% to the Gross Domestic Product (GDP), employing 84% of the working population, and providing 95% of the food supply (Katungi et al. 2021). The average land ownership per household is 0.27 ha, which is well below the 0.90 ha considered the minimum for economic viability (IFAD 2022).

Agricultural productivity in Burundi is hindered by several challenges, including pest outbreaks and crop diseases (Okonya et al. 2019), droughts and occasional floods (Nyairo et al. 2020), limited liquidity for inputs

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(such as fertilizers, plant protection products, productive seeds, and planting materials), land fragmentation (Mpozi et al. 2020), inefficient utilization of available water resources (Bisekwa et al. 2020), lack of liquidity and credit opportunities among small-scale farmers, and limited access to research and extension services (Ndagijimana 2021). Despite these challenges, most regions of the country have climatic conditions suitable for agriculture (Kessler et al. 2021).

Agriculture is particularly vulnerable to risks, many of which stem from climatic hazards. Agricultural risks impose a significant burden globally (Hazell et al. 2010). For instance, (Paridaens et al. 2012) showed that water scarcity and erosion due to heavy rainfall affect 22% and 14% of agricultural land, respectively, in the northern provinces of Burundi. Farmers are perceived as risky borrowers, which limits their access to credit, increases the cost of interest, and results in a clear impact by trapping farmers in a vicious cycle of low productivity and poverty (Hazell et al. 2010). Land degradation and climate change affect approximately one-third of the world's land area, leading to negative consequences for the income and food security of the agricultural population (Mirzabaev 2016). Agricultural risks are categorized in various ways by different researchers. A commonly used classification divides agricultural risks into two main groups: operational risks and financial risks (Hardaker et al. 2004). Agricultural risks can be examined in five primary areas: production, marketing, financial, legal, and social risks (Laurence et al. 2013). According to a literature review, rice production involves different sources of risk, including technological risks, political risks, economic risks, production risks, marketing risks, human or personal risks and financial risks.

In the study, a risk analysis was conducted on rice-producing agricultural enterprises in the Gihanga district, and an effort was made to partially fill the knowledge gap on this topic. The research results have guided subsequent studies on risks in the area, providing important data that can help rice producers make decisions under risky conditions, assist farmers in determining risk management strategies, and provide decision-makers with crucial information for their use.

2. Materials and Methods

The data for the study were obtained through face-to-face surveys with rice-producing agricultural enterprise owners in Gihanga. The survey form was incorporated into the KoBoCollect application to facilitate data collection and entry. In this study, the sample size was calculated according to the following formula based on the proportion of the main population, using an uncluttered simple random sampling method (Oğuz and Karakayacı 2017).

$$n = \frac{Np(1-p)}{(N-1)\sigma_{px}^2 p(1-p)} \quad (1)$$

In the formula,

n: Sample size

N: Number of enterprises in the population

σ_{px}^2 : The variance of the proportion and

p: 0,5.

The number of rice producers registered with the Imbo Rice Development Company (SRDI) is 9,826, and the survey was conducted with a 10% margin of error and a 95% confidence level to determine the number of enterprises to be surveyed. According to the formula mentioned above, the total sample size was calculated as 95 enterprises. In the formula, the value of p, which represents the probability of the event occurring, is set as 0.5 for risk-taking enterprises, while q, representing the probability of the event not occurring, is also set as 0.5 for risk-averse enterprises. Both values were taken as 0.5.

In examining the risk attitudes of producers in the study area, they were classified into three categories: risk-taker, risk-averse, and risk-neutral. To determine which group the producers belonged to, the reference gamble and preference scale methods were employed. The risk attitudes of the producers were identified based on the choices they made among the options presented (Holloway 1979). The classification of producers

into specific risk attitude groups was determined by following the steps outlined below (Holloway 1979). First, the producer was informed that they would receive a reward based on a certain probability. In the initial step, the producer was presented with a guaranteed reward alternative that was smaller than the probabilistic reward. The producer was then asked to choose between the two options. If the producer chose the probabilistic reward, the value of the guaranteed alternative was increased. This process was repeated until the producer became indifferent between the two options. Next, the probability value in the first step was increased, and the procedure was repeated. As a result, a graph was constructed with the horizontal axis representing the indifference points and the vertical axis representing the probabilities (Preference Curve). In the third step, the results obtained were plotted on this graph to determine the risk attitudes. In the study, the shape of the preference scale curve, which illustrates the risk attitudes of farmers using the reference gamble method, is presented below (Holloway 1979).

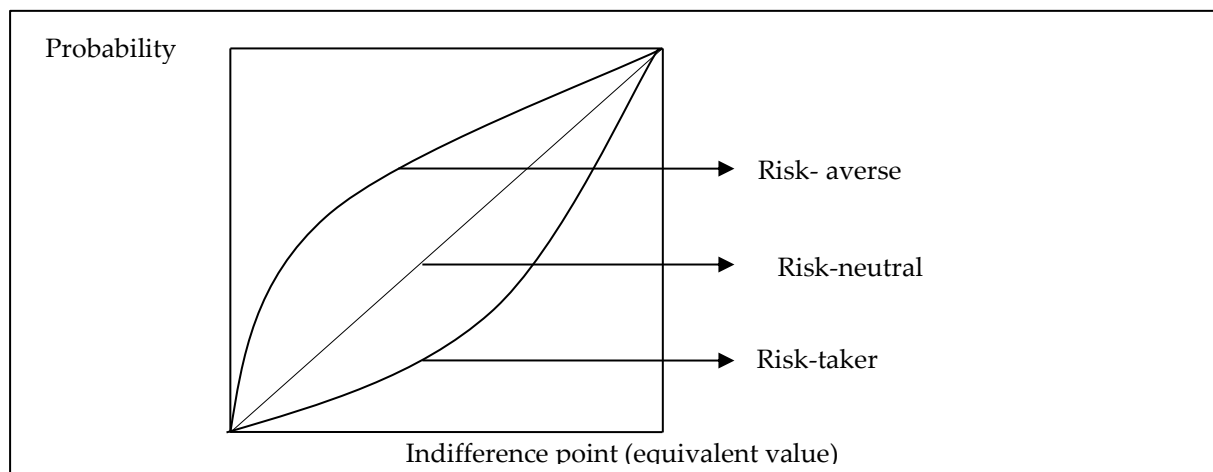


Figure 1. Preference Curve

The risk behaviors of business managers were categorized into three groups (risk-taker, risk-averse, and risk-neutral) using reference gambling and preference scales. However, it was assumed that being risk-neutral means not taking risks, so the business managers who were risk-neutral were also considered as part of the risk-averse group (Holloway 1979; Ceyhan et al. 1997). In this study, two groups were used: risk-taker and risk-averse. Additionally, the businesses examined in the study were divided into two large groups based on the size of the enterprises in Group I and Group II.

In the research area, factors considered as social, economic, and ecological risks were incorporated into the survey. Each factor was rated using a five-point Likert scale, and respondents were asked to evaluate the impact of these factors on the production process. The average of the responses provided by rice producers was calculated to generate risk scores, and the perceived levels of risk factors were determined. To systematically process and integrate the collected data, a database was created for the relevant surveys. For the evaluation and analysis of the data, the SPSS 25 statistical software program was utilized.

In this study, the Fine-Kinney method was applied to assess the risks associated with agricultural production in the examined enterprises. The Fine-Kinney method evaluates risks based on the factors of probability, frequency, and severity, and these values are multiplied to obtain a risk score. The parameters for probability, frequency, and potential outcomes have been explained. The severity of the damage caused to humans, businesses, or the environment in the event of risk occurrence is calculated. The following calculations were made to assess the risks that may be encountered in the enterprises examined in the study (Erzurumluoğlu et al. 2015).

The risk value is calculated as follows:

$$\text{Risk Value} = I \times F \times D \quad (2)$$

Where:

I = Probability (a value between 0.2 and 10)

F = Frequency (a value between 0.5 and 10)

D = Degree of Impact (the severity of damage or harm that the risk event would cause to humans, the workplace, or the environment if it occurs).

Table 1. Fine-Kinney method/decision and action based on risk level.

Rank	Risk Value	Decision	Action
1	$R < 20$	Acceptable Risk	Immediate action may not be required
2	$20 < R < 70$	Definite Risk	Should be included in the action plan
3	$70 < R < 200$	Significant Risk	Should be carefully monitored and addressed in the annual action plan
4	$200 < R < 400$	High Risk	Should be addressed in a short-term action plan
5	$R > 400$	Very High Risk	Work should be halted, and immediate measures should be taken

In the examined enterprises, after determining the probability, frequency, and severity (impact) of natural, economic, and social risks, the risk value was calculated based on the Fine-Kinney formula. Accordingly, the action plan was implemented in the order of the risk values presented in Table 1.

3. Results and Discussion

3.1. Rice Production

In this section of the study, the results obtained from the survey conducted in the Gihanga district of Bubanza province are presented. Table 2 shows the product inventory and cultivated areas.

Table 2. Annual crops production pattern (ha)

Farm Groups		Group I		Group II		Enterprise Average		Total
Risk Attitudes		Risk-Taker	Risk-Averse	Risk-Taker	Risk-Averse	Risk-Taker	Risk-Averse	Grand Total
Rice	Ha	0.75	0.75	0.67	0.77	0.71	0.76	1.47
	%	12.3	14.2	17	12.9	14.2	13.5	14
Maize	Ha	0.7	0.67	0.71	0.84	0.71	0.76	1.46
	%	11.5	12.7	18.1	14.1	14.1	13.4	14
Sweet potato	Ha	0.58	0.42	0.96	0.78	0.77	0.6	1.37
	%	9.51	7.97	24.4	13.1	15.4	10.7	14
Soybean	Ha	0.82	0.73	0.82	0.82	0.82	0.78	1.6
	%	13.4	13.9	20.9	13.8	16.4	13.8	16
Cowpea	Ha	0.75	0.71	0	0.9	0.38	0.81	1.18
	%	12.3	13.5	0	15.1	7.48	14.3	10
Dry Beans	Ha	0.5	0.61	0.77	0.85	0.64	0.73	1.37
	%	8.2	11.6	19.6	14.3	12.7	13	14
Peanut	Ha	0.5	0.5	0	0	0.25	0.25	0.5
	%	8.2	9.49	0	0	4.99	4.45	4.4
Cassava	Ha	0.5	0	0	0	0.25	0	0.25
	%	8.2	0	0	0	4.99	0	2.1
Fallow	Ha	1	0.88	0	1	0.5	0.94	1.44
	%	16.4	14.4	0	16.4	8.2	15.4	12
Total	Ha	6.1	5.27	3.93	5.96	5.02	5.62	10.6
	%	100	100	100	100	100	100	100

In this study two large groups were distinguished based on the size of the companies, group I whose surface area is less than or equal to 2.5 ha and group II with a surface area greater than 2.5 ha. The second based on behaviors in the face of risks (risk taker and risk averse) has been also analyzed. In the study area, rice, which occupies 1.47 ha per farm, is the dominant crop. According to the results of a study conducted by (Gahiro 2011) in Burundi, rice farms in the Imbo region were divided into two zones: Zone 1 and Zone 2. The average size of rice fields ranged between 1.25 ha and 1.60 ha, and the average area covered by rice was quite similar to that confirmed by this study. The Imbo plain includes two major groups of rice farms: the first group consists of farms with areas ranging from 0.2 to 0.8 ha, while the second group comprises farms in Zone 3 with large areas averaging 1.67 ha. In the study area, rice continues to be the most widely cultivated crop for various reasons, the most important of which are listed in Figure 2.

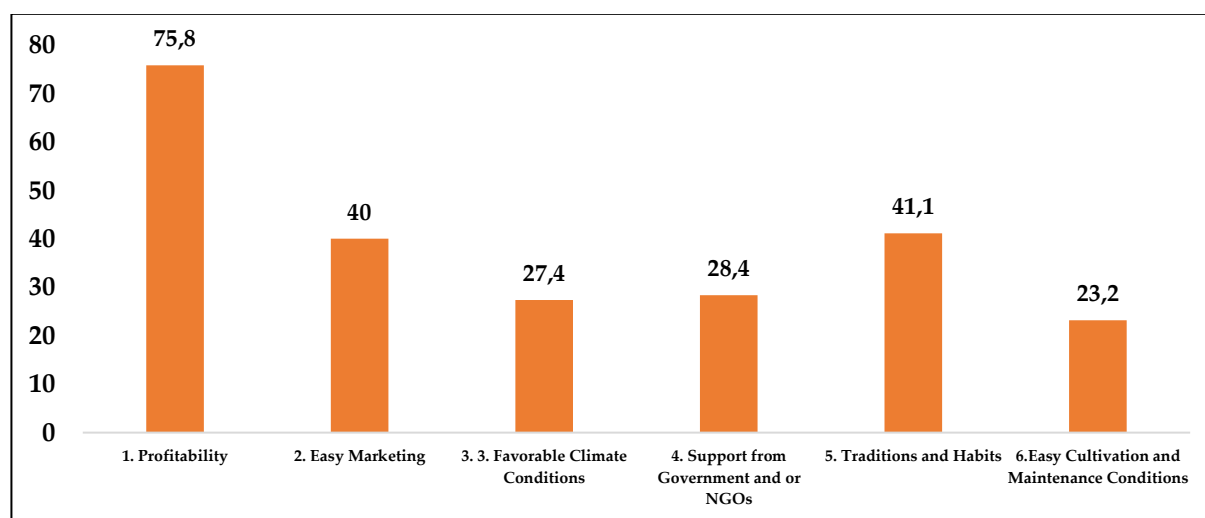


Figure 2. Reason for rice cultivation in the examined enterprises

This figure likely illustrates the percentage or score distribution of different factors that contribute to the prevalence of rice production in the study area. The factors include profitability, ease of marketing, favorable climate conditions, support from government and NGOs, traditions and habits, and ease of cultivation and maintenance. The main factor that drives producers in the study area to choose rice cultivation is the profitability of rice farming, with 75.8% of producers stating that rice is highly profitable. Although rice is a new crop in Burundi, it is based on traditional practices and customs. The second factor that inspired producers to focus their efforts on this crop is that 41.1% of participants were influenced by these traditional, non-mechanized practices. In studies conducted by (Edward et al. 2022) in Ghana and (Yohana and Yan 2021) in Tanzania, the main reasons driving them to cultivate rice and its profitability were identified. Data on the amount of rice produced and sold, as well as the sale price, are presented in Table 3.

Table 3. Rice production in the surveyed enterprises

Rice Production	N	Minimum	Maximum	Mean	Std. Deviation
Quantity of Rice Produced (Kg/year)	95	1500	8000	3878.95	1088.420
Quantity of Rice Sold per year	95	250	6000	3660.53	1143.271
Rice Price per year (USD/Kg)	95	0.68	1.27	1.10	259.589
Rice Yield (kg/Ha)	95	1000	5000	3546.32	955.589

* 1 US Dollar = 2922.5 BIF (08/02//2025).

The average quantity of rice produced per surveyed enterprise was found to be 3,878.95 kg, with the highest amount being 8,000 kg and the lowest quantity being 1,500 kg. According to Table 3, it was determined that not all of the produced quantity was sold, with the average annual amount sold being 3,660.53 kg. Based on the survey results, the average price was calculated at \$1.10/kg. The remaining quantity of rice, 218.42 kg (27.3

kg/person/year), was consumed on the farms. The average yield was determined to be 3,546.32 kg/ha. Indeed, the production techniques applied, the costs incurred in production, and the results obtained indicate that rice growers in Imbo are more productive (over 5 tons/ha) and competitive than farmers in swamp areas (Gahiro 2011). It was also noted that the average annual national rice consumption is 8.5 kg per person, which is lower than the amount consumed in the surveyed farms.

3.2. Risk Factors in the Examined Enterprises

As mentioned in the general introduction of this study, rice cultivation faces risks in various categories. Detailed informations are presented in Figure 3.

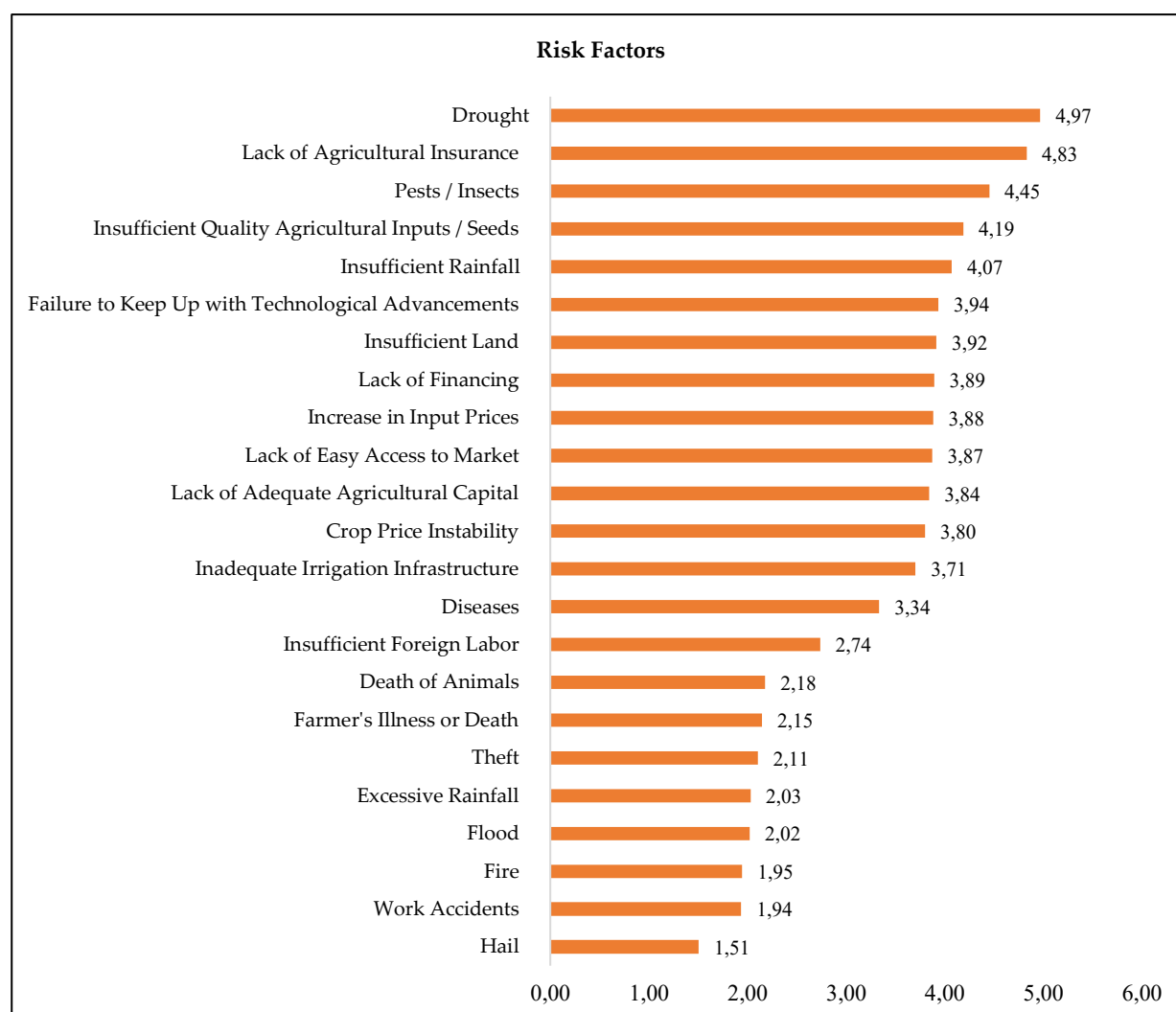


Figure 3. Potential risk factors encountered in the surveyed enterprises

Rice-growing farms face environmental, financial, human, and institutional risks. Despite the presence of water in the region, drought is indicated as the primary major risk. Risks such as the lack of agricultural insurance, plant diseases, insufficient quality of seeds and other inputs, and inadequate rainfall have scored above 4 on the Likert scale. According to (Wabi et al. 2021), irregular and decreasing rainfall is the greatest concern for irrigated rice producers.

Indeed, the lack of modern technologies, insufficient arable land, inadequate financing, high input prices, difficulty accessing markets, insufficient agricultural capital, lack of infrastructure, and various diseases are risks that threaten farmers and have received scores between 3 and 4 on the Likert scale. This situation has been validated in the study "Confronting Risks in Agriculture" by (Hardaker et al. 2004), which demonstrated that, in addition to market risks such as rising fertilizer prices and falling rice prices, financial risks like

increased interest rates, human risks like negligence leading to yield loss, and institutional risks such as changes in agricultural policies are also frequently encountered. This finding was also observed in the research conducted by (Nto et al. 2014) to assess risk management practices in rice production in Abia State. In that study, the main causes of financial risk in rice production included interest rates and the inability of rice farmers to access credit. Lastly, risks such as foreign labor shortages, animal deaths, theft, excessive rainfall, flooding, forest fires, workplace accidents, and hail were less frequently identified as threats to enterprises with scores below 3.

Rice producers have listed some strategies they can implement to reduce the risks mentioned above, and the most important of these are announced in Figure 4.

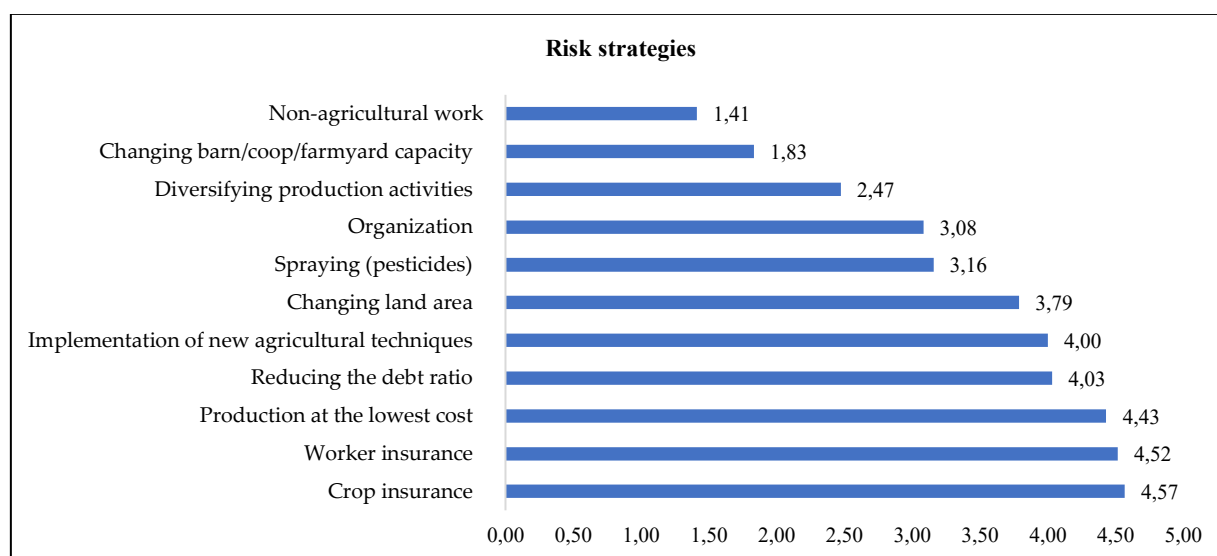


Figure 4. Risk strategies that can be applied in rice cultivation.

It has been determined that the most significant dimension of the risk strategy is agricultural insurance, with a score of 4.57. In the study area, no actual cases of agricultural insurance have been encountered. Similarly, worker insurance has been identified as another risk strategy with a score of 4.52. The transfer of risk to third parties such as futures markets, insurance companies, and financial investors is one of the important risk strategies discussed by (Näther and Theuvsen 2012). Producers have highlighted the risk associated with the strategy of reducing input usage levels and production costs (4.43). Although many input and fertilizer suppliers can offer credit to producers, they often hesitate due to the variable risks associated with producers (Hazell et al. 2010; Levine and Reinhard 2007).

Reducing production costs and the level of inputs will increase producers' profits. In fact, this is called cost minimization, and it is the primary goal of a rational producer. It has been suggested as a strategy to reduce debt levels and the associated financial risks (4.03). The adoption and implementation of new agricultural techniques have also been considered a risky strategy with a score of 4 on the Likert scale. Land capital is essential in agriculture, and in this context, land consolidation has been strongly desired as a risk strategy (3.79). In fact, the most well-known method for dealing with diseases and pests is agricultural pesticide application, and this same strategy has emerged with a score of 3.16. Another risk strategy considered important by producers is the establishment of cooperatives and the diversification of agricultural products, with scores of 3.08 and 2.47, respectively. According to (Kremen et al. 2012), product diversification can support climate adaptation, resilience, and food security.

However, the development of livestock farming and the expansion of non-agricultural activities are among the risk strategies that scored less than 2. Studies conducted by Mishra and Morehart (2002) and Nartea et al. (2003) in New Zealand, as well as by Mishra and Morehart (2001) and Davis and Patrick (1999) in the United States, have emphasized the importance of agricultural and non-agricultural investments in reducing risks. For many African farmers, these coping strategies are informal and rely on family and community structures,

such as food sharing, internal and external migration, money transfers, child labor, in-kind loans, or sending children to live with their parents (Heltberg and Siegel 2008). Typically, farms do not follow a single coping strategy during these difficult times; instead, they use various strategies to maximize their chances of survival (Heltberg and Siegel 2008).

3.3. Risk Assessment in the Surveyed Enterprises Using the Fine-Kinney Method

In this section, the Fine-Kinney method was used to assess the risks faced by the surveyed farms. The Fine-Kinney method is a systematic approach to risk evaluation that considers three main factors: the probability of occurrence, the severity of consequences, and the frequency of exposure. By analyzing these factors, the method helps prioritize risks and identify the most critical areas requiring intervention. In the surveyed farms, the Fine-Kinney method was used to classify risks. By grouping the risks using this method, their priority order was determined, and measures were taken according to their level of importance. Each risk was individually evaluated according to the Fine-Kinney method, and their risk levels were identified as presented in Table 4.

Table 4. Fine-Kinney method in rice cultivation

Risk Factors	Probability Scale	Frequency Scale	Impact/Damage	Risk Value	Risk Status
Lack of agricultural insurance	9.70	9.66	98.21	9197.52	Very High Risk
Drought	9.40	9.29	88.79	7753.19	
Pests / Insects	6.82	6.97	54.88	2609.56	
Insufficient rainfall	5.92	5.66	31.85	1067.13	
Insufficient quality agricultural inputs / seeds	5.32	5.24	31.27	871.47	
Lack of easy access to market	4.76	4.79	25.44	579.77	
Failure to keep up with technological advancements	4.32	4.29	22.17	411.40	
Increase in input prices	4.44	4.18	20.74	384.49	High Risk
Crop price instability	4.29	4.17	20.34	364.08	
Lack of financing	4.32	4.36	18.98	356.95	
Insufficient land	3.95	3.85	19.06	290.29	
Lack of adequate agricultural capital	3.94	3.83	16.92	255.16	
Inadequate irrigation infrastructure	3.58	3.60	16.48	212.70	
Diseases	3.39	3.45	13.66	160.14	Significant Risk
Insufficient foreign labor	2.84	2.78	10.39	81.90	
Theft	2.40	2.81	10.24	69.09	Definite Risk
Death of animals	1.41	2.09	5.41	15.93	Acceptable Risk
Excessive rainfall	1.34	1.65	4.14	9.18	
Flood	0.92	1.60	4.40	6.48	
Farmer's illness or death	0.89	1.33	3.38	4.01	
Work accidents	0.74	1.33	3.13	3.06	
Fire	0.68	1.17	3.13	2.50	
Hail	0.45	0.88	2.41	0.96	

The probability, frequency, and severity values of the risks are calculated using the Fine-Kinney method. Risks are categorized into different groups, such as natural, economic, and social risks. According to the data in Table 4, the risk values range from 0.96 to 9197.52.

In the study area, the most significant natural risks are drought, plant diseases, and insufficient rainfall. Risks originating from production techniques are also among the most notable. These include the lack of quality inputs, the underdevelopment of traditional agricultural practices, and the absence of modern irrigation infrastructure. However, agricultural insurance is not yet implemented in the soils of Burundi, which creates a significant disadvantage for agriculture.

Among the major risks, economic risks such as problems accessing distribution markets, high input prices, price instability in markets, insufficient financing, and inadequate agricultural capital have also emerged. In this study, social risks are classified as the least significant risks, with examples including work accidents and animal deaths.

Several studies have explored the multiple risk factors that influence agricultural productivity and sustainability across different African regions. For instance, Manzamasso (2021) conducted a study titled "The Effects of Price Variations, Weather Conditions, and Policy Changes on Maize and Rice Cultivation in Togo," which provided valuable insights into the systemic challenges faced by farmers. The study identified key constraints impacting agricultural productivity in Togo, including political implications, climate variability, and the fluctuations in market prices and policy shifts. These findings underscore the need for integrated risk management approaches that take into account both environmental and institutional dimensions in agricultural planning and decision-making.

In fact, these risk values are divided into five major categories based on their severity: Very High Risk, High Risk, Important Risk, Certain Risk, and Acceptable Risk. The most detailed information regarding Fine-Kinney analyses is explained in Table 5.

Table 5. Fine-Kinney method applied to rice in the surveyed farms

Risk Value	Risk Factors	Action
R<20	• Death of animals, • Excessive rainfall, • Flood, • Farmer's illness or death, • Work accidents, • Fire, • Hail	Immediate action may not be required.
20<R<70	• Theft	Should be included in the action plan.
70 <R<200	• Diseases, • Insufficient foreign labor	Should be closely monitored and addressed in the annual action plan.
200 <R<400	• Increase in input prices, • Crop price instability, • Lack of financing, • Insufficient land, • Lack of adequate agricultural capital, • Inadequate irrigation infrastructure	Should be addressed in the short-term action plan.
R>400	• Lack of agricultural insurance, • Drought, • Pests / Insects, • Insufficient rainfall, • Insufficient quality agricultural inputs /Seed • Lack of easy access to market, • Inadequate irrigation infrastructure	Work should be paused, and immediate measures should be taken.

When considering the risks examined in Gihanga, the risks that show the highest risk level, i.e., those with a risk level above 400, are classified as intolerable risks. These are risks that require decision-making in production activities and necessitate urgent action. Among these risks are the lack of agricultural insurance,

drought, pests/insects, insufficient rainfall, low-quality agricultural inputs/seeds, lack of easy market access, and inadequate irrigation infrastructure. Although it may not be possible to completely eliminate these risks, it is possible to minimize the damages through certain measures. These are risk factors that must definitely be taken into account.

The second risk group includes risks with a level between 200 and 400, such as increases in input prices, instability in product prices, lack of financing, insufficient land availability, inadequate agricultural capital, and insufficient irrigation infrastructure. These risks are considered to have a slightly lower negative impact, and it is ideal to address them by integrating them into a short-term action plan. Key risks evaluated in this group include inadequate agricultural capital, lack of financing, indebtedness, absence of crop insurance, and fluctuations in crop yields ranging between 200 and 400.

In their book titled "Coping with Risk in Agriculture", Hardaker et al. (2004) highlighted the prevalence of various types of risks commonly faced by farmers. These include market risks, such as rising fertilizer prices and falling paddy rice prices; financial risks, like increasing interest rates; human risks, such as negligence leading to yield losses; and institutional risks, including changes in agricultural policies. Their analysis underscores the complexity and interconnectivity of risk factors in the agricultural sector, emphasizing the need for comprehensive risk management strategies.

There are risks that should be included in the annual action plan, carefully monitored, and addressed. These are in the third group, with a risk level between 70 and 200, which includes issues such as human diseases and a shortage of foreign labor. Theft, with a risk value between 20 and 70, represents the fourth group and is inevitably included in the risk control action plan. Finally, the fifth group includes risks such as animal death, heavy rainfall, flooding, farmer illness or death, work accidents, fires, and hail, all with a risk level below 20, which fall under the normal risk group. These risks do not significantly affect production decisions. Despite the mild climate, fires are less frequent due to the scarcity of forests and shrubs, and the sparser vegetation. Almost all of the region is suitable for agriculture, and although rainfall is insufficient, there are numerous rivers with weak irrigation systems. Since intensive agriculture is practiced in the region and there are few animals, animal deaths are not considered a major risk affecting agricultural activities. Agriculture is primarily manual and non-mechanized, involving hoeing, so accidents arising from agricultural activities are less frequent. Although these risks are less significant, measures should still be taken to eliminate them.

According to the Norwegian report VKM (2013), titled "*Risk Assessment of Mycotoxins in Cereals in Norway*," it has been established that cereals can be contaminated by fungi producing mycotoxins, which are toxic secondary metabolites. These mycotoxins present in cereals may pose risks to both human and animal health. Prolonged ingestion of mycotoxins found in Norwegian cereals can lead to, among other effects, a reduction in immune responses, impaired growth, and reproductive dysfunction. The study also found that rice crops are vulnerable to this fungal disease. The risk assessment should encompass the fungi and toxins present in cereals and cereal-based products available in the Norwegian market.

Gihanga is a warm region located in the Imbo plain, where natural risks are prevalent due to climate change and the shortening of the rainy season. It is also an area with fertile yet dry soils. Burundian agriculture, in general, faces issues related to the lack of quality inputs, including problems with technology and mechanization of activities. The increase in input prices (seeds, fertilizers, pesticides, diesel, oil), the underpricing of agricultural products, and market imbalances are risks that discourage rice producers. These risks stem from the lack of information regarding the calculation of production costs and the absence of direct market access.

To successfully strengthen marketing strategies, it is recommended that sales be distributed throughout the year, direct sales without intermediaries be implemented, forward contracts be made, pricing be set for the future, and joining cooperatives and producer organizations that could facilitate market access. Farmers are unable to access credit due to the lack of repayment possibilities and are also faced with high bank interest rates. The simplest strategies applied against financial risks include: obtaining insurance against financial

losses, organizing investments, planning expenses, reducing debt, limiting credit, and selling assets that can be converted into cash.

4. Conclusions

In conclusion, the agricultural sector holds a critically important place in the economies of underdeveloped countries. However, due to its dependence on natural conditions, agriculture is a high-risk sector. Therefore, identifying risk factors and corresponding risk strategies, especially for key crops with significant production shares, is crucial for the development of the agricultural sector.

This study focused on determining risk factors and strategies for rice, one of the most widely produced crops in the Gihanga region of Burundi. Although rice cultivation is profitable, the Fine-Kinney method revealed that this crop faces various risks requiring immediate decisions and actions, as risk levels were found to exceed 400. These risks include the lack of agricultural insurance, drought, pests/insects, insufficient rainfall, low-quality agricultural inputs/seeds, lack of easy market access, and inadequate irrigation infrastructure. The study's results highlighted those strategies such as agricultural insurance, reducing production costs, adopting new farming techniques, land consolidation, and crop diversification can provide sustainable and long-term solutions for rice farming enterprises.

In this context, it is recommended to examine and adapt practices from other countries that align with the local infrastructure, and to reform national agricultural policies accordingly. By implementing these measures, the agricultural sector in Gihanga and similar regions can become more resilient, sustainable, and economically viable.

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References

- Edward O, Prince A, Akwasi M and Henry D (2022). Rice price volatility and transmission: Implications for food security in Ghana. <https://doi.org/10.1080/23322039.2022.2085605>
- Gahiro L (2011). Competitivite des filieres rizicoles burundaises : Le Riz De L'imbo Et Le Riz Des Marais <https://theses.hal.science/tel-00854623v1/document>
- Hardaker BJ, Huirne RBM, Anderson JR, Lien G (2004). *Coping Risk in Agriculture*. Second Edition. Oxfordshire: CABI Publishing, ISBN:0851998313, United Kingdom, p.332.
- Hazell P, Anderson J, Balzer N, Clemmensen AH, Hess U, Rispolli F (2010). The potential for scale and sustainability in weather index insurance for agricultural and rural livelihoods. IFAD and WFP, Rome, p. 153.
- Heltberg R, Siegel P (2008). Climate change: Challenges for social protection in Africa. Paper for conference on social protection for the poorest in Africa. Washington DC: World Bank.
- Holloway C (1979). *Decision making under uncertainty: models and choices*, Prentice-Hall, Inc., Englewood Cliffs, New Jersey.
- IFAD (2022). Republic of Burundi: Country Strategic Opportunities Programme (2022–2027); International Fund for Agricultural Development: Rome, Italy.
- Katungi E, Nduwarigira E, Ntukamazina N, Niragira S, Mutua M, Kalempera S, Onyango P, Nchanji E, Fungo R, Birachi E, Rubyogo JC, Bruchara RA (2020). Food security and common bean productivity: impacts of

improved technology adoption among smallholder farmers in Burundi; Pan-Africa Bean Research Alliance (PABRA): Nairobi, Kenya.

- Kessler A, Reemst L, Beun M, Slingerland E, Pol L, de Winne R (2021). Mobilizing farmers to stop land degradation: A different discourse from Burundi. *Land Degrad & Development* 32, 3403–3414. <https://onlinelibrary.wiley.com/doi/10.1002/ldr.3763>
- Kremen C, Iles A, Bacon C (2012). Diversified farming systems: An agroecological, systems-based alternative to modern industrial agriculture. *Ecology and Society* 17(4): 44.
- Laurence C, Gene G, Steve I, Doug J, Rod S (2013). Introduction to risk management: Understanding agricultural risks, 2nd Ed., Extension Risk Management Education and Risk Management Agency, United State Department of Agriculture.
- Manzamasso H. (2021). Impacts of price, weather and policy changes on maize and rice farming in Togo. *African Journal of Economic and Management Studies* (2021) 12 (3): 357–380. <https://doi.org/10.1108/AJEMS-09-2020-0427> .
- Mirzabaev A (2016). Land degradation and sustainable land management innovations in Central Asia. Springer, Cham. https://link.springer.com/chapter/10.1007/978-3-319-25718-1_13
- Mpozi BB, Mizero M, Egesa AO, Nguezet PMD, Vanlauwe B, Ndimanya P, Lebailly P (2020). Land access in the development of horticultural crops in East Africa. A case study of passion fruit in Burundi, Kenya, and Rwanda. *Sustainability* 12, 3041. <https://www.mdpi.com/2071-1050/12/7/3041>
- Näther, Theuvsen L (2012). Risk management im Pferdebetrieb: Leitfaden für Pferdebetriebe: So behalten Sie die Risiken im Griff.
- Ndagijimana M (2021). Coping with risk and climate change in farming: Exploring an index-based crop insurance in Burundi. Ph.D. Thesis, Wageningen University and Research: Wageningen, The Netherlands.
- Nto P, Mbanasor JA, Osuala AE (2014). Evaluation of risk management practices in rice production in Abia State, Nigeria. *American Journal of Experimental Agriculture* 4(3), 263-274.
- Nyairo R, Machimura T, Matsui TA (2020). Combined analysis of sociological and farm management factors affecting household livelihood vulnerability to climate change in rural Burundi. *Sustainability* 12(10), 4296. <https://www.mdpi.com/2071-1050/12/10/4296>
- Oğuz C, Karakayacı Z (2017). Tarım Ekonomisinde Araştırma ve Örneklem Metodolojisi, Selçuk Üniversitesi Ziraat Fakültesi Tarım Ekonomisi Bölümü Yüksek Lisans Ders Kitabı 1.Basım.
- Okonya JS, Ocimati W, Nduwayezu A, Kantungeko D, Niko N, Blomme G, Legg JP, Kroschel J (2019) Farmer reported pest and disease impacts on root, tuber, and banana crops and livelihoods in Rwanda and Burundi. *Sustainability* 11(6), 1592. <https://www.mdpi.com/1660-4601/16/3/400>
- Paridaens AM, Belotti L, Régi S, Mahwane J, Zoem JP (2012). Analyse des données secondaires de la sécurité alimentaire, vulnérabilité et nutrition au Burundi. Burundi. Retrieved from <https://documents.wfp.org/stellent/groups/public/documents/wfp253438.pdf>.
- VKM, (2013). Risk assessment of mycotoxins in cereal grain in Norway. <https://vkm.no/download/18.2994e95b15cc545071615a36/1510054265635/Risk%20assessment%20of%20mycotoxins%20in%20cereal%20grain%20in%20Norway.pdf>
- Wabi M, Vanhove W, Idohou R, Hounkpèvi A, Kakai R L, Damme P (2021). Characterization of spatio-temporal trends in longterm rainfall of three weather stations in Benin: Implications for Agricultural Decision Making. <https://orcid.org/0000-0003-1854-7306>
- Yohana J, Yan Y (2021). Price risk perceptions and adoption of management strategies by smallholder rice farmers in Mbeya region, Tanzania. <https://www.tandfonline.com/doi/full/10.1080/23311932.2021.1919370>.



The Effects of Earthquakes on Occurring in Türkiye on Demographic Structure and Agricultural Sector

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HIGHLIGHTS

- Earthquakes significantly affect agricultural production and rural livelihoods.
- Population shifts after earthquakes alter regional food and labor supply patterns.
- Strong correlations were found between disasters and agricultural output losses.
- Türkiye's hilly topography increases earthquake impact in fertile agricultural zones.

Abstract

This study aims to provide information on the relationship between earthquake disasters, demographic structure, and the agricultural sector in Türkiye. Natural disasters such as earthquakes bring many social and economic consequences. These include changes in population structure and damage to agricultural systems. Agriculture is one of the sectors most affected by these disasters. Earthquakes can cause damage to agricultural infrastructure, livestock production, cultivated lands, and food supply chains. Additionally, the agriculture-based industry, especially the food and textile sectors, may also be negatively affected. In countries where agriculture contributes significantly to national income, disasters can slow economic growth and rural development. In this study, several major earthquakes (magnitude ≥ 6.9) in Türkiye were evaluated in terms of their impacts on population and agricultural indicators. Simple and chain index calculations were made, and the Spearman rank correlation method was used to analyze the relationship between demographic changes and agricultural variables such as livestock numbers and crop production. The results show that there are strong positive correlations between population and indicators like cereals, fruits, and vegetables. It was found that earthquakes cause temporary or permanent migrations and disruptions in agricultural productivity. In addition, severe damage to rural infrastructure and livestock shelters was observed. The effect of public support and recovery efforts after the earthquakes was also evaluated. In conclusion, this study reveals that earthquakes significantly affect Türkiye's agricultural sector and rural population. The findings emphasize the need to develop integrated rural and agricultural policies that consider disaster risks. This research can provide insight for future planning in food security and disaster resilience.

Keywords: earthquakes; demographic change; agricultural sector; correlation analysis; rural migration; Türkiye

1. Introduction

Türkiye is located in the Alpine-Himalayan seismic belt, one of the most dynamic earthquake belts in the world, and is frequently faced with destructive earthquakes due to its geological structure on active fault lines

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(Şaroğlu et al. 1987; Pelit 2024; Şikoğlu and Ser 2024). The North Anatolian Fault Line (NAF), the Eastern Anatolian Fault Line (EAF), and the fault systems extending in Western Anatolia cause destructive earthquakes in different parts of the country (Ozel and Solmaz 2012; Şenol 2020; Ateş and Karataş 2023).

Considering the historical process, it is known that there have been 23 earthquakes with a magnitude of 6.9 and above in Anatolia since the 1500s. In the 20th century, Türkiye also experienced devastating earthquakes (magnitude 6.9 and above) (Ozel and Solmaz 2012). Some of these are; These earthquakes include the Mürefte earthquake in 1912 (magnitude 7.3), Ayvalık earthquake in 1919 (magnitude 7.0), Hakkari earthquake in 1930 (magnitude 7.6), Erzincan earthquake in 1939 (magnitude 7.9), Niksar-Erbaa earthquake in 1942 (magnitude 7.0), Tosya-Lâdik earthquake in 1943 (magnitude 7.2), Bolu-Gerede earthquake in 1944 (magnitude 7.2), Çaldıran earthquake in 1976 (magnitude 7.5), Gölcük earthquake in 1999 (magnitude 7.4), Düzce earthquake in 1999 (magnitude 7.2), and Van earthquake in 2011 (magnitude 7.2). When we look at the last 120 years (after 1900), it is seen that there have been 200 major and destructive earthquakes in Türkiye. This means that there are more than 1.5 major and destructive earthquakes every year. In these earthquakes, a total of 95 thousand people lost their lives, and nearly 600 thousand buildings were severely damaged (Yolcu and Bekler 2020). Especially earthquakes with a magnitude of over 6.9 are events that cause social, physical and economic difficulties and loss of life for human life, make it difficult to continue life in its normal course or interrupt it, and affect the life of living beings, as well as the social and economic structure of the country (Çetin and Yanar 2023). Earthquakes also affect social structure, population and economic activities in the long term (Tercan 2008). Demographic structure and the agricultural sector are among the areas that feel the effects of earthquakes most intensely (Şenol 2020). Major earthquakes change the population distribution and cause serious production and infrastructure losses in agriculture (Çığ and Toprak 2023). This situation has devastating effects on the livelihoods and living conditions of the population, especially in rural areas (Yenilmez 2023). The repercussions of such disasters can be more complex as the post-disaster recovery process takes longer, and vulnerable communities suffer more damage during this process.

This study examines the effects of earthquakes of magnitude 6.9 and above in Türkiye (1939 Erzincan, 1999 Gölcük, 2011 Van, 2023 Kahramanmaraş, etc.) on demographic structure and the agricultural sector. It aims to understand the interactions between earthquake impact and demographic structure and the agricultural sector and to contribute to the development of sustainable strategies in this context. A better understanding of post-earthquake problems and the development of effective solution strategies can shape not only emergency management but also long-term development policies. In this context, the results of the study are expected to contribute at both academic and practical levels.

2. Materials and Methods

The main material of the study consists of statistical data on population and the agricultural sector, reports on earthquakes, primary and secondary data, and scientific studies published by relevant institutions and organizations. Literature and statistics were analyzed, and index calculations were made to show annual changes. Simple and chained indices were used to measure change over time (Çömlekçi 1998). In simple indices, the aim is to determine how much the value of each period has increased or decreased compared to the previous period, and to examine the proportional changes of the values (Kaul and Chowdhury 2007). The general formula of the simple index is: $I_t = (y_t/y_0) * 100$, (I_t denotes the number of simple indices for period t , y_t denotes the value of period t for which the index is to be calculated, y_0 denotes the value of the period chosen as the base. The general formula of the chain index: $I_t = (y_t/y_{t-1}) * 100$ (I_t : the number of chained indices for period t).

In this context, the loss of life in earthquakes and the effects of demographic changes on population movements and losses in agricultural production were analyzed comparatively with statistical data. Correlation analysis was applied to examine the relationships between demographic structure, livestock assets, and production amounts in earthquake regions. Correlation analysis is used to measure the relationship between variables. Spearman's rank correlation takes values between -1 and +1. If the correlation coefficient is +1, it can be said that there is a positive perfect linear relationship between the variables, and if it is -1, it can

be said that there is a negative perfect linear relationship between the variables (Kalaycı 2017). The relationship between the agricultural sector and demographic structure was evaluated by utilizing scientific studies in literature.

3. Research Finding and Discussion

In Türkiye, earthquakes of magnitude 7.0 and above have deeply affected both social structure and economic activities throughout history. An overview of some of these earthquakes (1939 Erzincan, 1942 Erbaa-Niksar, 1999 Kocaeli/Düzce, 2011 Van, 2023 Kahramanmaraş) is presented below:

3.1. 1939 Erzincan Earthquake Example

The 1939 Erzincan Earthquake is one of the largest earthquakes in Türkiye's history. The 7.8-magnitude earthquake on December 27, 1939, killed 32,962 people, injured 100,000 people, and severely damaged 116,720 buildings (Kandilli Observatory). Apart from Erzincan, the earthquake also affected Amasya, Tokat, Gümüşhane, and neighboring provinces (Arpacı 2018). Limited transportation and winter conditions created serious difficulties in search and rescue, health, and shelter services. This information on the demographic structure before and after the earthquake is based on the results of the general census. While the population of Erzincan was 157 thousand in 1935, it increased to 158 thousand in 1940 (Yavuz, 2016). This limited increase is related to the loss of life and migration. Migration and administrative changes caused a total population to change of approximately 65-70 thousand (Yavuz 2012). One area that was heavily affected by the earthquake was the agricultural sector. The 1939 earthquake disrupted crop and animal production in Erzincan to a great extent. The state provided animal and seed support to farmers (Yavuz 2016). The buildings destroyed in the earthquake and livestock losses are given in Table 1. A total of 41,837 buildings were destroyed, including houses, schools, mosques, and barns. In addition, a total of 44,342 animals, including 13,203 cattle, 29,412 sheep and goats, and 1,727 passenger animals, perished.

Table 1. The number of buildings were destroyed, and livestock wiped out in the earthquake.

Demolished Buildings	Center	Refahiye	Kemah	Tercan	İliç	Total
Number of Villages	138	100	75	80	68	461
Number of Houses in Villages	13,305	3,732	3,325	6,506	3,059	29,927
Number of houses damaged	11,098	2,902	1,040	5,036	448	20,524
Shop	1,006	17	11	0	0	1,034
Mill	6	0	1	0	0	7
Stable	4,245	2,666	267	1,335	337	8,850
Haystack	3,494	2,337	275	1,474	297	7,877
School	62	28	3	1	1	33
Mosque	77	28	3	1	0	32
Corral	0	0	5	0	0	5
Wasted Animal	Merkez	Refahiye	Kemah	Tercan	İliç	Toplam
Ox	3,336	1,607	13	199	5	5,160
Cow	4,590	1,864	65	181	4	6,704
Manda	973	360	6	0	0	1,339
At	738	187	0	23	0	948
Merkep	526	221	7	23	2	779
Sheep	18,670	9,518	394	536	46	23,164
Goat	0	5,383	77	689	99	6,248

3.2. 1942 Erbaa-Niksar Earthquake Example

In 1940, Erbaa had 72 thousand inhabitants, most of whom lived in rural areas, subsisting on agriculture. Tobacco and wheat were the main crops. Tobacco production was also an important source of livelihood in Niksar, where 35,326 people lived in its towns and villages, and 81.16% (28,671) of the population lived in rural areas. In addition, wheat, barley, rice and walnut production was not negligible. Tobacco, rice, and walnuts were the export products of the region. While the rice yield was 500,000 kg in 1936, it was estimated to reach 1,000,000 kg in 1937. The income from agricultural products, especially tobacco, in both districts ensured that the socio-economic status of the people was at a good level (Akkuş 2022). The loss of life and property in Erbaa as a result of the earthquake is given in Table 2. Tobacco production, one of the most important income items of Erbaa, was also negatively affected. Hundreds of thousands of kilograms of tobacco were buried under the rubble, and most of them became unusable. On the other hand, tobacco was also exposed to the ravages of winter and snow, and the warehouses used as tobacco warehouses were destroyed, leaving no structure suitable for storage. Processing the tobacco stored in rows in Erbaa was not possible due to a lack of space. Therefore, the Chief Directorate of Tokat İnhisar (Tekel) was asked to purchase the tobacco in Erbaa in series or send it to the warehouses to be established in the district of Tokat. Thus, the impact of the severe damage to Erbaa's economy was minimized. In Erbaa, where a significant part of the society was agricultural producers, the situation of the landless and the poor, who worked seasonally in wheat and tobacco cultivation and in winter as tobacco balancing and bundling laborers, posed a significant problem. After the earthquake, many women, widows, and orphans faced unemployment and hardship. These people, numbering around 500, struggled with food, shelter, and health problems throughout the winter.

On the agricultural level, it was found that the fall planting in Erbaa in 1942 was better than in 1941, but some of the fields that were ready for planting were not planted. In the background of this phenomenon, the loss of 492 cattle in the center and 2,161 cattle in the sub-districts and villages during the earthquake reduced the ability of producers to cultivate and cultivate the land. In addition, a significant number of farmers were busy clearing the rubble of their destroyed houses and constructing shacks on the other hand. These obligations severely disrupted agricultural production activities. Due to the vital role of cattle in the continuity of agricultural production, land cultivation, and planting, the producers in Erbaa requested that they be sent a few tractors and that they be provided with seeds from the wheat in the warehouse of the Office.⁹⁵ Within the framework of these agricultural developments, the Ministry of Agriculture decided to provide seed aid to farmers on January 12, 1943, and allocated 70 tons of wheat and 70 tons of barley to Erbaa and 50 tons of wheat to Niksar, and requested the provincial authority to distribute the seeds to the farmers and not to interrupt their cultivation.

Table 2. Erbaa-Niksar earthquake damage.

Location	Dead Wounded		Partially Demolished House	Completely Destroyed House	Cattle Died	Perished Small Cattle
Town	210*	239	496	791	492	216
Central District	49	94	151	250	952	000
Hayati Nahiyesi	73	156	563	329	235	8
Karayaka Sub-district	14	37	500	110	111	126
Sonusa Sub-district	31	45	200	300	163	17
Bidevi Sub-district	66	74	107	267	700	3
Total	443	645	2,017	2,047	2,653	370

3.3. 1999 Kocaeli/Düzce Earthquake Example

The 1999 Kocaeli/Düzce earthquake (also known as the Gölcük earthquake) occurred with a magnitude of 7.8 according to Kandilli observatory data. In the earthquake, 120,000 houses were severely damaged and 2,000 were destroyed. The economic damage is estimated to be around \$23 billion. On the other hand, the earthquake, which occurred in industrialized and densely populated urban areas, especially in oil refineries,

various automotive factories, and Turkish maritime areas, increased the severity and caused great damage to life and property, both environmentally, socially, and especially economically (Marza 2004). The number of buildings that had to be completely removed after the earthquakes amounted to 23,400. Of the 93,000 houses and 15,000 businesses, 16,400 were severely damaged, while 220,000 houses were less severely affected. Widespread building collapses in the two earthquakes caused a significant number of casualties. There were 18,373 deaths and 48,901 hospitalized injuries, of which about 40% were permanently disabled (Durukal and Erdik 2008). The Kocaeli earthquake is considered to be the largest event to cause damage in an industrialized region since the 1906 San Francisco and 1923 Tokyo earthquakes. In the Kocaeli earthquake, 70% of the total insured losses were caused by direct damage and 30% by business interruption. The insurance industry's estimates of total insured losses resulting from the Kocaeli earthquake were in the region of \$1.5-3.5 billion, compared with the estimated \$550-750 million paid by the industry (Scawthorn and Johnson 2000). The region affected by the earthquake is both geographically large and economically dynamic. It constitutes the industrial heartland of Türkiye. The main industries are automobiles, petrochemicals, motor and railway vehicle manufacturing and repair, basic metals, synthetic fiber and yarn production and weaving, paint and varnish production, and tourism. The four most severely affected districts (Kocaeli, Sakarya, Bolu, and Yalova) account for more than 7 percent of the country's GDP and 14 percent of industrial value added. Per capita income is almost twice the national average. Despite containing only 4 percent of the country's population, the region provides more than 16 percent of budget revenues. The immediate surrounding districts (Bursa, Eskişehir and İstanbul) are indirectly affected by their close economic ties with the former area, for example industries and small businesses that provide material inputs to each other's production processes. They are also at a common seismic risk and therefore face great uncertainty for the future because of recent events. When we combine the seven cities, the wider earthquake zone accounts for 35% of the national GDP and almost half of the country's industrial production (Bibbee et al. 2000). Approximately 501.5 billion TL was required to repair irrigation structures in Kocaeli.

According to the Ministry of Agriculture and Rural Affairs, there is no significant damage in rural areas, but 621 barns, 39 poultry houses, and 2 fish facilities were damaged to varying extents. Some agricultural buildings and facilities were damaged by the earthquake. 327 cattle, 45 sheep and goats, 493,170 poultry and 154,500 fish died. 14,191 doses of vaccine were lost. In the poultry sector, production and slaughter programs of chicken combines were disrupted as many farmers' poultry houses were severely damaged. Prolonged and frequent power outages prevented the business from running, feed could not be sent to the poultry houses and animals could not be brought to slaughter from many poultry houses. Some chicken meat spoiled in cold stores and in refrigerated trucks during transportation. Most of the companies lost their dealer network in the earthquake zone, were unable to ship and sell their goods, could not collect their existing receivables and even lost the chance to collect them in the future.

3.4. 2011 Van Earthquake Example

The 7.2 magnitude Van earthquake on October 23, 2011 caused serious loss of life and property. In the 2011 Van earthquakes, 75% of the total 15,158 houses (excluding unclassified houses built after the earthquake) in Erciş City were damaged (Table 3). Of the damaged houses, 24% were heavily damaged, 10% were moderately damaged and 41% were slightly damaged. In Van, 16.8% of the working population is employed in the agricultural sector. Therefore, agriculture is an important economic activity in Van. Especially in the suburbs, this activity continues intensively. In addition to houses and workplaces, animal shelters used for animal husbandry activities were also severely damaged in the earthquake. As a matter of fact, 82% of the animal shelters (1,294 barns) were damaged to varying degrees in the earthquake.

Table 3. Structures destroyed in the earthquake.

Damaged structures	Damaged	%	No Damage	%	Total	%
Housing	11,337	74.79	3,821	25.21	15,158	100.00
Workplace	2,308	85.93	378	14.07	2,686	100.00
Stable	1,294	82.32	278	17.68	1,572	100.00

The situation is clearer when looking at Table 4, which includes the population and agricultural sector before and after the earthquake (TUIK). While the provincial population was 979,671 in 2007, it increased to 1,022,310 in 2009 and to 1,035,418 in 2010. The statistics of these four years show that the province's population is in a continuous upward trend. While the increase in the provincial population was expected to continue in this manner, the earthquake that occurred in 2011 reversed this situation. In other words, instead of increasing, the province's population decreased and returned to the level of 2009. The population of 1,022,000 in 2011 continued its previous upward trend after the earthquake. It is observed that the population of the province decreased significantly in the census years after the earthquake and then increased again at constant rates.

In this part of the research, correlation analysis was conducted to determine the relationship between the population structure of Van province before and after the earthquake, as well as the production of cattle, small cattle, cereals, and other crops, and the total production of vegetables, fruits, beverages, and spice plants (Table 5). According to the Spearman correlation coefficient analysis, a positive and significant relationship was found between the demographic structure in Van province and the number of small cattle ($r_{\text{Spearman}} = .775$ $p < 0.01$). The population increase in the province leads to a rise in ovine husbandry. No significant relationship was found between demographic structure and cattle numbers. One of the reasons for this may be the increase in subsidies for cattle breeding during the earthquake period, which disrupted the change due to population growth. There is a significant positive correlation between demographic structure and the production amount of cereals and other crops ($r_{\text{Spearman}} = .723$ $p < .01$), total production amount of vegetables ($r_{\text{Spearman}} = .875$ $p < .01$), fruits, beverages and spice crops ($r_{\text{Spearman}} = .877$ $p < .01$). This indicates that an increase in population leads to an increase in crop production and a decrease in population leads to a reduction in crop production (Table 5).

Cang et al. (2022) analyzed China in the period between 1995-2018 and found that there is a significant inverted U-shaped relationship between disaster losses and economic growth. Tasri et al. (2022) found that unemployment and poverty variables have a significant effect on the disaster loss variable in their research involving Indonesia in the period 1990-2019.

The earthquake in the province caused a significant decline in the population during the census years and then the population started to increase again. To further elaborate on the issue, it would be sufficient to look at Table 6, which provides migration data for the province. While the number of migrants received by the province in 2008 was 21,187, it showed a continuous increase until 2012, and although the rate of increase in 2013 was higher than the previous periods, it was less than the previous year. In 2011, the year of the earthquake, this increases continued, albeit very slightly. In 2012, migration to the province increased by more than 2 times compared to the previous year and reached 50,003. This can be explained by the return of those who left the province during the earthquake and the positive effects of the investments made in the province. In 2013, although the number of migrants received by the province decreased significantly compared to the previous year, it was still high compared to the period before the earthquake. The number of migrants received by the province in this period is over 32 thousand. When we look at the amount of migration given by the province, it is noteworthy that the values change in a fluctuating manner. In 2008, 2009, and 2010, the province emigrated approximately 30,000 each year, but in 2011, due to the earthquake, the province emigrated 72,000. In 2012, although not as high as in the previous year, the province again experienced a high rate of emigration, exceeding 46 thousand, but declined to 38 thousand in 2013. These values indicate that the province continues to experience significant emigration, and it is understood that this trend intensified in the period following the earthquake. If we look at the net migration rate of Van province, it is noteworthy that the values are variable. In 2008, net migration was -9.01, in 2009 it was -4.21, and in 2010 it was -7.77. In 2011, the net migration deficit reached the highest level with -46.67 due to the earthquake. In the study conducted by Trinh et al. (2021) on Vietnam in the period 2006-2008, it was found that more severe disasters are directly related to a greater probability of migration.

Table 4. Changes in population, number of cattle, number of sheep and goats, cereal cultivation area, vegetable cultivation area and fruit cultivation area for 2007-2023.

Years	Population			Cattle			Small Cattle			Cereal			Vegetable			Fruit		
	*	**		*	**		*	**		*	**		*	**		*	**	
2007	979,671	100.00	100.00	181,513	100.00	100.00	2,665,446	100	100.00	269,029	100	100.00	34,988	100	100.00	12,555	100	100.00
2008	1,004,369	102.52	102.52	172,138	94.84	94.84	2,553,175	95.79	95.79	253,415	94.20	94.20	31,441	89.86	89.86	14,899	118.67	118.67
2009	1,022,310	104.35	101.79	174,612	96.20	101.44	2,451,078	91.96	96.00	227,758	84.66	89.88	30,613	87.50	97.37	14,589	116.20	97.92
2010	1,035,418	105.69	101.28	158,033	87.06	90.51	2,332,697	87.52	95.17	1,038,733	386.10	456.07	29,749	85.03	97.18	13,979	111.34	95.82
2011	1,022,532	104.38	98.76	198,049	109.11	125.32	2,304,525	86.46	98.79	1,218,859	453.06	117.34	32,281	92.26	108.51	14,252	113.52	101.95
2012	1,051,975	107.38	102.88	194,690	107.26	98.30	2,372,499	89.01	102.95	1,063,896	395.46	87.29	30,599	87.46	94.79	15,391	122.59	107.99
2013	1,070,113	109.23	101.72	192,843	106.24	99.05	2,483,657	93.18	104.69	923,056	343.11	86.76	36,017	102.94	117.71	15,991	127.37	103.90
2014	1,085,542	110.81	101.44	163,958	90.33	85.02	2,691,934	100.99	108.39	906,786	337.06	98.24	33,388	95.43	92.70	19,030	151.57	119.00
2015	1,096,397	111.91	101.00	167,388	92.22	102.09	2,703,581	101.43	100.43	1,012,865	376.49	111.70	36,402	104.04	109.03	25,345	201.87	133.18
2016	1,100,190	112.30	100.35	162,728	89.65	97.22	2,658,215	99.73	98.32	2,840,073	1,055.68	280.40	38,895	111.17	106.85	23,904	190.39	94.31
2017	1,106,891	112.99	100.61	186,099	102.53	114.36	2,738,054	102.72	103.00	2,676,788	994.98	94.25	66,775	190.85	171.68	25,186	200.61	105.36
2018	1,123,784	114.71	101.53	177,346	97.70	95.30	2,650,531	99.44	96.80	2,077,138	772.09	77.60	66,276	189.42	99.25	24,889	198.24	98.82
2019	1,136,757	116.03	101.15	180,693	99.55	101.89	2,708,012	101.60	102.17	1,707,764	634.79	82.22	71,592	204.62	108.02	22,090	175.95	88.75
2020	1,149,342	117.32	101.11	197,483	108.80	109.29	3,166,236	118.79	116.92	1,929,639	717.26	112.99	88,220	252.14	123.23	27,892	222.16	126.27
2021	1,141,015	116.47	99.28	166,401	91.67	84.26	3,384,220	126.97	106.88	1,568,159	582.90	81.27	105,754	302.26	119.88	33,983	270.67	121.84
2022	1,128,749	115.22	98.92	133,137	73.35	80.01	3,413,510	128.07	100.87	2,166,933	805.46	138.18	102,524	293.03	96.95	33,956	270.46	99.92
2023	1,127,612	115.10	99.90	133,193	73.38	100.04	3,280,145	123.06	96.09	2,241,235	833.08	103.43	102,227	292.18	99.71	34,193	272.35	100.70

Source: (TUIK, 2024)

Notes: * Simple index values, ** Chain index values, Population: (person), Cattle: Cattle Production (Number), Small Cattle: Small Cattle Production (Number), Cereals: Production of cereals and other vegetable crops (tons), Vegetables: Total production of vegetables (tons), Fruits: Fruits, beverage and spice crops production

Table 5. Analysis of the relationship between demographic structure and agricultural sector of Van province.

		Correlations					
		Population	Cattle	Small Cattle	Cereal	Vegetable	Fruit
Spearman's rho	Population	Correlation	1.000	-.176	.775**	.723**	.875**
		P		.498	.000	.001	.000
		N	17	17	17	17	17
	Cattle	Correlation		1.000	-.368	-.164	-.341
		P			.147	.529	.395
		N		17	17	17	17
	Small Cattle	Correlation			1.000	.495*	.902**
		P				.043	.000
		N			17	17	17
	Cereal	Correlation				1.000	.676**
		P					.003
		N				17	17
	Vegetable	Correlation					1.000
		P					.875**
		N				17	17
	Fruit	Correlation					
		P					1.000
		N					17

** . Correlation is significant at the 0.01 level (2-tailed).

* . Correlation is significant at the 0.05 level (2-tailed).

Table 6. Migration information regarding Van Province (2008-2013).

	2008	2009	2010	2011	2012	2013
Migration Received	21,187	22,866	23,231	23,415	50,003	32,118
Migration	30,275	27,175	31,312	72,273	46,639	38,507
Net Migration	-9,088	-4,309	-8,081	-48,858	3,364	-6,389
Net Migration Rate (%)	-9,01	-4,21	-7,77	-46,67	3,20	-5,95

3.5. 2023 Kahramanmaraş Earthquake Example

On February 6, 2023, two earthquakes of magnitude 7.7 and 7.6 occurred in Kahramanmaraş, affecting 15.7% of the 13.4 million population in the disaster zone covering 10 provinces. Moreover, such a large size of the disaster zone, which includes 13% of Türkiye's 25.3 million households, increases losses (TurkStat 2024). There are 3,029,422 households in the earthquake zone, with an average household size of 3.5 persons. Considering that the average household size in Türkiye is 3.2 persons, the number of people living in households in the provinces in the region is above the average of Türkiye (TCSBB, 2023). In the 10 provinces affected by the earthquake, there are natural protected areas, nature parks, wetlands, forest areas, wildlife development areas, and important river basins with endemic plant and animal species. 4.35% of Türkiye's ecologically important areas are in this region (TCSBB, 2023). According to a report prepared by the Presidency of Strategy and Budget of the Republic of Türkiye, the total number of houses categorized as urgent demolition, collapsed, or heavily damaged is 507,853. The number of houses with moderate damage was estimated as 130,054, and the number of houses with minor damage as 1,248,576 (Table 7). According to these data, 2,273,551 people directly faced housing problems after the earthquake. The ongoing impact of the earthquakes and the conditions in the earthquake zone deepen the housing problem.

On the other hand, 14,314 barns and 94,217 commercial establishments were severely damaged in areas declared “disasters affecting general life”; total damage amounted to \$2.2 billion. The geography affected by the earthquake's accounts for about 20% of Türkiye's agricultural production. The effects of the earthquakes also displaced a large part of the local agricultural population (FAO 2023). The region's 40.3 million decare of agricultural land accounts for 16.9 percent of Türkiye's agricultural land. By 2022, 26 percent of Türkiye's fruit

growing area and 16.2 percent of its arable agriculture area are in these provinces. The region has an important place in the country's agriculture in terms of apricot, almond, pomegranate and olive production. In Türkiye, 13 percent of cattle and 17.8 percent of sheep and goats are found in the earthquake provinces. The provinces in the earthquake zone are located in the Seyhan, Ceyhan, Asi and Euphrates basins, which are among the richest basins in terms of water resources in Türkiye. Thirty percent of Türkiye's basin precipitation area and 39 percent of the annual runoff amount are in these basins (TCSBB 2023). The total number of agri-food enterprises in Türkiye is 457,723. Of these, 54,573 are affected by the earthquake. Adana has the highest number of enterprises (13,300), followed by Gaziantep (8,839), Hatay (8,829), Diyarbakır (8,600), and Kahramanmaraş (5,401) (FAO 2023). There are Adana, Diyarbakır, Gaziantep, Hatay, and Şanlıurfa Food Control Laboratories operating under TOBB in the region. Malatya Sugar Factories of Türkiye Şeker Fabrikaları A.Ş., privately owned Elbistan Sugar Factory, and Adana and Diyarbakır Meat Combines of the Meat and Milk Board are also operating in the region (TOBB 2024). Of the 12 privately owned product warehouses with a capacity of 558,250 tons in Adana, Diyarbakır, Gaziantep, Kahramanmaraş, and Hatay, 26.1 percent were heavily damaged, 33.4 percent were moderately damaged, and 40.6 percent were slightly damaged. The total cost of these damages is estimated at 221 million TL (11.7 million USD). In the livestock sector, 8,241 cattle, 64,260 sheep and goats, and 42,000 heads of poultry died. In addition, 533,000 chicks perished in Adıyaman and 168,000 in Malatya. In this context, it is estimated that breeders suffered a loss of 602.5 million TL (31.9 million USD) due to animal deaths (TCSBB, 2023). Of the 18 warehouses with a total capacity of 315,100 tons belonging to the Turkish Grain Board (TMO) in the region, 9.5 percent were destroyed, 22.1 percent were moderately damaged, and 68.4 percent were slightly damaged. Total damage is estimated at 81.6 million TL (4.3 million USD). As a result of this disaster, there was a significant loss of life among the elderly population, which is widespread in rural areas and villages, and serious damage to the agricultural sector. The population of 10.8 million in 2007 increased to 13.42 million in 2022 and then experienced a remarkable decline to 13.18 million in 2023. This decline may be due to migration movements and deaths in the region as a result of the 2023 Kahramanmaraş earthquake. The number of cattle increased by 96% in 2023 compared to 2007 (from 1,061,042 to 2,082,022). The highest increase was seen between 2018 and 2021, with a slight decline in 2022, and a rebound in 2023. The increase in 2023 may indicate the start of recovery efforts. There was an increase of 79% compared to 2007, but a decrease in 2022 compared to 2021, and an increase again in 2023. Small ruminants still play an important role in agricultural production.

Table 7. Damage assessment report by province.

Province	Total Emergency + Heavy + Destroyed	Number of Moderately Damaged Houses	Number of Less Damaged Houses
Adana	2,952	11,768	71,072
Adıyaman	56,256	18,715	72,729
Diyarbakır	8,602	11,209	113,223
Gaziantep	29,155	20,251	236,497
Kahramanmaraş	99,326	17,887	161,137
Malatya	71,519	12,801	107,765
Hatay	215,255	25,957	189,317
Kilis	2,514	1,303	27,969
Osmaniye	16,111	4,122	69,466
Şanlıurfa	6,163	6,041	199,401
Total	507,853	130,054	1,248,576

Source: (TCSBB, 2023)

Table 8. Changes in population, number of cattle, number of sheep, grain planting area, vegetable planting area and fruit planting area between 2007-2023.

Years	Population	*	**	Cattle	*	**	Small Cattle	*	**	Cereal	*	**	Vegetable	*	**	Fruit	*	**
2007	10,817,288	100.00	100.00	1,061,042	100.00	100.00	3,215,340	100.00	100.00	13,041,023	100.00	100.00	3,742,040	100.00	100.00	3,054,548	100.00	100.00
2008	11,052,730	102.18	102.18	1,025,919	96.69	96.69	3,128,259	97.29	97.29	10,763,647	82.54	82.54	3,906,264	104.39	104.39	3,145,089	102.96	102.96
2009	11,249,820	104.00	101.78	1,033,063	97.36	100.70	3,913,990	121.73	125.12	12,366,071	94.82	114.89	3,791,752	101.33	97.07	3,644,044	119.30	115.86
2010	11,437,638	105.73	101.67	1,169,093	110.18	113.17	2,966,884	92.27	75.80	13,533,132	103.77	109.44	3,727,008	99.60	98.29	3,540,059	115.89	97.15
2011	11,639,701	107.60	101.77	1,334,631	125.78	114.16	3,489,608	108.53	117.62	14,458,721	110.87	106.84	3,548,796	94.84	95.22	3,764,982	123.26	106.35
2012	11,800,365	109.09	101.38	1,502,810	141.64	112.60	3,978,651	123.74	114.01	14,308,930	109.72	98.96	3,511,558	93.84	98.95	3,887,367	127.26	103.25
2013	11,969,176	110.65	101.43	1,533,505	144.53	102.04	4,329,221	134.64	108.81	15,716,089	120.51	109.83	3,668,539	104.47	104.47	4,201,888	137.56	108.09
2014	12,147,617	112.30	101.49	1,551,173	146.19	101.15	4,864,282	151.28	112.36	14,341,000	109.97	91.25	3,529,611	96.21	96.21	3,512,683	115.00	83.60
2015	12,310,842	113.81	101.34	1,542,274	145.35	99.43	4,459,827	138.70	91.69	15,830,804	121.39	110.39	3,683,854	104.37	104.37	4,461,650	146.07	127.02
2016	12,502,248	115.58	101.55	1,617,676	152.46	104.89	4,484,066	139.46	100.54	14,574,763	111.76	92.07	3,809,873	103.42	103.42	4,280,022	140.12	95.93
2017	12,676,288	117.19	101.39	2,026,425	190.98	125.27	4,965,520	154.43	110.74	16,067,602	123.21	110.24	3,736,190	98.07	98.07	4,809,681	157.46	112.38
2018	12,870,105	118.98	101.53	2,250,870	212.14	111.08	5,307,748	165.08	106.89	15,033,374	93.56	93.56	3,791,883	101.49	101.49	4,773,536	156.28	99.25
2019	13,028,146	120.44	101.23	2,264,371	213.41	100.60	5,565,337	173.09	104.85	15,163,870	94.38	100.87	3,787,499	99.88	99.88	4,472,875	146.43	93.70
2020	13,216,008	122.17	101.44	2,205,694	207.88	97.41	6,182,902	192.29	111.10	17,038,147	106.04	112.36	3,865,952	102.07	102.07	4,507,238	147.56	100.77
2021	13,309,886	123.04	100.71	2,165,024	204.05	98.16	6,462,097	200.98	104.52	16,284,255	101.35	95.58	3,840,039	99.33	99.33	5,255,053	172.04	116.59
2022	13,421,699	124.08	100.84	2,048,716	193.09	94.63	6,167,836	191.83	95.45	16,988,752	105.73	104.33	3,519,562	91.65	91.65	5,475,715	179.26	104.20
2023	13,188,335	121.92	98.26	2,082,022	196.22	101.63	5,755,648	179.01	93.32	17,725,885	110.32	104.34	3,534,541	100.43	100.43	7,301,395	239.03	133.34

Source: (TUIK, 2024)

Notes: * Simple index values, ** Chain index values, Population: (person), Cattle: Cattle Production (Number), Small Cattle: Small Cattle Production (Number), Cereals: Production of cereals and other vegetable crops (tons), Vegetables: Total production of vegetables (tons), Fruits: Fruits, beverage and spice crops production (Tons)

Cereal production has been volatile. It peaked in 2020 (17 million tons), but declined slightly in the following years. In 2023, it increased again, reaching 17.7 million tons. This increase can be explained by improvements in production policies or a favorable change in climatic conditions. Vegetable production is generally stable, with a significant decline (91.65%) in 2022. In 2023, this production increased again. Post-earthquake revitalization efforts may have been effective here as well. This table shows that there is a general upward trend in agricultural production with population growth. However, deviations in some years (especially 2023) show that natural disasters and migration movements directly affect agriculture and livestock activities. Population declines during crisis periods, such as earthquakes, leads to temporary fluctuations in agricultural production. The increase in the number of fruits and small ruminants in particular shows that these areas have a higher resilience capacity (Table 9).

Table 9. Analysis of the relationship between demographic structure and agricultural sector of Kahramanmaraş province.

		Correlations					
		Population	Cattle	Small Cattle	Cereal	Vegetable	Fruit
		Correlation					
Spearman's rho	Population	1.000	.914**	.963**	.897**	.007	.917**
	P		.000	.000	.000	.978	.000
	N	17	17	17	17	17	17
	Cattle		1.000	.909**	.782**	.103	.811**
	P			.000	.000	.694	.000
	N		17	17	17	17	17
	Small Cattle			1.000	.855**	.074	.858**
	P				.000	.779	.000
	N			17	17	17	17
	Cereal				1.000	-.113	.904**
	P					.667	.000
	N				17	17	17
	Vegetable					1.000	-.044
	P						.866
	N					17	17
	Fruit						1.000
	P						
	N						17

** . Correlation is significant at the 0.01 level (2-tailed).

Correlation analysis was conducted to determine the relationship between population structure and animal and crop production in Kahramanmaraş and its surrounding provinces (Table 9). The results of the analysis are like those of Van province. According to the Spearman correlation coefficient, positive and significant relationships were found between demographic structure and cattle ($r = 0.914$) and ovine ($r = 0.963$) livestock. Similarly, significant relationships were found between population and cereal ($r = 0.897$) and fruit and vegetable production ($r = 0.917$). This indicates that an increase in population increases production, while a decrease in population leads to a decrease in livestock and production. Panwar and Sen (2019) state that disasters affect different sectors according to their intensity and types, and that these effects are more pronounced in developing countries.

4. Conclusion and Suggestions

Türkiye is located in a region prone to frequent natural disasters. Indeed, many earthquakes in the last eighty years, especially the Erzincan earthquake in 1939 and the Marmara earthquake in 1999, have caused the loss of many lives and heavy economic losses. Most recently, the 7.8 and 7.6 magnitude earthquakes in Kahramanmaraş on February 6, 2023, caused heavy losses not only to the regional economy but also to the national economy. The most obvious consequences of earthquakes are high mortality rates, physical

destruction of buildings and infrastructure, and extensive damage to agricultural land, all of which harm the regional economy. The physical loss of buildings and infrastructure, the decline in the labor force, and the loss of arable farmland not only cause short-term damage, but also have significant economic consequences, such as a decline in consumer confidence, potential earnings, and the production and quality of the labor force, leading to recessions and a slowdown in investment. As a result of the major earthquakes, infrastructure and superstructure collapsed, hundreds of thousands of buildings were destroyed, and qualified labor and education were lost. In addition, tourism in the region came to a halt, and agriculture and animal husbandry activities suffered a major blow. There is a lack of information on the quantitative economic impact of these disasters on agriculture, the characteristics of the affected population, food safety, production, and marketing. As a result of the earthquakes, collapses, cracks, landslides, slides, splits, or fractures in the agricultural lands make it difficult to carry out agricultural production. In addition, agricultural irrigation systems, i.e., agricultural structures such as irrigation canals and pipes, farms, animal shelters, etc, are damaged by these effects on agricultural lands. Migration due to these unfavorable conditions caused by earthquakes will also cause a delay in agricultural production. In addition to these physical problems, earthquakes also damage plant and animal production activities. These damages may be in the form of delay or inability to carry out agricultural production activities, as well as loss of products and stored inputs during harvesting, and animal waste. Distortions in the land structure will increase production and harvest losses, and feeding problems will arise due to collapse damage in farms.

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References

- Akkuş T (2022). Hasip Ahmet Aytuna'nın raporu ışığında 1942 Erbaa-Niksar depremi ve Tokat'taki gelişmeler. *Belgi Dergisi* 2(24): 165–190.
- Arpacı M (2018). Şehrin çöküşü ve hafıza mekânının inşası: 1939 Erzincan depremi üzerine. *Kebikeç: İnsan Bilimleri İçin Kaynak Araştırmalı Dergisi* 45.
- Ateş T, Karataş L (2023). 6 Şubat 2023 depreminden sonra hasar tespit çalışmalarında izlenen sorunlar ve çözüm önerileri. In: Kahramanmaraş Merkezli Depremler Sonrası İçin Akademik Öneriler. Özgür Yayınları, Gaziantep, pp. 143–152.
- Bibbee A, Gönenç R, Jacobs S, Konvitz J, Price R (2000). Economic effects of the 1999 Turkish earthquakes: An interim report.
- Cang D, Xu Y, Wang G (2022). The relationship between economic growth and disaster losses—Based on linear and nonlinear ARDL model in China. *Sustainability* 14(15), 9760.
- Çetin MŞ, Yanar Hİ (2023). Kamu hizmeti olarak depremle mücadele ve etken bir suje olarak yerel yönetimlerin rolü. Conference Book, pp. 215–223.
- Çığ F, Toprak Ç (2023). Buğday üretimi üzerindeki depremlerin etkileri. 4th International Çukurova Agriculture and Veterinary Congress, 27–28.
- Çömlekçi N (1998). Temel istatistik: ilke ve teknikleri. Bilim Teknik Yayınevi.
- Durukal E, Erdik M (2008). Physical and economic losses sustained by the industry in the 1999 Kocaeli, Türkiye earthquake. *Natural Hazards* 46, 153–178.

- FAO (2023). Türkiye Initial Assessment on Possible Impacts of Earthquake in 11 Provinces. Food and Agriculture Organization of the United Nations. <https://openknowledge.fao.org/server/api/core/bitstreams/33e279ac-c015-4282-9cf1-fb5f3d14f6ea/content> (access date: 05.12.2024).
- Kalaycı Ş (2017). SPSS uygulamalı çok değişkenli istatistik teknikleri. Asil Yayın Dağıtım, Ankara, pp. 1–426.
- Kaul R, Chowdhury R (2007). Applied Statistics–Economic Statistics.
- Marza VI (2004). On the death toll of the 1999 Izmit (Türkiye) major earthquake. ESC General Assembly Papers, European Seismological Commission, Potsdam.
- Ozel G, Solmaz A (2012). Türkiye’de deprem tekrarlanma zamanının tahmini ve neotektonik bölgelere göre depremselliğin Markov zinciri ile incelenmesi. *Çankaya University Journal of Science and Engineering* 9(2).
- Panwar V, Sen S (2019). Economic impact of natural disasters: An empirical re-examination. *Margin: The Journal of Applied Economic Research* 13(1): 109–139.
- Pelit İ (2024). Afet lojistiği sorunları ve çözüm önerileri: Kahramanmaraş depremi. *Sosyal, Beşeri ve İdari Bilimler Alanında Uluslararası Araştırmalar XXV*, pp. 195–218.
- Scawthorn C, Johnson G (2000). Preliminary report: Kocaeli (Izmit) earthquake of 17 August 1999. *Engineering Structures* 22(7), 727–745.
- Şaroğlu F, Emre Ö, Aydoğan B (1987). Türkiye’nin diri fayları ve depremsellikleri. Mineral Research and Exploration Institute (MTA) of Türkiye Report 8174.
- Şenol C (2020). Türkiye’de meydana gelen büyük depremlerin yerleşme ve demografik yapı üzerindeki etkileri (1927–2020). *Uluslararası Sosyal Bilimler Akademisi Dergisi* 4, 620–644.
- Şıkoğlu E, Ser İŞ (2024). Regional analysis of active faults in Türkiye and their relationship with vulnerable population. Özgür Yayın-Dağıtım Co. Ltd., Gaziantep, pp. 1–109.
- Tasri ES, Karimi K, Muslim I (2022). The effect of economic variables on natural disasters and the impact of disasters on economic variables. *Heliyon* 8(1).
- TCSBB (2023). Kahramanmaraş ve Hatay depremleri raporu. T.C. Cumhurbaşkanlığı Strateji ve Bütçe Başkanlığı. <https://www.sbb.gov.tr/2023-kahramanmaras-ve-hatay-depremleri-raporu/> (access date: 04.12.2024).
- Tercan B (2008). Afet bölgelerinde yeniden yerleştirme ve iskân politikaları: Doğubayazıt afetzedede yerleşim alanları uygulama örneği. Ankara Üniversitesi, Ankara, pp. 1–340.
- TOBB (2024). Sanayi İstatistikleri. Türkiye Odalar ve Borsalar Birliği. <http://sanayi.tobb.org.tr> (access date: 03.10.2024).
- Trinh TA, Feeny S, Posso A (2021). The impact of natural disasters on migration: Findings from Vietnam. *Journal of Demographic Economics* 87(3), 479–510.
- TÜİK (2024). İl İstatistikleri. <https://data.tuik.gov.tr/Kategori/GetKategori?p=nufus-ve-demografi-109&dil=1> (access date: 04.12.2024).
- Yavuz E (2012). Erzincan’da idari ve siyasi hayat: 1923–1960. Erzurum.
- Yavuz E (2016). 1939 Erzincan depremi ve depremin etkileri. Uluslararası Erzincan Sempozyumu, Erzincan, pp. 443–452.
- Yenilmez DT (2023). Deprem ve göç ilişkisi üzerine bir değerlendirme. *Akademik Düşünce Dergisi* 7, 39–52.
- Yolcu M, Bekler T (2020). Deprem kültürü ve farkındalık çalışmaları: Şili ve Elazığ depremlerinin karşılaştırılması. *Lapseki Meslek Yüksekokulu Uygulamalı Araştırmalar Dergisi* 1(2), 71–82.



Investigation of Genetic Polymorphism in Selected Thyme (*Thymus vulgaris* L.) Accessions Using SCoT Molecular Markers

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HIGHLIGHTS

- In this study, thirty-two thyme genotypes were used as plant material.
- Determining genetic polymorphism is highly important for the species' adaptation to nature, enhancing its commercial value, developing high-quality products, and breeding programs.
- Molecular characterization of some thyme genotypes included in the study was conducted to reveal their genetic diversity and to ensure the sustainable conservation of natural resources.

Abstract

Identifying plant species and evaluating their variation should not be based solely on morphological characteristics. Such studies should be expanded through biochemical and DNA analyses. In this context, the aim of our study is to reveal the genetic diversity of some thyme (*Thymus*) samples naturally growing in the flora of Divriği district of Sivas province, and to contribute to the sustainable conservation of natural resources as well as to determine their agricultural utilization potential. Additionally, this study aims to explore the use of SCoT (Start Codon Targeted) markers in evaluating the diversity among different thyme genotypes. The plants were collected from their natural habitats, and DNA was extracted from fresh leaves using the CTAB method. A total of 36 SCoT markers were screened in the samples and the 14 most polymorphic markers were selected for analysis. In this study, a total of 169 bands were obtained from the 14 SCoT primers used to determine the genetic relationships among the thyme samples. Among these, 141 bands were polymorphic, resulting in a polymorphism rate of 83.43%. The data obtained allowed for the construction of a dendrogram grouping the analyzed ecotypes according to their similarity indices. According to the UPGMA dendrogram and the correlation matrix generated from the SCoT molecular data, the lowest similarity (0.326) was observed between samples G12 and G17, while the highest similarity (0.854) was found between G8 and G10. As a result, it was demonstrated that evaluating variation in *Thymus* species and establishing similarity indices using SCoT markers is possible, providing a solid basis for advanced molecular genetic analyses.

Keywords: *Thymus vulgaris* L.; SCoT marker; polymorphism

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1. Introduction

Thyme, which holds a significant place both in global cuisine and traditional medicine, is a perennial aromatic plant belonging to the *Lamiaceae* family (Gavaric et al. 2015). Thyme species are rich in essential oils, phenolic compounds, flavonoids, vitamins, and minerals. Due to these chemical constituents, thyme exhibits strong antioxidant, antimicrobial, antifungal, anti-inflammatory, and anticancer properties (Shabnum and Wagay 2011). Thyme is widely utilized in the food industry both in fresh and dried forms as a spice, while its essential oils are extensively used in the cosmetic, pharmaceutical, and disinfectant industries. Additionally, thyme tea and extracts are commercially valuable functional products (Miraj and Kiani 2016). Thyme (*Thymus vulgaris* L.) is one of the most commonly used aromatic plants worldwide due to its high economic value, aromatic characteristics, and medicinal effects (Prasanth Reddy et al. 2014). Given their wide ecological distribution and adaptability to diverse environmental conditions, thyme species exhibit a high degree of genetic variation (Basch et al. 2004). Although the Sivas province is not highly suitable for large-scale thyme cultivation, local thyme species are found naturally within the flora of districts such as Zara, Divriği, and İmranlı, where they are collected on a limited scale for traditional use. Natural populations in these areas display morphological and chemical variation due to ecological differences, which presents a valuable opportunity for the conservation of local genetic resources (Koyuncu et al. 2010; Celep and Dirmenci 2017; Fafal et al. 2024). Local thyme species generally possess richer aroma profiles and are more commonly preferred in traditional medicine (Gouyon et al. 1986). This variation, known as genetic polymorphism, is critically important for the sustainability, adaptability, and breeding programs of the species (Vernet et al. 1986). Genetic polymorphism enables thyme species to develop tolerance to different climate, soil, and environmental conditions (Rustaiee et al. 2013). This diversity allows plants to be more resilient against stress factors such as drought, diseases, pests, and climate change. Genetic variation observed particularly in thyme species growing naturally in semi-arid regions supports their adaptive capacity.

Genetic diversity directly influences the quantity and composition of essential oil constituents. The levels of compounds such as carvacrol, thymol, p-cymene, and γ -terpinene can vary significantly among genotypes. These differences have a direct impact on product quality, commercial value, and the potential applications of the plant (Amiot et al. 2005). In this regard, genetic polymorphism is a fundamental factor in determining aromatic quality. The main objectives of thyme breeding programs are to enhance traits such as high yield, disease resistance, essential oil content, and specific aroma profiles (György et al. 2020). Genetic polymorphism enables the selection and development of such traits. Identifying genetically distinct individuals is crucial for the development of superior lines in breeding programs (Thompson et al. 2004). The genetic diversity found in natural thyme populations is of great importance for the conservation of local species. Conserving genetically rich species plays a strategic role in ensuring ecosystem sustainability and meeting future agricultural demands (Rustaiee et al. 2013). Therefore, the molecular identification and conservation of local varieties are essential components of sustainable agricultural practices (El-Demerdash et al. 2019). Techniques such as ISSR, RAPD, AFLP, SCoT and SSR used in the detection of genetic polymorphism are widely employed to elucidate the genetic structure of thyme species and to analyze inter- and intra-genotypic relationships (Sayed Ibrahim et al. 2024). These techniques allow for more precise species identification and classification (Khalil et al. 2012; Elsherbeny and Eldemerdash 2019).

The aim of this study is to determine the genetic polymorphism among different thyme genotypes collected from gardens in the Divriği district of Sivas and to reveal the genetic variation present. The findings are expected to contribute to the conservation of thyme germplasm in the region and support future breeding efforts.

2. Materials and Methods

Fresh leaves were collected from 32 different thyme samples belonging to the *Thymus vulgaris* L. germplasm, cultivated in farmer gardens in the Divriği district of Sivas. Information related to the thyme samples is presented in Table 1.

Table 1. Data of thyme genotypes characterized.

Genotype Code	Taxonomy	Collected Location	Genotype Code	Taxonomy	Collected Location
G1	<i>Thymus vulgaris</i> L.	Sivas/Divriği	G17	<i>Thymus vulgaris</i> L.	Sivas/Divriği
G2	<i>Thymus vulgaris</i> L.	Sivas/Divriği	G18	<i>Thymus vulgaris</i> L.	Sivas/Divriği
G3	<i>Thymus vulgaris</i> L.	Sivas/Divriği	G19	<i>Thymus vulgaris</i> L.	Sivas/Divriği
G4	<i>Thymus vulgaris</i> L.	Sivas/Divriği	G20	<i>Thymus vulgaris</i> L.	Sivas/Divriği
G5	<i>Thymus vulgaris</i> L.	Sivas/Divriği	G21	<i>Thymus vulgaris</i> L.	Sivas/Divriği
G6	<i>Thymus vulgaris</i> L.	Sivas/Divriği	G22	<i>Thymus vulgaris</i> L.	Sivas/Divriği
G7	<i>Thymus vulgaris</i> L.	Sivas/Divriği	G23	<i>Thymus vulgaris</i> L.	Sivas/Divriği
G8	<i>Thymus vulgaris</i> L.	Sivas/Divriği	G24	<i>Thymus vulgaris</i> L.	Sivas/Divriği
G9	<i>Thymus vulgaris</i> L.	Sivas/Divriği	G25	<i>Thymus vulgaris</i> L.	Sivas/Divriği
G10	<i>Thymus vulgaris</i> L.	Sivas/Divriği	G26	<i>Thymus vulgaris</i> L.	Sivas/Divriği
G11	<i>Thymus vulgaris</i> L.	Sivas/Divriği	G27	<i>Thymus vulgaris</i> L.	Sivas/Divriği
G12	<i>Thymus vulgaris</i> L.	Sivas/Divriği	G28	<i>Thymus vulgaris</i> L.	Sivas/Divriği
G13	<i>Thymus vulgaris</i> L.	Sivas/Divriği	G29	<i>Thymus vulgaris</i> L.	Sivas/Divriği
G14	<i>Thymus vulgaris</i> L.	Sivas/Divriği	G30	<i>Thymus vulgaris</i> L.	Sivas/Divriği
G15	<i>Thymus vulgaris</i> L.	Sivas/Divriği	G31	<i>Thymus vulgaris</i> L.	Sivas/Divriği
G16	<i>Thymus vulgaris</i> L.	Sivas/Divriği	G32	<i>Thymus vulgaris</i> L.	Sivas/Divriği

2.1. Genomic DNA Isolation and PCR

DNA extraction from thyme samples was performed based on the CTAB protocol described by Doyle and Doyle (1990). The concentrations of stock DNA were measured using a MaestroNano Pro spectrophotometer (MN913A, MaestroGen), and the DNA stocks were diluted to a final concentration of 5 ng/ μ L. The selected SCoT primers, PCR reaction mixture content and PCR cycling conditions used for PCR amplifications are presented in Table 2. For electrophoresis of the PCR products, a 2% agarose gel prepared in Tris-borate-EDTA (TBE) buffer was used. DNA bands were subsequently visualized under UV light. A total of 36 SCoT primers were screened and 14 primers that exhibited polymorphic patterns were selected for further analysis (Table 2).

Table 2. SCoT primers used for PCR amplification

SCoT Primers Code	DNA Sequences (5'-3')	Tm °C	PCR Reaction Mixture Content	PCR Amplification
SCoT 1	CAACAATGGCTACCACCA	54	4 μ L DNA (20 ng) 1 μ L primer 10 μ L PCR master mix (Eco Tech, Cat No: ET5) 10 μ L dH ₂ O	94 °C - 3 min 94 °C - 1 min 54-63 °C 1 min 72 °C - 1 min 72 °C - 8 min 35 cycles
SCoT 12	ACGACATGGCGACCAACG	58		
SCoT 14	ACGACATGGCGACCACGC	61		
SCoT 16	ACCATGGCTACCACCGAC	58		
SCoT 20	ACCATGGCTACCACCGCG	61		
SCoT 21	ACGACATGGCGACCCACA	58		
SCoT 22	AACCATGGCTACCACCAC	56		
SCoT 24	CACCATGGCTACCACCAT	56		
SCoT 26	ACCATGGCTACCACCGTC	58		
SCoT 28	CCATGGCTACCACCGCCA	61		
SCoT 30	CCATGGCTACCACCGGCG	63		
SCoT 31	CCATGGCTACCACCGCCT	61		
SCoT 33	CCATGGCTACCACCGCAG	61		
SCoT 36	GCAACAATGGCTACCACC	56		

2.2. Statistical Analysis

The bands obtained from the PCR analysis were scored as 1 for presence and 0 for absence. A dendrogram based on Jaccard's similarity coefficient was generated using the UPGMA (Unweighted Pair Group Method with Arithmetic Mean) algorithm in the MVSP 3.22 software (Kovach 2007). The application of MVSP 3.22 to the SCoT molecular data enabled the generation of a genetic similarity matrix. In addition, principal component analysis (PCA) was performed among thyme populations using the MVSP 3.22 software.

3. Results and Discussion

The gel images of PCR results for the primers, which produced the most polymorphic bands, are shown in Figure 1 are shown.

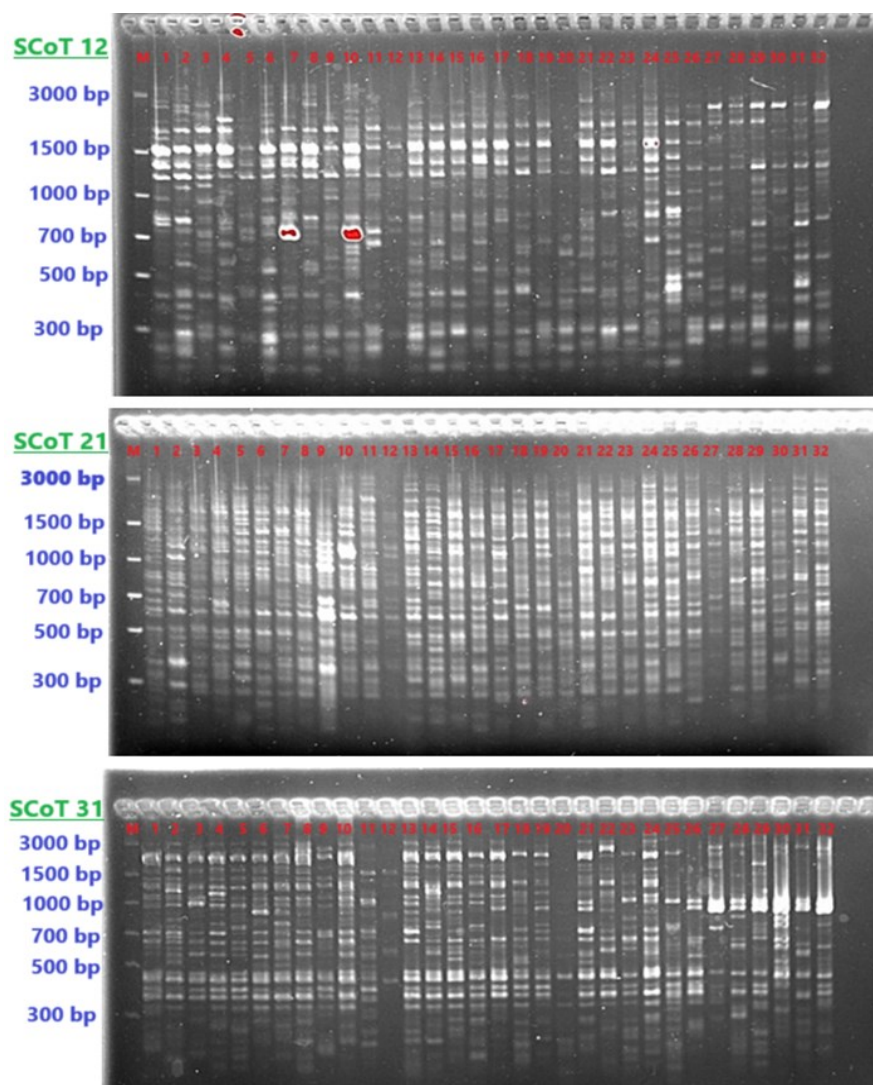


Figure 1. Gel image of bands amplified with SCoT 12, SCoT 21 and SCoT 31 primers: M: generuler.

In this study, a total of 169 bands were obtained from 14 SCoT primers used to determine the genetic relationships among thyme samples. Among these, 141 bands were polymorphic, resulting in a polymorphism rate of 83.43%. According to the UPGMA dendrogram and the correlation matrix generated from the SCoT molecular data, the lowest similarity (0.326) was observed between samples G12 and G17, while the highest similarity (0.854) was observed between samples G8 and G10 (Figure 2, Table 3).

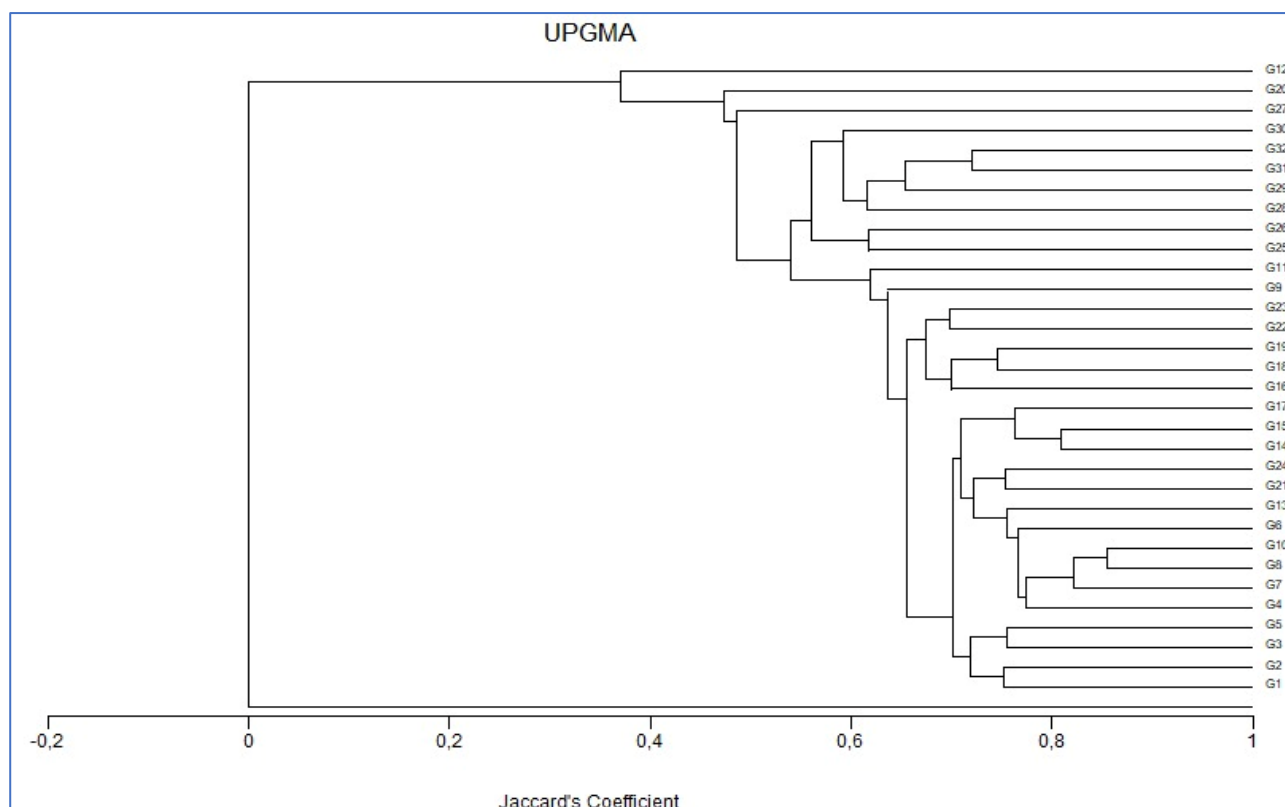


Figure 2. UPGMA dendrogram of genetic similarity between SCoT markers and 32 Thyme genotypes.

Table 3. Pairwise genetic distance matrix obtained from 14 SCoT primers.

	G1	G2	G3	G4	G5	G6	G7	G8	G9	G10	G11	G12	G13	G14	G15	G16	G17	G18	G19	G20	G21	G22	G23	G24	G25	G26	G27	G28	G29	G30	G31	G32
1	1,000																															
2	0,752	1,000																														
3	0,733	0,738	1,000																													
4	0,686	0,752	0,734	1,000																												
5	0,669	0,736	0,756	0,770	1,000																											
6	0,660	0,703	0,671	0,771	0,694	1,000																										
7	0,717	0,771	0,716	0,793	0,752	0,766	1,000																									
8	0,697	0,760	0,707	0,769	0,707	0,779	0,851	1,000																								
9	0,639	0,662	0,664	0,645	0,676	0,643	0,676	0,704	1,000																							
10	0,723	0,764	0,687	0,760	0,721	0,747	0,792	0,854	0,660	1,000																						
11	0,617	0,585	0,654	0,624	0,654	0,610	0,608	0,648	0,623	0,698	1,000																					
12	0,375	0,336	0,382	0,346	0,378	0,362	0,353	0,360	0,438	0,358	0,423	1,000																				
13	0,688	0,740	0,676	0,736	0,698	0,735	0,732	0,792	0,637	0,784	0,628	0,348	1,000																			
14	0,645	0,724	0,634	0,651	0,635	0,649	0,703	0,718	0,583	0,687	0,563	0,336	0,733	1,000																		
15	0,698	0,752	0,697	0,736	0,720	0,699	0,743	0,769	0,634	0,736	0,636	0,377	0,785	0,809	1,000																	
16	0,593	0,651	0,640	0,705	0,713	0,643	0,676	0,680	0,599	0,638	0,600	0,361	0,706	0,652	0,743	1,000																
17	0,681	0,689	0,669	0,697	0,658	0,671	0,692	0,707	0,594	0,709	0,607	0,326	0,733	0,729	0,796	0,713	1,000															
18	0,614	0,595	0,638	0,678	0,662	0,664	0,662	0,678	0,609	0,636	0,610	0,397	0,669	0,650	0,714	0,733	0,748	1,000														
19	0,588	0,603	0,590	0,631	0,662	0,640	0,686	0,678	0,618	0,657	0,595	0,383	0,657	0,626	0,691	0,669	0,699	0,746	1,000													
20	0,388	0,407	0,436	0,471	0,463	0,435	0,446	0,448	0,456	0,428	0,432	0,358	0,448	0,463	0,471	0,484	0,463	0,610	0,538	1,000												
21	0,616	0,660	0,662	0,712	0,720	0,687	0,743	0,699	0,634	0,691	0,579	0,377	0,702	0,697	0,736	0,669	0,708	0,714	0,691	0,504	1,000											
22	0,617	0,662	0,688	0,681	0,664	0,655	0,688	0,680	0,589	0,649	0,613	0,402	0,660	0,664	0,692	0,672	0,712	0,719	0,669	0,574	0,716	1,000										
23	0,555	0,593	0,591	0,657	0,664	0,630	0,652	0,612	0,620	0,614	0,635	0,381	0,603	0,582	0,610	0,659	0,570	0,709	0,617	0,595	0,645	0,698	1,000									
24	0,679	0,721	0,702	0,729	0,713	0,703	0,773	0,750	0,638	0,778	0,617	0,369	0,695	0,667	0,682	0,616	0,725	0,660	0,684	0,432	0,754	0,709	0,638	1,000								
25	0,482	0,524	0,496	0,507	0,532	0,525	0,524	0,513	0,474	0,483	0,485	0,390	0,524	0,532	0,539	0,581	0,543	0,605	0,504	0,491	0,550	0,583	0,552	0,521	1,000							
26	0,507	0,538	0,522	0,521	0,536	0,507	0,507	0,487	0,511	0,497	0,535	0,370	0,517	0,536	0,531	0,537	0,503	0,560	0,463	0,457	0,531	0,529	0,607	0,524	0,617	1,000						
27	0,512	0,500	0,504	0,450	0,496	0,436	0,437	0,449	0,504	0,438	0,504	0,375	0,448	0,442	0,460	0,473	0,474	0,562	0,441	0,391	0,493	0,489	0,475	0,453	0,518	0,564	1,000					
28	0,496	0,486	0,557	0,479	0,548	0,507	0,466	0,487	0,500	0,467	0,548	0,392	0,497	0,504	0,511	0,538	0,462	0,574	0,532	0,509	0,555	0,565	0,597	0,483	0,538	0,556	0,581	1,000				
29	0,479	0,552	0,536	0,556	0,550	0,542	0,563	0,530	0,538	0,471	0,504	0,351	0,541	0,528	0,556	0,588	0,539	0,611	0,546	0,527	0,579	0,664	0,623	0,571	0,593	0,570	0,513	0,628	1,000			
30	0,543	0,529	0,523	0,479	0,504	0,518	0,529	0,497	0,536	0,507	0,524	0,363	0,507	0,493	0,500	0,504	0,493	0,527	0,508	0,481	0,500	0,485	0,545	0,514	0,539	0,570	0,552	0,559	0,574	1,000		
31	0,545	0,583	0,592	0,577	0,582	0,596	0,553	0,561	0,561	0,571	0,574	0,355	0,582	0,510	0,546	0,542	0,571	0,630	0,569	0,516	0,577	0,633	0,606	0,581	0,578	0,606	0,516	0,664	0,661	0,625	1,000	
32	0,565	0,581	0,545	0,565	0,559	0,617	0,593	0,589	0,594	0,591	0,548	0,359	0,559	0,548	0,554	0,507	0,580	0,583	0,591	0,440	0,586	0,563	0,556	0,636	0,527	0,531	0,500	0,556	0,648	0,610	0,720	1,000

Based on the SCoT molecular data, a PCA image shown in Figure 3 was obtained using the MVSP 3.22 software. The UPGMA dendrogram and the PCA analysis were consistent with each other. Genotypes that are genetically similar were positioned close to one another in the PCA plot. PCA is an effective dimensionality reduction method for multivariate data sets (Mishra et al. 2017). Numerous similar studies have been conducted by researchers to determine the genetic diversity of different thyme genotypes. Shayan et al (2025) investigated the level of polymorphism in a thyme population using ISSR and SCoT markers, and reported that SCoT was more effective in detecting polymorphism in *Thymus daenensis*. In another study evaluating the genetic diversity among different *Thymus* species using SCoT and ISSR analyses, 39 bands (24 polymorphic – 60.52% polymorphism) were obtained from five SCoT primers, and 23 bands (14 polymorphic – 60.86% polymorphism) were obtained from five ISSR primers (Alqahtani et al. 2020). Beicu et al (2020) analyzed 13

natural thyme ecotypes using four SCoT markers (SCoT 11, SCoT 14, SCoT 35, and SCoT 36). As a result, 117 alleles were amplified with an average of 29.25 alleles per primer. All bands were found to be polymorphic. The variance analysis revealed an average PIC value of 0.370 and an average polymorphism index (PI) of 10.57. Ahmed et al. (2022) used five RAPD, six ISSR, and six SCoT primers to assess the genetic diversity levels in four plant species belonging to the Lamiaceae family. Using RAPD primers, a total of 41 amplified bands were identified with a polymorphism rate of 73.71%. ISSR primers generated a total of 31 bands with a polymorphism rate of 54.83%, while SCoT primers produced 43 bands with a polymorphism rate of 39.53%. Karagöz et al (2022) successfully characterized the population structure of 70 oregano genotypes using SCoT markers. A total of 109 polymorphic fragments were generated with 10 SCoT primers, and the average PIC value was calculated as 0.36.

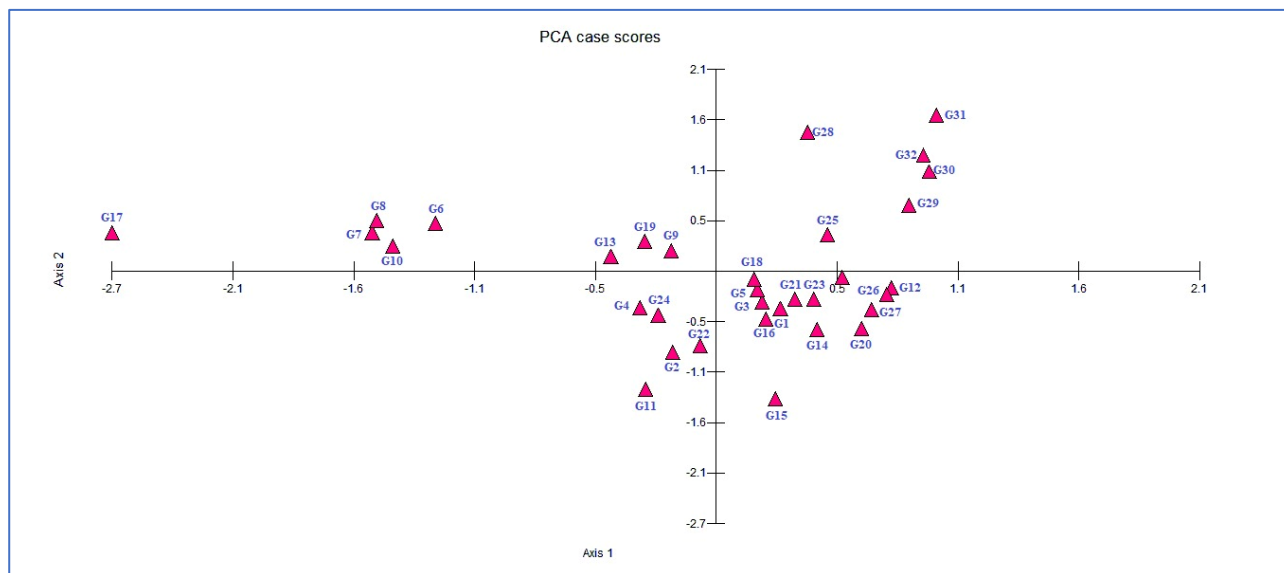


Figure 3. According to SCoT markers principal component analyses of 18 Thyme genotypes using MVSP 3.22 software.

4. Conclusions

Biochemical and DNA analyses are conducted to reveal variations within populations. In this study, the genetic diversity of some thyme (*Thymus*) samples naturally growing in the flora of Divriği district of Sivas province was investigated. In this way, the potential use of SCoT markers in evaluating the diversity among different thyme genotypes was also explored. The data obtained enabled the construction of a dendrogram grouping the analyzed ecotypes according to their similarity indices, and revealed a significant level of variation within the population. As a result, it was demonstrated that variation in *Thymus* species can be effectively evaluated using SCoT markers, and that these findings can contribute to the sustainable conservation of natural resources as well as the determination of their agricultural utilization potential. This indicates that the study provides a basis for advanced molecular genetic analyses. Our results suggest that evaluating genetic diversity and population structure in natural populations can provide comprehensive information for the conservation of endemic and endangered species, and can be effectively used in future breeding programs.

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References

- Ahmed AR, Soliman KA, Al-Senosy NK, Omar SA (2022). Genetic polymorphisms of four Egyptian plant species using some molecular markers techniques RAPD, ISSR, and SCoT. *Journal of Agricultural Chemistry and Biotechnology* 13(1), 21-24.
- Alqahtani MM, Abdein MA, Abou El-Leel OF (2020). Morphological and molecular genetic assessment of some *Thymus* species. *Biosciences Biotechnology Research Asia* 17(1), 103-113.
- Amiot J, Salmon Y, Collin C, Thompson JD (2005). Differential resistance to freezing and spatial distribution in a chemically polymorphic plant *Thymus vulgaris*. *Ecology Letters* 8(4), 370-377.
- Basch E, Ulbricht C, Hammerness P, Bevins A, Sollars D (2004). Thyme (*Thymus vulgaris* L.), thymol. *Journal of Herbal Pharmacotherapy* 4(1), 49-67.
- Beicu R, Popescu S, Neacsu A, Imbrea IM (2020). Applicability of ScoT (Start Codon Targeted) markers in evaluation of *Thymus* genetically variability. *Research Journal of Agricultural Science* 52(1), 24-30.
- Celep F, Dirmenci T (2017). Systematic and biogeographic overview of *Lamiaceae* in Türkiye. *Natural Volatiles and Essential Oils* 4(4), 14-27.
- Doyle JJ, Doyle JL (1990). Isolation of plant DNA from fresh tissue. *Focus* 12, 13-15.
- El-Demerdash ESS, Elsherbeny EA, Salama YAM, Ahmed MZ (2019). Genetic diversity analysis of some Egyptian *Origanum* and *Thymus* species using AFLP markers. *Journal of Genetic Engineering and Biotechnology* 17, 1-11.
- Elsherbeny E, Eldemerdash ES (2019). Genetic diversity among *Thymus* spp. using RAPD and ISSR markers. *Egyptian Journal of Desert Research* 69(2), 91-106.
- Fafal T, Kayalar H, Birim D, Armağan G, Tüzün BS, Taştan P, Kıvcak B (2024). Assessment of antioxidant and neuroprotective activity of plants from the *Lamiaceae* family. *İstanbul Journal of Pharmacy* 54(3), 403-408.
- Gavarić N, Kladar N, Mišan A, Nikolić A, Samojlik I, Mimica-Dukić N, Božin B (2015). Postdistillation waste material of thyme (*Thymus vulgaris* L., *Lamiaceae*) as a potential source of biologically active compounds. *Industrial Crops and Products* 74, 457-464.
- Gouyon PH, Vernet P, Guillerm JL, Valdeyron G (1986). Polymorphisms and environment: the adaptive value of the oil polymorphisms in *Thymus vulgaris* L. *Heredity* 57(1), 59-66.
- György Z, Incze N, Pluhár Z (2020). Differentiating *Thymus vulgaris* chemotypes with ISSR molecular markers. *Biochemical Systematics and Ecology* 92, 104118.
- Karagöz H, Hosseinpour A, Karagöz FP, Cakmakci R, Haliloglu K (2022). Dissection of genetic diversity and population structure in oregano (*Origanum acutidens* L.) genotypes based on agro-morphological properties and start codon targeted (SCoT) markers. *Biologia* 77(5), 1231-1247.
- Khalil R, Khalil R, Li Z (2012). Determination of genetic variation and relationship in *Thymus vulgaris* populations in Syria by random RAPD markers. *Plant Biosystems-An International Journal Dealing with all Aspects of Plant Biology* 146 (sup1), 217-225.
- Kovach WL (2007). MVSP-A MultiVariate Statistical Package for Windows, ver. 3.1. Kovach Computing Services, Pentraeth Wales, UK.
- Koyuncu O, Yaylaci O, Öztürk D, Potoglu Erkara I, Savaroglu F, Akcoskun O, Ardic M (2010). Risk categories and ethnobotanical features of the *Lamiaceae* taxa growing naturally in Osmaniye (Bilecik/Türkiye) and environs. *Biological Diversity and Conservation* 3(3), 31-45.
- Miraj S, Kiani S (2016). Study of pharmacological effect of *Thymus vulgaris*: A review. *Der Pharmacia Lettre* 8(9), 315-320.

- Mishra SP, Sarkar U, Taraphder S, Datta S, Swain D, Saikhom R, Laishram M (2017). Multivariate statistical data analysis-principal component analysis (PCA). *International Journal of Livestock Research* (7), 60–78.
- Prasanth Reddy V, Ravi Vital K, Varsha PV, Satyam S (2014). Review on *Thymus vulgaris* traditional uses and pharmacological properties. *Medicinal and Aromatic Plants* 3(164), 2167-0412.
- Rustaiee AR, Yavari A, Nazeri V, Shokrpour M, Sefidkon F, Rasouli M (2013). Genetic diversity and chemical polymorphism of some *Thymus* species. *Chemistry & Biodiversity* 10(6), 1088-1098.
- Sayed Ibrahim A, Çelik C, Karakurt Y, Sevindik E (2024). Physiological, biochemical, and molecular characterization of some cucumber (*Cucumis sativus* L.) genotypes. *International Journal of Vegetable Science* 30(6), 673-694.
- Shabnum S, Wagay MG (2011). Essential oil composition of *Thymus vulgaris* L. and their uses. *Journal of Research and Development* 11, 83-94.
- Shayan A, Shokrpour M, Nazeri V, Babalar M, Mehrabi A (2025). Assessment of diversity and genetic differentiation in polycross-derived populations of *Thymus daenensis* using ISSR and SCoT markers. *Genetic Resources and Crop Evolution* 72, 4931–4945. <https://doi.org/10.1007/s10722-024-02214-w>
- Thompson JD, Tarayre M, Gauthier P, Litrico I, Linhart YB (2004). Multiple genetic contributions to plant performance in *Thymus vulgaris*. *Journal of Ecology* 99(1), 45-56.
- Vernet P, Gouyon RH, Valdeyron G (1986). Genetic control of the oil content in *Thymus vulgaris* L: a case of polymorphism in a biosynthetic chain. *Genetica* 69(3), 227-231.



Chemical Composition of Hydrodistillated Essential Oil of *Heracleum antasiaticum* MANDEN (L.) and its Antimicrobial Activity Against Food-Borne Microorganisms

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HIGHLIGHTS

- Elemicin and apiole were identified as major components of the *Heracleum antasiaticum* essential oil.
- The oil exhibited broad-spectrum antimicrobial activity against food-borne microbes.
- An antagonistic effect was observed on probiotic bacteria such as *Lactobacillus* spp.
- Potential use of the oil as a natural food preservative was demonstrated.

Abstract

The essential oil obtained by hydrodistillation from the aerial parts of *Heracleum antasiaticum* MANDEN from Türkiye was analyzed by GC and GC-MS. Forty-five compounds were characterized, representing 92.7 % of the total components detected, and elemicin (27.8%), apiole (26.2%), *n*-octanol (4.9%), α -zingiberene (3.9%), octyl acetate (3.8%), and (E)- γ -bisabolene (3.1%) were identified as predominant components. In addition, in this study, the essential oil was tested for its antimicrobial activity against 23 different food-borne microorganisms, including 20 bacteria, 1 fungus, and 2 yeast species. The essential oil of *Heracleum antasiaticum* exhibited considerable inhibitory effects against all bacteria, fungi, and yeast species tested.

Keywords: *Heracleum antasiaticum*; essential oil; elemicin; apiole; antimicrobial activity

1. Introduction

The genus *Heracleum* L., the largest genus of the family Apiaceae, contains more than 120 species and is represented by 17 species in Türkiye. Within the species of this genus, *H. antasiaticum* is a stout perennial plant

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that reaches 50-100 cm in height and features white flowers, typically growing on the edge of forests and streams (Davis et al. 1988; Davis 1972; Duman 2000; Logacheva 2008).

Heracleum species are traditionally used as food additives, spices, and flavoring agents and show anti-inflammatory, antimicrobial, anticholinesterase, antioxidant, antiviral, cytotoxic, and anticarcinogenic effects. Earlier studies revealed that essential oils of *Heracleum* species were mainly rich in octyl acetate. However, they also contain main components such as octyl butyrate, octyl butanoate, hexyl butanoate, hexyl butyrate bornyle acetate, alpha pinene, beta pinene, elemicine, 1,8 cineole and e-anethole (Baser et al. 2000; Chu et al. 2012; Habibi et al. 2010; İşcan et al. 2003; Jagannath et al. 2012; Karimi and Ito 2012; Karuppusamy and Muthuraja 2010; Li et al. 2013; Maggi et al. 2014; Miladinović et al. 2013; Najafabadi et al. 2011; Radjabian et al. 2013; Sefidkon et al. 2002; Tkachenko 2009; Yousefirad and Karimzadeh 2008). The results of the studies mentioned here show that there is considerable variation within the genus *Heracleum*. This highlights the importance of better understanding the essential oil composition of other *Heracleum* species.

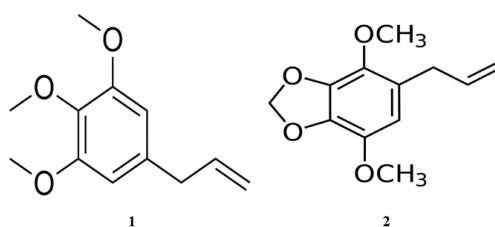


Figure 1. Chemical structures of compounds 1; elemicin, 2; apiol.

Many studies have been published on the composition and the antimicrobial properties of *Heracleum* essential oils (Akcın et al. 2013; Guleria et al. 2011; Jagannath et al. 2012; Maggi et al. 2014; Miladinović et al. 2013). These studies have emphasized the existence of marked chemical differences among the oils extracted from different species and indicated that the oils of some species of this genus had antibacterial and antifungal activity. Although a few studies (Ergene et al. 2007) have investigated *H. antasiaticum*, data on the chemical composition and antimicrobial activity of its essential oil remain limited. Therefore, this knowledge gap prompted us to identify the chemical composition of the hydrodistilled essential oil of *H. antasiaticum* growing wild in Türkiye, and to evaluate its antimicrobial activity against food-borne microorganisms.

2. Materials and Methods

2.1. Antimicrobial Activity

2.1.1. Microbial Strains

The essential oil was tested individually against a range of 23 microorganisms, including 20 bacteria, 1 fungus, and 2 yeast species. The microorganisms used are listed in Tables 2 and 3. Microorganisms were provided by the Food Microbiology Laboratory, Department of Food Engineering, Faculty of Agriculture, Ataturk University, Erzurum, Türkiye. The identification of the organisms used in the study was confirmed by the Microbial Identification System (Sherlock Microbial Identification System version 4.0, MIDI Inc., Newark, DE), API (BioMerieux, France), BIOLOG (MicroStation ID System, Biolog Inc., Hayward) and classical identification test from Bergey's manual of determinative bacteriology (John et al. 1994).

2.2. Experimental Design

2.2.1. Plant Material Collection and Preparation

The aerial parts of *H. antasiaticum* were collected at the flowering stage in August 2024 in the vicinity of Erzurum (at an altitude of about 2100 m), Türkiye. The taxonomic identification of plant material was confirmed by a senior plant taxonomist, Ali Kandemir, in Department of Biology, Erzincan University, Erzincan, Türkiye. Collected plant material was dried in the shade and ground in a grinder with a 2 mm mesh. The voucher specimen has been deposited at the Herbarium of the Department of Science, Erzincan University, Education Faculty, Erzincan, Türkiye.

2.2.2. Isolation of the essential oil

The aerial parts of air-dried plant material were subjected to hydro distillation using a Clevenger-type apparatus for 3 hours. The obtained essential oil was dried over anhydrous sodium sulphate and, after filtration, stored at +4 °C until tested and analysed.

2.3. Chemical Characterization of Essential Oil

2.3.1. GC analysis conditions

The analysis of the essential oil was performed using a Thermofinnigan Trace GC/A1300 (E.I.) equipped with an SGE/BPX5 MS capillary column (30 m x 0.25 mm i.d., 0.25 µm). Helium was the carrier gas, at a flow rate of 1 mL/min. Injector temperature was set at 220 °C. The programme used was 50-150 °C at a rate of 3 °C/min, held isothermal for 10 minutes, and finally raised to 250 °C at 10 °C/min. Diluted samples (1/100, v/v, in methylene chloride) of 1.0 µL were injected manually and in the splitless mode. Quantitative data were obtained from the FID area percentage data.

2.3.2. GC-MS analysis conditions

The analyses of the essential oils were performed using a Thermofinnigan Trace GC/Trace DSQ /A1300, (E.I Quadrupole) (Thermo Finnigan, CA, USA) equipped with an SGE-BPX5 MS capillary column (Scientific Instrument Services Inc., NJ, USA) (30 m x 0.25 mm i.d., 0.25 µm). For GC-MS detection an electron ionization system with ionization energy of 70 eV was used. Helium, at a flow rate of 1 mL/min, was the carrier gas. Injection and MS transfer line temperatures were set at 220 °C and 290 °C, respectively. The programme used was 50-150 °C at a rate of 3 °C/min, held isothermal for 10 minutes and finally raised to 250 °C at 10 °C/min. Diluted samples (1/100, v/v, in methylene chloride) of 1.0 µL were injected manually and in the splitless mode. The components were identified based on the comparison of their relative retention time and mass spectra with those of standards, Wiley7N, NIST library data of the GC-MS system and literature data (Adams 2007; Jennings 1980). The results were also confirmed by the comparison of the compounds elution order with their relative retention indices on non-polar phases reported in the literature (Adams 2007).

2.4. Antimicrobial Testing Procedures

2.4.1. Disk Diffusion Assay

Antimicrobial tests were carried out by the disk diffusion method (Çetin et al. 2009; Murray 1995) using 100 µL of suspension containing 10⁸ colony forming units (CFU)/mL of bacteria, 10⁶ CFU/mL of yeast, and 10⁴ spores/mL of fungi spread on nutrient agar (NA), sabouraud dextrose agar (SDA), and potato dextrose agar (PDA) medium, respectively. The disks (6 mm in diameter) impregnated with 10 µL of essential were placed on the inoculated agar. The inoculated plates were incubated at 37 °C for 24 h for mesophilic bacteria, 20 °C for 48 h for psychophysics, 30 °C for 48 h for the yeast and at room temperature for 72 h for fungi isolates (Harrigan 1998). Antimicrobial activity was evaluated by measuring the zone of inhibition against the test organisms. Each assay was repeated triple.

2.4.2. MIC Agar Dilution Assay

The agar dilution method, as described previously by (Gul et al. 2002), was used to determine the MIC values of the fungus isolate. The essential oil of *H. antasiaticum* was added aseptically to sterile molten PDA medium, containing Tween 20 (Sigma 0.5%, v/v), at the appropriate volume to produce the concentration range of 7.8-500 µg/mL. The resulting PDA solutions were immediately poured into petri plates after vortexing. The inoculated plates were incubated at room temperature for 72 h. At the end of the incubation period, the plates were evaluated for the presence or absence of growth. Each test was repeated at least triple.

3. Results and Discussion

This section may be divided by subheadings. It should provide a concise and precise description of the experimental results, their interpretation, as well as the experimental conclusions that can be drawn.

3.1. Chemical composition of *H. antasiaticum* essential oil

In the present study, the oil isolated from aerial parts of *H. antasiaticum* was analyzed, and GC/MS analysis of the oil allowed the identification of a total of 45 compounds, which represented 92.7 % of the oil (Table 1).

Table 1. Essential oil composition of *Heracleum antasiaticum*.

RT	RI ^{a)}	Components	%	Identification ^{b)}
13.56	994	Myrcene	0.2	GC, MS, RI
13.94	999	Yomogi alcohol	0.4	MS, RI
14.56	1014	<i>n</i> -Octanal	0.6	GC, MS, RI
15.41	1034	<i>p</i> -Cymene	0.6	GC, MS, RI
15.84	1045	(<i>Z</i>)- β -Ocimene	0.2	GC, MS, RI
16.39	1055	(<i>E</i>)- β -Ocimene	0.3	GC, MS, RI
17.00	1067	γ -Terpinene	1.3	GC, MS, RI
17.88	1082	<i>n</i> -Octanol	4.9	GC, MS, RI
19.20	1106	Linalool	0.1	GC, MS, RI
19.54	1113	<i>n</i> -Nonanal	0.2	GC, MS, RI
22.13	1158	3-Methyl-2-butenyl-3-methyl butanoate	0.1	MS, RI
22.77	1172	<i>n</i> -Nonanol	0.3	GC, MS, RI
23.22	1178	Terpinen-4-ol	0.1	GC, MS, RI
24.16	1191	Methyl chavicol	0.2	GC, MS, RI
24.52	1197	Octyl acetate	3.8	GC, MS, RI
25.39	1217	(<i>Z</i>)-Carveol	0.1	GC, MS, RI
26.76	1255	(<i>Z</i>)-Anethole	0.2	GC, MS, RI
28.35	1287	(<i>E</i>)-Anethole	0.7	GC, MS, RI
28.54	1289	Thymol	0.4	GC, MS, RI
28.91	1296	Carvacrol	0.1	GC, MS, RI
30.50	1340	α -Cubebene	0.5	MS, RI
31.82	1373	α -Copaene	1.1	GC, MS, RI
32.20	1383	β -Bourbonene	0.5	MS, RI
32.37	1386	α -Isocomene	1.2	MS, RI
33.54	1413	α -Cedrene	0.1	GC, MS, RI
33.76	1419	β -Caryophyllene	0.9	GC, MS, RI
34.25	1437	(<i>E</i>)- α -Bergamotene	1.1	MS, RI
35.08	1456	(<i>Z</i>)- β -Farnesene	0.3	MS, RI
35.33	1460	α -Humulene	0.3	GC, MS, RI
36.12	1478	γ -Muurolene	tr ^{c)}	MS, RI
36.40	1486	Germacrene D	2.5	MS, RI
36.93	1496	α -Zingiberene	3.9	MS, RI
37.44	1508	β -Bisabolene	1.8	MS, RI
37.91	1512	γ -Cadinene	1.9	MS, RI
38.19	1518	(<i>E</i>)- γ -Bisabolene	3.1	MS, RI
38.50	1523	γ -Cuprenene	0.7	MS, RI
38.99	1530	Selina-3,7(11)-diene	2.1	MS, RI
39.80	1548	Elemicine (1)	27.8	MS, RI
40.99	1574	Spathulenol	0.5	MS, RI
41.21	1579	Caryophyllene oxide	0.2	GC, MS, RI
44.81	1633	Gossonorol	0.3	MS, RI
46.30	1654	Cedr-8(15)-en-9- α -ol	0.3	MS, RI
48.11	1681	Apiole (2)	26.2	MS, RI
56.83	1957	(<i>E</i>)-Phytol	0.5	GC, MS, RI
58.85	2000	<i>n</i> -Eicosane	0.1	GC, MS, RI
Total			92.7	

^{a)} RI: Retention index relative to n-alkanes on a SGE-BPX5 column. ^{b)} MS: Tentative identification based on computer matching of the mass spectra of peaks with the Wiley7N and TRLIB libraries and published data (Shibamoto and Jennings 1980; Adams 2007); RI: comparison of retention indices based on published data (Adams 2007); GC: identification based on tR of authentic compounds on the SGE-BPX5 column. ^{c)} tr: Traces (less than 0.1%).

The main components of the oil were elemicin (27.8%), apiole (26.2%), *n*-octanol (4.9%), α -zingiberene (3.9), and octyl acetate (3.8%) (Table 1). Previous studies showed that octyl acetate was usually the most abundant component of *Heracleum* essential oils. However, the chemical composition of the essential oil has been noted to vary with the studied *Heracleum* species, with the main components consisting of octyl butyrate (İşcan et al.

2003; Li et al. 2013; Maggi et al. 2014), octyl butanoate (Miladinović et al. 2013), hexyl butanoate (Miladinović et al. 2013; Yousefirad and Karimzadeh 2008), hexyl butyrate (Baser et al. 2000; Karimi and Ito 2012; Radjabian et al. 2013; Tkachenko 2009; Yousefirad and Karimzadeh 2008), bornyle acetate (Jagannath et al. 2012), alpha pinene (Jagannath et al. 2012), beta pinene (Chu et al. 2012; Karuppusamy and Muthuraja 2010), 1.8 cineole (Karuppusamy and Muthuraja 2010) and e-anethole (Sefidkon et al. 2002). The essential oils from different parts of *Heracleum pastinacifolium* subsp. *incanum* were found to contain apiole, elemicine, and myristicine as major constituents, with notable variations among flower-fruit, root, and aerial part compositions (Yuca et al. 2024). Although few *Heracleum* species contained elemicine (Habibi et al. 2010; Najafabadi et al. 2011), none of the studies dealing with the essential oils of *Heracleum antasiaticum* did not report elemicine as main component. To our knowledge, this is the first study documenting elemicine as the main component in the genus *Heracleum antasiaticum*. On the other hand, apiole, another main component of our oil, was also documented in only one study within the *Heracleum* genus (Chu et al. 2012). Taken together, these findings concerning the composition of *H. antasiaticum* essential oil indicate that further research on the unexplored *Heracleum* species is needed to fully understand the extent of the essential oil variation within the genus *Heracleum*.

3.2. Antimicrobial activity

The antimicrobial activity of the essential oil of *H. antasiaticum* against the food-borne microorganisms was qualitatively and quantitatively determined by evaluating the presence of inhibition zones, zone diameter, and MIC values. In antimicrobial activity tests we used 20 bacteria, 1 filamentous fungi, and 2 yeast species (Tables 2 and 3). In general, the essential oil of *H. antasiaticum* had a broad antimicrobial spectrum and inhibited all tested microorganisms except for *S. Typhimurium*. As seen in Table 2 and 3, gram positive bacteria such as *B. cereus* and *S. aureus* that cause important issues in food industry had greater inhibition zone and MIC values than other bacteria. This supports the idea that cell wall structure is a critical determinant in the efficiency of antimicrobial substance.

Table 2. Antibacterial activities of essential oil of *Heracleum antasiaticum* against the bacterial strains tested.

Test Bacteria	Essential Oil		Antibiotic	
	DD ^a	MIC ^b	DD ^c	MIC ^d
Pathogenic and saprophytic				
<i>Acinetobacter lwoffii</i> BC 2819	12	62.5	18(OFX10)	7.8
<i>Alcaligenes faecalis</i> BC 0452	20	250	20(OFX10)	7.8
<i>Bacillus cereus</i> BC 6830	32	7.8	14(SAM20)	7.8
<i>Enterobacter cloacea</i> BC 3213	22	125	24(KF 30)	7.8
<i>Escherichia coli</i> BC 1402	13	500	22(OFX10)	15.62
<i>Escherichia coli</i> BC 2326	9	500	26(AZM15)	7.8
<i>Flavobacterium indologenes</i> BC 1520	10	500	27(AZM15)	7.8
<i>Listeria monocytogenes</i> BC 8353	16	250	22(SAM20)	7.8
<i>Proteus mirabilis</i> BC 2644	11	500	28(OFX10)	125
<i>Proteus vulgaris</i> KÜKEM 1329	18	250	18(AMC30)	7.8
<i>Pseudomonas fluorescens</i> BC 7324	14	125	31(OFX10)	125
<i>Pseudomonas pseudoalkaligenes</i> BC3445	18	500	32(OFX10)	125
<i>Pseudomonas putida</i> BC 1617	15	250	16(TE30)	125
<i>Salmonella Typhimurium</i> RSSK 95091	-	-	12(TE30)	7.8
<i>Staphylococcus aureus</i> ATCC 29213	26	250	34(TE30)	7.8
<i>Staphylococcus aureus</i> BC 7231	28	250	22(KF30)	7.8
<i>Staphylococcus hominis</i> BC 2288	11	500	24(KF30)	15.62
<i>Bifidobacterium bifidum</i> ATCC 29521	13	500	34.1 (CC2)	7.8
<i>Lactobacillus acidophilus</i> BC 3219	17	250	15.2(KF30)	7.8
<i>Lactobacillus plantarum</i> BC 7321	14	500	20.2(NV5)	7.8

Given that the essential oil of *H. antasiaticum* had an effect on food-borne pathogens such as *E. coli*, *B. cereus*, *L. monocytogenes* and *S. aureus*, and on the bacteria such as *Pseudomonas*, *Proteus*, *Flavobacterium*, *Acinetobacter* and *Alcaligenes* that play a role in food spoilage, our results shows that this oil can be considered as an alternative in preserving foods and in shelf-life extension in the food industry. It is of interest to note that *H.*

antasiaticum essential oil possesses an antagonistic effect on probiotic microorganisms such as *Bifidobacterium bifidum*, *Lactobacillus acidophilus*, and *Lactobacillus plantarum* (Table 2). Therefore, the consumption of commercial products containing *H. antasiaticum* essential oil is not relevant, as it may have an adverse impact on probiotic bacteria, depending on the oil concentration. In this context, care should be taken to minimize the use of essential oils and other components containing elemicine and apiole in relatively higher concentrations, as observed in the present study, to alleviate health issues in infants and elderly people. In fact, this situation was seen in our previous study conducted on Florence fennel. In that study, we found that fennel oil in rich apiole and (E)-anethole had a similar impact against probiotic bacteria (Cetin et al. 2010).

In antimicrobial tests, we used two yeast (i.e. *Candida albicans* and *Sacharomyces cerevisiae*) and one fungi (i.e. *Aspergillus flavus*) strain. Of these, *A. flavus*, a saprophytic soil fungus that infects and contaminates preharvest and postharvest seed crops with the carcinogenic secondary metabolite aflatoxin (Amaike and Keller 2011), was influenced by *H. antasiaticum* essential oil. As observed from Table 3, the anticandidal effect of this oil was found to be higher than that of Amphotericin B, used as a standard antifungal agent. A similar effect was also observed on *Sacharomyces cerevisiae* (Table 3).

Table 3. Antibacterial activities of essential oil of *Heracleum antasiaticum* against the bacterial strains tested.

Test Bacteria	Essential Oil		Antibiotic	
	DD ^a	MIC ^b	DD ^c	MIC ^d
Yeast				
<i>Candida albicans</i> ATCC 1223	17	31.25	15	8
<i>Sacharomyces cerevisiae</i> BC 6541	15	62.5	8	62.5
Fungi				
<i>Aspergillus flavus</i> BC 101	12	250	17	250

^a DD, inhibition zone in diameter (mm) around the disks (6 mm) impregnated with 10 µL of essential oil ^b Minimal inhibitory concentration as µg/mL. ^c DD, inhibition zone in diameter (mm) around the standard, Amphotericin B (20 µg/disk Amphotericin B) impregnated disks were used as positive reference standards antibiotic disks (Sigma). ^d Amphotericin B (µg/mL) was used as reference antibiotic in micro well dilution assay (Sigma).

So far, the antimicrobial activity of *H. antasiaticum* essential oil has not been described in the literature. However, one study related to the antimicrobial activity of ethanolic and aqueous extracts of *H. antasiaticum* was carried out, and it was observed that the extracts differed significantly in their activity against test microorganisms. In our present study, this antimicrobial effect of *H. antasiaticum* essential oil was probably due to the main components of this oil, elemicin and apiole (Firuza et al. 2010; Kazemi and Rostami 2015; Pavlović et al. 2012; Tavares et al. 2008; Ušjak et al. 2017)

4. Conclusions

The essential oil exhibited a broad-spectrum antimicrobial activity, effectively inhibiting a range of food-borne pathogens and spoilage organisms, including *E. coli*, *B. cereus*, *L. monocytogenes*, *Pseudomonas spp.*, and *Aspergillus flavus*. However, its antagonistic effect on beneficial probiotic strains such as *Lactobacillus* and *Bifidobacterium* suggests that caution is needed when considering its use in products intended for human consumption.

Overall, the essential oil of *H. antasiaticum* presents promising potential as a natural preservative in the food industry. Nonetheless, further studies focusing on its toxicological safety, mechanism of action, and formulation optimization are warranted to support its practical application.

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References

- Adams RP (2007). Identification of Essential Oil Components by Gas Chromatography/Mass Spectroscopy. Allured Publishing Co., Carol Stream, Illinois, USA. p.104.
- Akcin A, Seyis F, Akcin TA, Cayci YT, Coban AY (2013). Chemical composition and antimicrobial activity of the essential oil of endemic *Heracleum platytaenium* Boiss. from Turkey. *Journal of Essential Oil Bearing Plants* 16(2), 166–171.
- Amaike S, Keller NP (2011). *Aspergillus flavus*. *Annual Review of Phytopathology* 49, 107–133.
- Baser K, Kürkçüoğlu M, Adigüzel N, Aytac Z, Joulain D, Laurent R (2000). Composition of the essential oil of *Heracleum paphlagonicum* Czeaczott. *Journal of Essential Oil Research* 12(3), 385–386.
- Chu SS, Cao J, Liu QZ, Du SS, Deng ZW, Liu ZL (2012). Chemical composition and insecticidal activity of *Heracleum moellendorffii* Hance essential oil. *Chemija* 23(2), 108–112.
- Çetin B, Özer H, Çakir A, Mete E, Tosun M, Öztürk E, Polat T, Kandemir A (2009). Chemical composition of hydrodistilled essential oil of *Artemisia incana* (L.) Druce and antimicrobial activity against foodborne microorganisms. *Chemistry & Biodiversity* 6(12), 2302–2310.
- Çetin B, Özer H, Çakir A, Polat T, Dursun A, Mete E, Öztürk E, Ekinici M (2010). Antimicrobial activities of essential oil and hexane extract of Florence fennel [*Foeniculum vulgare* var. *azoricum* (Mill.) Thell.] against foodborne microorganisms. *Journal of Medicinal Food* 13(1), 196–204.
- Davis P, Tan K, Mill R (1988). *Flora of Turkey and the Aegean Islands*. Edinburgh University Press, Edinburgh, UK. Vol. 10.
- Davis PH (1972). *Heracleum* L. In: Davis PH (Ed), *Flora of Turkey and East Aegean Islands*, Vol. 4, Edinburgh University Press, Edinburgh, UK, pp. 488–500.
- Duman H (2000). *Flora of Turkey and East Aegean Islands*. Edinburgh University Press, Edinburgh, UK. Vol. 11, p.144.
- Ergene A, Tan S, Mirici S, Güler P, Yıldırım S (2007). Antimicrobial activity of *Heracleum antasiaticum*. In: *International Medicinal and Aromatic Plants Conference on Culinary Herbs*, 16–20 April 2007, Antalya, Turkey. *Acta Horticulturae* 826: 267–270.
- Firuzi O, Asadollahi M, Gholami M, Javidnia K (2010). Composition and biological activities of essential oils from four *Heracleum* species. *Food Chemistry* 122(1), 117–122.
- Gul HI, Ojanen T, Hänninen O (2002). Antifungal evaluation of bis Mannich bases derived from acetophenones and their corresponding piperidinols and stability studies. *Biological and Pharmaceutical Bulletin* 25(10), 1307–1310.
- Guleria S, Saini R, Jaitak V, Kaul V, Lal B, Rahi P, Gulati A, Singh B (2011). Composition and antimicrobial activity of the essential oil of *Heracleum thomsonii* (Clarke) from the cold desert of the western Himalayas. *Natural Product Research* 25(13), 1250–1260.
- Habibi Z, Eshaghi R, Mohammadi M, Yousefi M (2010). Chemical composition and antibacterial activity of essential oil of *Heracleum rechingeri* Manden from Iran. *Natural Product Research* 24(11), 1013–1017.
- Harrigan WF (1998). *Laboratory Methods in Food Microbiology*. Gulf Professional Publishing, San Diego, USA.
- İşcan G, Demirci F, Kürkçüoğlu M, Kıvanç M, Can Başer KH (2003). The bioactive essential oil of *Heracleum sphondylium* L. subsp. *ternatum* (Velen.) Brummitt. *Zeitschrift für Naturforschung C* 58(3–4), 195–200.
- Jagannath N, Ramakrishnaiah H, Krishna V, Gowda PJ (2012). Chemical composition and antimicrobial activity of essential oil of *Heracleum rigens*. *Natural Product Communications* 7(7), 943–946.

- Jennings W (1980). *Qualitative Analysis of Flavor and Fragrance Volatiles by Glass Capillary Gas Chromatography*. Elsevier, Amsterdam, Netherlands.
- John GH, Holt NR, Krieg PH (1994). *Bergey's Manual of Determinative Bacteriology* (9th Edition). Williams & Wilkins, Baltimore, USA.
- Karimi AG, Ito M (2012). Sedative effect of vapor inhalation of essential oil from *Heracleum afghanicum* Kitamura seeds. *Journal of Essential Oil Research* 24(6), 571–577.
- Karuppusamy S, Muthuraja G (2010). Radical scavenging activities of *Heracleum aquilegifolium* Wight (Apiaceae) fruit oils in vitro. *Zeitschrift für Naturforschung C* 65(11–12), 653–659.
- Kazemi M, Rostami H (2015). Chemical composition, antimicrobial and antioxidant activities of the essential oil of *Psammogeton canescens*. *Natural Product Research* 29(3), 277–280.
- Li W, Chen L, Wu C, Xin J (2013). Analysis of the essential oil from seed of *Heracleum moellendorffii* Hance cultivated in northeast China. *Asian Journal of Chemistry* 25(8), 4701–4704.
- Logacheva M, Valiejo-Roman C, Pimenov M (2008). ITS phylogeny of West Asian *Heracleum* species and related taxa of Umbelliferae–Tordylieae WDJ Koch, with notes on evolution of their psbA-trnH sequences. *Plant Systematics and Evolution* 270, 139–157.
- Maggi F, Quassinti L, Bramucci M, Lupidi G, Petrelli D, Vitali LA, Papa F, Vittori S (2014). Composition and biological activities of hogweed [*Heracleum sphondylium* L. subsp. *ternatum* (Velen.) Brummitt] essential oil and its main components octyl acetate and octyl butyrate. *Natural Product Research* 28(17), 1354–1363.
- Miladinović D, Ilić B, Mihajilov-Krstev TM, Nikolić D, Cvetković O, Marković M, Miladinović L (2013). Antibacterial activity of the essential oil of *Heracleum sibiricum*. *Natural Product Communications* 8(9), 1309–1311.
- Murray PR, Baron EJ, Pfaller MA, Tenover FC, Tenover RH (1995). *Manual of Clinical Microbiology*. American Society for Microbiology, Washington, DC, USA.
- Najafabadi RE, Mohammadi M, Yousefi M, Habibi Z (2011). Chemical composition and antibacterial activity of essential oils from flowers, seeds and stems of *Heracleum rechingeri* (Manden) from Iran. *Journal of Essential Oil Bearing Plants* 14(6), 746–750.
- Pavlović I, Petrović S, Radenković M, Milenković M, Couladis M, Branković S, Drobac MP, Niketić M (2012). Composition, antimicrobial, antiradical and spasmolytic activity of *Ferula heuffelii* Griseb. ex Heuffel (Apiaceae) essential oil. *Food Chemistry* 130(2), 310–315.
- Radjabian T, Salimi A, Rahmani N, Shokravi A, Mozaffarian V (2013). Essential oil composition of some wild populations of *Heracleum persicum* Desf. Ex Fischer growing in Iran. *Journal of Essential Oil Bearing Plants* 16(6), 841–849.
- Sefidkon F, Dabiri M, Mohammad N (2002). Analysis of the oil of *Heracleum persicum* L. (leaves and flowers). *Journal of Essential Oil Research* 14(4), 295–297.
- Tavares AC, Gonçalves MJ, Cavaleiro C, Cruz MT, Lopes MC, Canhoto J, Salgueiro LR (2008). Essential oil of *Daucus carota* subsp. *halophilus*: composition, antifungal activity and cytotoxicity. *Journal of Ethnopharmacology* 119(1), 129–134.
- Tkachenko K (2009). Essential oils from roots of certain *Heracleum* species. *Chemistry of Natural Compounds* 45(4), 578–580.
- Ušjak L, Petrović S, Drobac M, Soković M, Stanojković T, Ćirić A, Niketić M (2017). Essential oils of three cow parsnips—composition and activity against nosocomial and foodborne pathogens and food contaminants. *Food & Function* 8(1), 278–290.
- Yousefirad M, Karimzadeh R (2008). Chemical composition of the essential oil of *Heracleum persicum* seeds of Iran. *Asian Journal of Chemistry* 20(5), 3345–3348.

Yuca H, Sefalı A, Aydın B, Karadayı M, Gülşahin Y, Yazıcı A, Karakaya S, Demirci B, Çoban F, Özdemir E, Demir AY, Güvenalp Z (2024). Phytochemical analysis and biological evaluation of essential oils and extracts from *Heracleum pastinacifolium* subsp. *incanum* (Boiss. & A. Huet) PH Davis, an endemic plant from Turkey. *Natural Product Research* 4, 1–11.



Prediction of Lactation Milk Yield in Simmental Cattle Milked with Robotic Milking System Using CHAID and CART Algorithms

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HIGHLIGHTS

- Robotic milking systems improve efficiency and hygiene while reducing the need for human labor.
- Days in Milk (DIM) is the most important factor affecting lactation milk yield (LMY).
- Cows on higher feed allocations achieve notably increased milk yields.
- Advanced algorithms support tailored strategies for improved milk yield and animal welfare in robotic milking farms.

Abstract

Animal husbandry has long been a key component of agriculture, fulfilling essential nutritional needs. Technological advancements have gradually replaced human labor with machines, particularly in dairy farms, where the milking process is vital for economic sustainability. Robotic milking systems have emerged as significant innovations, allowing for efficient, hygienic, and automated milking while reducing dependence on labor. This study aims to predict lactation milk yield (LMY) in Simmental cows during their first lactation period using the Classification and Regression Tree (CART) and Chi-squared Automatic Interaction Detector (CHAID) algorithms, both of which are widely applied in data mining. To achieve this, the independent variables included Days in Milk (DIM), Status (S), Number of Inseminations (NI), Milk Flow Rate (MFR), Number of Robot Rejection (NRR), Rumination Time (RT), Time Spent in the Robot (TSR), Feed Amount in the Robot (FAR), Feed Consumption Rate in the Robot (FCRR), and Milking Frequency (MF). The analysis identified DIM as the most influential predictor of LMY, while FAR, RT, and MF also played significant roles in the prediction model. Findings from the CHAID algorithm demonstrated that feed allocation based on milk yield in robotic systems directly impacted lactation milk yield. Especially, newly calved cows (DIM <30 days) produced an average of 5 692 L of milk; however, those receiving more than 5.09 kg of feed in the robotic system (FAR >5.09) exhibited an estimated lactation yield of 8 426 L. During the 30–81 days of lactation, increased feed availability was positively correlated with milk yield. Additionally, the CART algorithm supported these findings, reinforcing days in milk (DIM) as a key determinant in estimating lactation milk yield. In terms of predictive performance, the CHAID algorithm achieved an R² value of 78.5% and demonstrated superior prediction accuracy in most criteria, except for MAPE and MAD. Overall, robotic milking

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systems enhance the individualized management of dairy cows by optimizing factors such as feed allocation and milking frequency. Further research in this area could provide valuable insights, even for farms without robotic milking systems, guiding dairy farmers on strategies to maximize lactation milk yield effectively.

Keywords: Robotic milking; milk yield; cattle, data mining; CART; CHAID

1. Introduction

Animal husbandry has been an important and indispensable part of agriculture for generations, providing for individuals' fundamental nutritional requirements. For this purpose, the care, feeding, etc. needs of animals raised on farms have been met by human power for many years. However, thanks to technological developments, machines have started to replace human labor over time (Isık et al. 2021; Demir and Öztürk 2010)

In dairy farms, a significant portion of income is derived from milk, making the milking process a critical component of farm management (Britt et al. 2018). For this reason, the milking procedure must be performed quickly, hygienically, and with minimal labor input (Bach and Cabrera 2017). Technological advancements have enabled the automation of milking process using robotic systems, thereby significantly reducing reliance on human labor. Although the initial installation costs of robotic systems are high, their long-term benefits, including labor cost reduction, improved hygienic conditions, and providing continuous operation, make them advantageous over time. A study conducted by Mathijs (2004) in Belgium, Denmark, Germany, and the Netherlands revealed that robotic milking operations saved approximately 20% in labor costs compared to traditional systems, with this difference being statistically significant.

Robotic milking systems began to be developed in the late 20th century, with significant contributions emerging from the Netherlands, Sweden, and the United States in the early 1990s (Bach and Cabrera 2017; Simões Filho et al. 2020). One of the first robotic milking systems was introduced in the Netherlands in 1992, capable of automatically identifying cows in the herd, performing the milking process autonomously, and monitoring both the quality and quantity of milk during the procedure. As a result, robotic milking systems gradually gained popularity and were widely adopted in modern dairy farming operations worldwide, with the growing demand for this technology evident in its rapid rate of adoption (Bach and Cabrera 2017; Ji et al. 2022).

Robots are automatic programmable devices that perform all operations of the milking cycle with maximum accuracy and minimal variation. They handle numerous functions, such as preparing the udder, connecting the milking machine, and disinfecting teat liners. Robotic milking allows for individualized milking frequency based on daily milk yield and lactation phase. Furthermore, robotic milking systems give priority to animal welfare by providing a consistent and efficient milking process, promoting long-term improvements in farm productivity, milk yield, and animal health, while also enhancing farmers' working conditions and facilitating better monitoring and management of the animals (Jacobs and Siegford 2012; Rodenburg 2017; Tse et al. 2018; Coşkun et al. 2023; Himu and Raihan 2024; Johansen et al. 2025).

The aim of this study is to predict lactation milk yield (LMY) in Simmental cows during the first lactation period in robotic milking farms using the variables Days in Milk (DIM), Status (S), Number of Inseminations (NI), Milk Flow Rate (MFR), Number of Robot Rejection (NRR), Rumination Time (RT), Time Spent in the Robot (TSR), Feed Amount in the Robot (FAR), Feed Consumption Rate in the Robot (FCRR), and Milking Frequency in a Day (MF) through the application of CART (Classification and Regression Trees) and CHAID (Chi-squared Automatic Interaction Detector) algorithms.

2. Materials and Methods

2.1 Animal Material

The material of this study consists of 106 Simmental cows in the first lactation period, obtained from a dairy farm in Denizli utilizing a robotic milking system. While the roughage sources for feeding the animals were hay, alfalfa, and meadow grass given ad libitum in the paddock, concentrated feed was given in the automatic

weighing feeders in the milking robot while the animals were milked. Lactation Milk Yield (LMY), Days in Milk (DIM), Status (S), Number of Inseminations (NI), Milk Flow Rate (MFR), Number of Robot Rejection (NRR), Rumination Time (RT), Time Spent in the Robot (TSR), Feed Amount in the Robot (FAR), Feed Consumption Rate in the Robot (FCRR), and Milking Frequency (MF) variables were obtained from these cows.

2.2. Method

Lactation milk yield of the cows was predicted using the independent variables DIM, S, NI, MFR, NRR, RT, SR, FAR, FCRR, and MF via CART and CHAID algorithms.

2.2.1. Chi-squared Automatic Interaction Detector (CHAID) Algorithm

The CHAID (Chi-squared Automatic Interaction Detection) algorithm is a data mining algorithm developed by Gordon V. Kass in 1980. The algorithm is designed to explore relationships between dependent and independent variables and to identify the groups that best explain the dependent variable. Unlike other decision tree algorithms such as CART, which uses splitting points based on certain criteria, CHAID determines split points based on the significance level of the chi-square test. This approach allows for the evaluation of whether the differences between the resulting classes are statistically significant, making the splits based on hypothesis testing. Additionally, the CHAID algorithm permits more than two splits, unlike many other algorithms. Moreover, CHAID combines and splits categories of independent variables to prevent overfitting, thus reducing the risk of overlearning the model (Kass, 1980; Maimon and Rokach, 2014; Altay et al., 2021).

2.2.2. Classification and Regression Trees (CART) Algorithm

The CART algorithm, developed by Breiman et al. in 1984, is an extension of the AID (Automatic Interaction Detection) decision tree algorithm introduced by Morgan and Sonquist (1963a, b). CART is a non-parametric statistical method used for solving classification and regression problems with both categorical and continuous data. This algorithm transforms the complex structures within a heterogeneous dataset into simple decision structures by dividing the dataset into homogeneous groups. CART examines both the interactions between independent variables and the relationships between dependent and independent variables, with branching occurring in a binary tree structure. (Altay and Albayrak Delialioğlu 2022; Altay 2022b). In the process of selecting the best independent variable using the CART algorithm, the Gini index is used as the branching criterion (Zhang et al. 2018). The Gini index defines the purity of a category after partitioning based on a specific feature. The split leading to the formation of the purest classes is considered the best split. A situation where all individuals belong to a single class is considered pure. The Gini index varies between 0 and 1; 0 indicates perfect classification purity, where all individuals belong to the same class, resulting in only one class. A value of 1 indicates that individuals are randomly distributed across different classes. A Gini index value of 0.5 means that individuals are equally distributed among the classes. When constructing a regression tree, features with the lowest Gini index value are preferred (Maimon and Rokach 2014). The Gini Index is computed by taking one minus the sum of the squared class probabilities, as illustrated in Equation (1) (Tangirala 2020).

$$\text{Gini Index (L)} = 1 - \sum_{i=1}^j p_i^2 \quad (1)$$

j : Number of class

L : A dataset with j different class labels

P_i : Relative frequency if class i in T'

2.2.3. Data Analysis

In the study, regression tree algorithms, CHAID and CART, were used to predict lactation milk yield in 106 Simmental dairy cows. The algorithms were performed with a parent node size of 6, a child node size of 3 and 5-fold cross-validation. The regression tree analyses were conducted with IBM SPSS Statistics 23 software package (IBM Corp. Released 2015). Model fit criteria were obtained with the "ehaGoF" package (Eyduran 2020; R Core Team 2020). The Pearson correlation coefficients between variables were calculated and correlogram plots were generated using the 'corrplot' package in R (Wei and Simko 2021).

2.2.4. The Performance Criteria Used to Evaluate the Goodness of Fit of Data Mining Algorithms

The goodness-of-fit criteria used to assess the predictive performance of the CART and CHAID algorithms are provided in Table 1 (Grzesiak and Zaborski 2012; Zaborski et al. 2019). In the evaluation of the prediction performance of tree-based data mining algorithms used in LMY prediction, the goodness-of-fit criteria, including the global relative error of approximation (RAE), standard deviation ratio (SDratio), root-mean-square error (RMSE), mean absolute percentage error (MAPE), and mean absolute deviation (MAD), should be very close to 0, while the (adjusted) coefficient of determination (AdjR² and R²) values should be close to 1 (Altay 2022a; Topal et al. 2010).

Table 1. Goodness-of-fit criteria considered in the study.

Equation	Equation (continued)
$RMSE = \sqrt{\frac{1}{n} \sum_{i=1}^n (y_i - \hat{y}_i)^2}$	$MRAE = \sqrt{\frac{1}{n} RAE}$
$RRMSE = \frac{RMSE}{\bar{y}} * 100$	$MAPE = \frac{1}{n} \sum_{i=1}^n \left \frac{y_i - \hat{y}_i}{y_i} \right * 100$
$SD_{ratio} = \frac{\sqrt{\frac{1}{n-1} \sum_{i=1}^n (\varepsilon_i - \bar{\varepsilon})^2}}{\sqrt{\frac{1}{n-1} \sum_{i=1}^n (y_i - \bar{y})^2}}$	$MAD = \frac{1}{n} \sum_{i=1}^n y_i - \hat{y}_i $
$CV(\%) = \frac{\sqrt{\frac{1}{n-1} \sum_{i=1}^n (y_i - \bar{y})^2}}{\bar{y}} * 100$	$R^2 = 1 - \frac{\sum_{i=1}^n (y_i - \hat{y}_i)^2}{\sum_{i=1}^n (y_i - \bar{y})^2}$
$r = \frac{cov(y_i, \hat{y}_i)}{S_{y_i} S_{\hat{y}_i}}$	$Adj - R^2 = 1 - \frac{(1 - R^2)(n - 1)}{(n - k - 1)}$
$PI = \frac{RRMSE}{1 + r}$	$AIC = n \ln \left[\frac{1}{n} \sum_{i=1}^n (y_i - \hat{y}_i)^2 \right] + 2k$
$ME = \frac{1}{n} \sum_{i=1}^n (y_i - \hat{y}_i)$	
$RAE = \sqrt{\frac{\sum_{i=1}^n (y_i - \hat{y}_i)^2}{\sum_{i=1}^n y_i^2}}$	$AIC_c = AIC + \frac{\text{if } n/k > 40}{2k(k+1)} \frac{1}{n-k-1}$

RMSE: root mean square error, RRMSE: relative root mean square error, SDR: standard deviation ratio, CV: coefficient of variation, r: Pearson's correlation coefficients, PI: performance index, ME: mean error, RAE: relative approximation error, MRAE: mean relative approximation error, MAPE: mean absolute percentage error, MAD: mean absolute deviation, R²: coefficient of determination, Adj-R²: adjusted coefficient of determination, AIC: Akaike's information criterion, CAIC: corrected Akaike's information criterion

3. Results and Discussion

Descriptive statistics for lactation milk yield, days in milk, milk flow rate, rumination time, time spent in the robot, feed amount in the robot, feed consumption rate in the robot, and milking frequency, obtained from 106 Simmental cows in their first lactation, are presented in Table 2.

Table 2. Descriptive statistics for the continuous variables considered in the study.

Variables	Mean± SEM	Min	Max	CV
LMY (L)	8 902.00 ±191.000	915.00	12 673.00	% 22.10
DIM (days)	168.30 ±11.100	1.00	362.00	% 67.77
MFR (kg/min)	2.82 ±0.082	1.02	5.82	% 29.80
RT (min)	525.68 ±8.840	144.00	688.00	% 17.31
TSR (sec)	361.85 ±8.950	192.00	705.00	% 25.47
FAR (kg)	3.41 ± 0.129	1.00	5.63	% 39.07
FCRR (%)	0.96 ± 0.007	0.63	1.00	% 7.05
MF (times/day)	2.98 ±0.049	1.00	4.10	% 16.77

LMY: Lactation Milk Yield, DIM: Days in Milk, MFR: Milk Flow Rate, RT: Rumination Time, TSR: Time Spent in the Robot, FAR: Feed Amount in the Robot, FCRR: Feed Consumption Rate in the Robot, MF: Milking Frequency

Upon examining Table 2, it can be observed that the average lactation milk yield for the cows is 8 902 liters, with most of the cows being in the mid-lactation period (DIM; 168 days). The average daily milking frequency is 3 times, and nearly all of the feed provided in the robot is consumed by the cows. The average rumination time for the cows is 526 minutes, while the time spent in the milking robot is approximately 362 seconds (around 6 minutes).

The frequency distribution table and percentages for the values of Status, Number of Inseminations, and Robot Rejection Number for 106 Simental cows are provided in Table 3.

Table 3. The frequency distribution table for the discrete/categorical variables considered in the study.

Variables	Levels	n	%
Status (S)	Estrus	9	8.5
	Inseminated	39	36.8
	Non-pregnant	20	18.9
	Pregnant	38	35.9
	1	62	58.5
Number of Inseminations (NI)	2	24	22.6
	3	11	10.4
	4	6	5.7
	5	1	0.9
	6	2	1.9
Number of Robot Rejection (NRR)	0	61	57.6
	1	32	30.2
	2	7	6.6
	3	5	4.7
	4	1	0.9

The Pearson correlation coefficients among the continuous variables measured from the cows in the study are presented in Figure 1 using a correlogram plot.

The correlogram in Figure 1 demonstrates a generally positive but weak relationship among the variables. The strongest correlations with lactation milk yield are observed for milking frequency (0.61*) and rumination time (0.58**) ($p < 0.01$). Johnston and DeVries (2018) indicated that cows with longer rumination times had higher milk yields. Additionally, negative correlations were observed between days in milk and both the feed amount in the robot and the feed consumption rate in the robot (-0.63^{**} $p < 0.01$, -0.21^{*} $p < 0.05$). Therefore, in the early stages of lactation, cows have higher feed requirements, leading to a greater amount of feed being allocated in the robot. However, while the feed consumption rate is relatively lower in the initial days of lactation, it increases as lactation progresses. Considering that feed demand is high during the first 2.5–3 months post-calving, but not all the allocated feed is consumed, implementing appropriate adjustments could help reduce overall feed costs and improve farm efficiency.

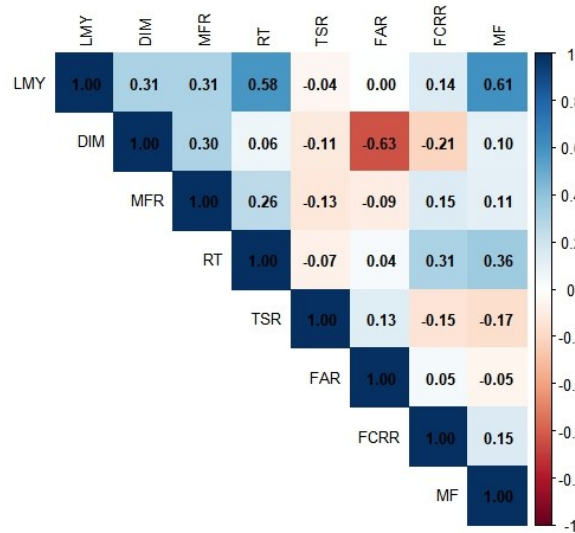


Figure 1. Correlogram graph of data for dairy cows [LMY: Lactation Milk Yield, DIM: Days in Milk (DIM), MFR: Milk Flow Rate, RT: Rumination Time, TSR: Time Spent in the Robot, FAR: Feed Amount in the Robot, FCRR: Feed Consumption Rate in the Robot, MF: Milking Frequency]

3.1. CHAID Algorithm

The tree diagram for the CHAID algorithm used to predict lactation milk yield is presented in Figure 2. In predicting lactation milk yield, the most critical variable is days in milk. In the herd, the average lactation milk yield (LMY) of newly calved cows ($n=10$, $DIM<30$) is 5 692 L. Given that feed allocation in robotic milking systems is based on milk yield, the 10 cows in Node-1 are divided into three groups according to the feed amount in the robot. Among these groups, those receiving more than 5.09 kg of feed exhibit the highest average LMY, reaching 8 426 L.

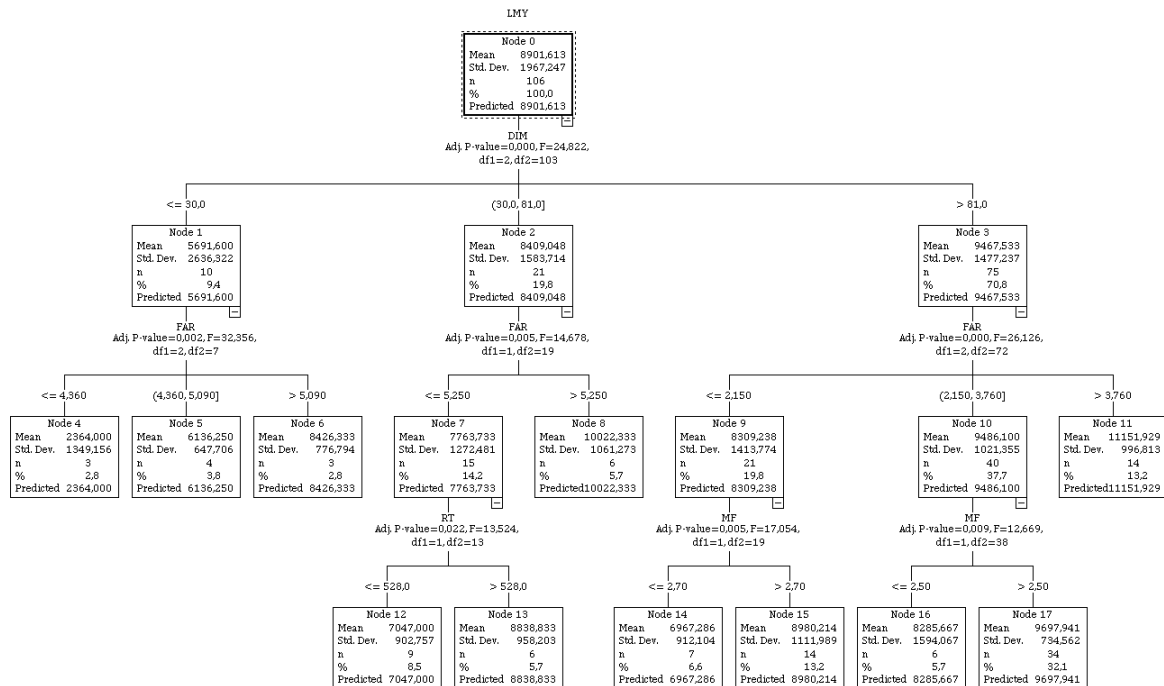


Figure 2. The results of CHAID algorithm (LMY: Lactation Milk Yield, DIM: Days in Milk, FAR: Feed Amount in the Robot, RT: Rumination Time, MF: Milking Frequency)

For cows in days 30 to 81 of lactation ($n=21$, $30 < \text{DIM} < 81$), when FAR is less than 5.25 kg, the average LMY is 7 764 L. Conversely, when FAR exceeds 5.25 kg, the average LMY reaches 10 022 L. The cows in the first group ($n=15$, $\text{FAR} < 5.25$ kg) are further divided into two subgroups based on rumination time. In this subgroup, cows with a rumination time exceeding 528 minutes have a significantly higher average LMY (8 839 L) compared to those with a rumination time of less than 528 minutes. Johnston and DeVries (2018) observed in their study that for every 1-hour increase in rumination time, there was an average increase of 1.26 kg day^{-1} in milk yield. Similarly, Dado and Allen (1994) observed that high-producing dairy cattle tended to have fewer, but longer, rumination time.

The group with the highest average lactation milk yield (Node-3) consists of cows that are at least 81 days post-calving. Within this group, cows are further divided into three sub-categories based on feed allocation in the robot. Among these sub-categories, the group with the highest average lactation milk yield (Node-11, $n=14$, mean $\text{LMY}=11\,152 \text{ L}$) is associated with a feed allocation (FAR) of 3.76 kg or more. Notably, milk yield in cows during their first lactation increases after the 81st day of lactation (i.e., after the service period), while the feed amounts allocated in the robot are relatively lower compared to those in the earlier stages of lactation.

For cows with a days in milk yield greater than 81, those in subgroups with feed amounts in the robot below 2.15 kg or between 2.15–3.76 kg had a higher average lactation milk yield when the milking frequency was approximately three times per day. It has been observed that when the milking frequency is three times daily, milk yield increases compared to systems with a twice-daily milking frequency (Erdman and Varner 1995; Amos et al. 1985; Gisi et al. 1986). Furthermore, Hart et al. (2013) emphasized that increasing the milking frequency from two to three times per day resulted in an approximate increase of 2.9 kg/day in daily milk yield.

When lactation milk yield was predicted using the CHAID algorithm with days in milk, reproductive status, number of inseminations, milk flow rate, number of robot rejections, rumination time, time spent in the robot, feed amount in the robot, feed consumption rate in the robot, and milking frequency as predictor variables, the coefficient of determination was found to be 78.5%, which was statistically significant ($p < 0.01$).

3.2. CART Algorithm

In the CART algorithm given in Figure 3, which allows for a binary tree structure, days in milk was identified as the most influential variable on lactation milk yield, similar to the CHAID algorithm. In this model, the average lactation milk yield was found to be 9 211 L at least 18 days post-calving. During the second period (the first 18 days post-calving), the cow's milk yield increased approximately 2.5 times compared to the first 7 days.

At least 18 days after calving, when the milking frequency of high-yielding cows was 2.85 or higher, the average lactation milk yield was found to be approximately 9 786 L. In the group with a milking frequency below 2.85, cows with a rumination time exceeding 603 minutes had a higher average milk yield (9 761 L). However, in cows milked more than 2.85 times per day, those with a rumination time longer than 527 minutes had an average lactation milk yield of 10 161 L.

Cows milked less than 2.85 times per day and with a rumination time below 603 minutes, but with a time spent in the robot exceeding 419 seconds, had a higher lactation milk yield (8 923 L). At least 18 days after calving, in cows with a daily milking frequency greater than 2.85, an increase in rumination time and time spent in the robot was associated with higher milk yield. The highest milk yield was observed in the group in Node-20, where the milk flow rate was above 2.95. Similarly, studies conducted in this context have shown that increasing milking frequency from twice to three times per day improves milk yield without exhibiting any adverse effects on reproductive performance indicators (Kruip et al., 2002).

When lactation milk yield was predicted using the CART algorithm with days in milk, status, number of inseminations, milk flow rate, number of robot rejection, rumination time, time spent in the robot, feed amount in the robot, feed consumption rate in the robot, and milking frequency as predictor variables, the determination coefficient was found to be 77.3% ($p < 0.01$).

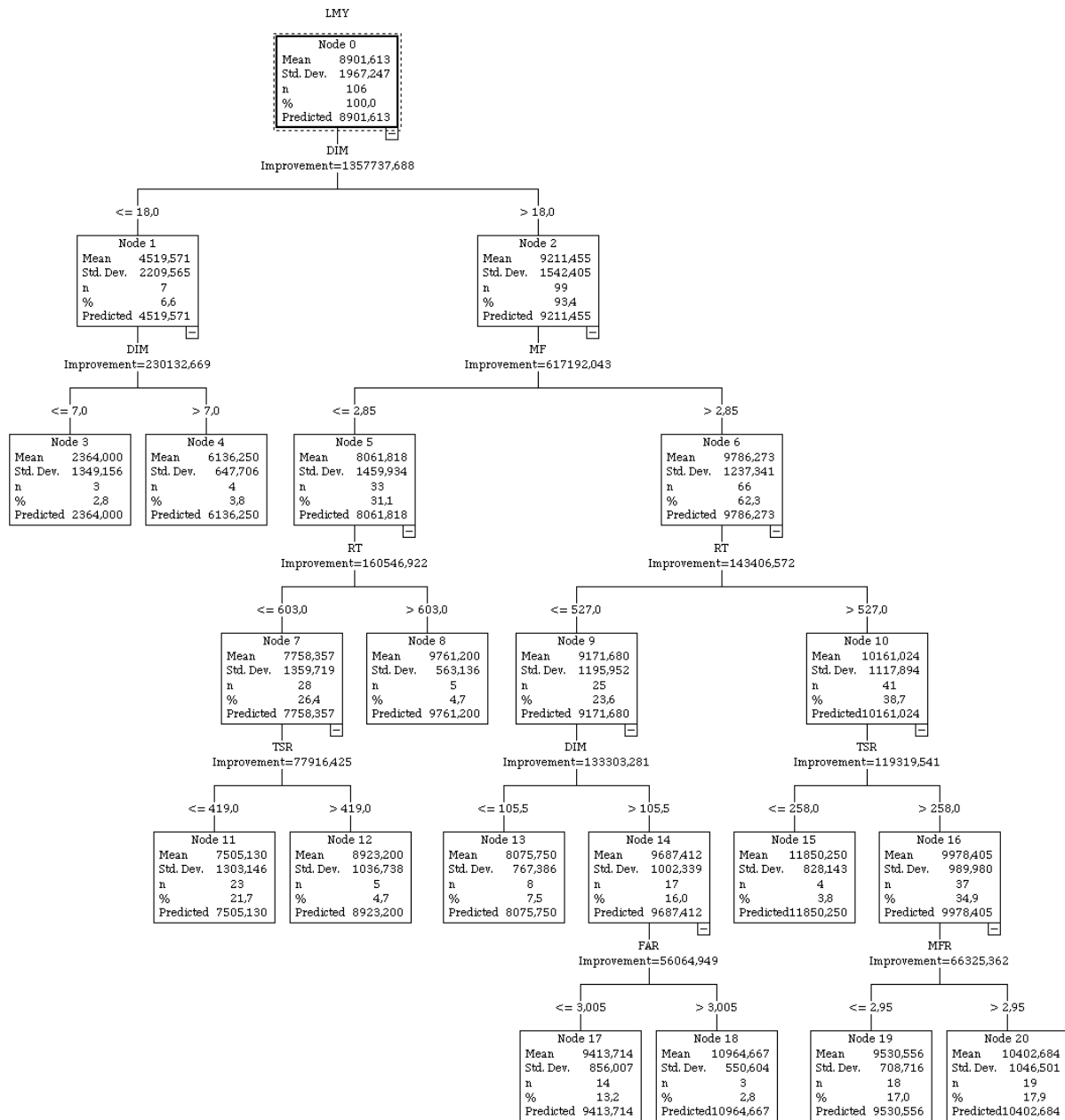


Figure 3. The results of CART algorithm (LMY: Lactation Milk Yield, DIM: Days in Milk, MF: Milking Frequency, RT: Rumination Time, TSR: Time Spent in the Robot, FAR: Feed Amount in the Robot, MFR: Milk Flow Rate)

3.3. Goodness-of-Fit Criteria for Data Mining Algorithms

When considering the goodness-of-fit criteria, it was observed that the prediction performances of both the CHAID and CART algorithms were relatively similar (Table 4). However, in all criteria except for MAPE and MAD, the CHAID algorithm demonstrated relatively better prediction performance compared to CART. In this context, the use of the CHAID algorithm instead of the CART algorithm for predicting lactation milk yield in robotic milking systems, based on automatically measured parameters, would allow for more reliable results.

Table 4. Predictive performance criteria for CHAID and CART algorithms.

Prediction Performance Criteria	CHAID	CART
RMSE	907.739	933.599
RRMSE	10.197	10.488
SDR	0.464	0.477
CV	10.250	10.540
r	0.886	0.879
PI	5.407	5.582
ME	0.028	0.132
RAE	0.010	0.010
MRAE	0.010	0.010
MAPE	10.143	9.652
MAD	742.877	698.736
R ²	0.785	0.773
Adj-R ²	0.781	0.769
AIC	1447.923	1453.878
AIC _c	1448.039	1453.994

4. Conclusions

The dairy industry is increasingly influenced by technological advancements and continues to evolve. The development of milking robots is expected to become more important in the future due to their potential to reduce labor and ensure reliable food supply. The rapid development of technological tools and algorithms will greatly contribute to the production and improvement of new products and systems.

This study focuses on predicting lactation milk yield in first-lactation Simmental cows milked by robotic milking systems, utilizing data mining algorithms such as CHAID and CART, based on routinely collected data within the system. The findings obtained from the algorithms will assist the researcher in determining the additional feed amount to be provided during milking in small enterprises where robotic milking systems are not available and are quite costly.

Furthermore, by evaluating the effects of parameters such as milk yield, feed consumption during milking, time spent in the robot, rumination time, and milk flow rate on lactation milk yield, this study will facilitate adjustments aimed at increasing farm profitability. It is recommended that further comprehensive studies be conducted on other characteristics that are thought to be related to lactation milk yield. The results of this study provide practical insights into dairy cattle farms.

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Conflicts of Interest: The authors declare no conflict of interest.

Ethical Statement: This study was conducted using data obtained from a voluntary dairy farm operating a robotic milking system. The data were collected automatically by the system as part of routine herd management practices, without any experimental intervention or harm to the animals. Therefore, ethical approval was not required for this research.

References

Altay Y (2022a). Prediction of the live weight at breeding age from morphological measurements taken at weaning in indigenous Honamli kids using data mining algorithms. *Tropical Animal Health and Production* 54(3), 172.

- Altay Y (2022b). Phenotypic characterization of hair and Honamli goats by using classification trees algorithms and multivariate adaptive regression splines (MARS). *Kafkas Üniversitesi Veteriner Fakültesi Dergisi* 28(3), 401-410. <https://doi.org/10.9775/kvfd.2022.27163>
- Altay Y and Albayrak Delialioğlu R (2022). Diagnosing Lameness with the Random Forest Classification Algorithm Using Thermal Cameras and Digital Colour Parameters. *Mediterranean Agricultural Sciences* 35, 47-54.
- Altay Y, Boztepe S, Eydurán E, Keskin I, Tariq MM, Bukhari FA, Ali I (2021). Description of factors affecting wool fineness in Karacabey Merino sheep using CHAID and MARS algorithms. *Pakistan Journal of Zoology* 53(2), 691. <https://doi.org/10.17582/journal.pjz/20190329150359>
- Amos HE, Kiser T, Loewenstein M. (1985). Influence of milking frequency on productive and reproductive efficiencies of dairy cows. *Journal of Dairy Science* 68(3), 732-739.
- Bach A, Cabrera V (2017). Robotic milking: Feeding strategies and economic returns. *Journal of Dairy Science* 100(9), 7720-7728. <https://doi.org/10.3168/jds.2016-11694>
- Breiman L, Friedman JH, Olshen RA, Stone CJ (1984). Classification and regression trees. Chapman and Hall, Wadsworth Inc., New York, NY, USA.
- Britt J, Cushman R, Dechow C, Dobson H, Humblot P, Hutjens M, Jones G, Ruegg P, Sheldon I, Stevenson J (2018). Invited review: Learning from the future—A vision for dairy farms and cows in 2067. *Journal of Dairy Science* 101(5), 3722-3741. <https://doi.org/10.3168/jds.2017-14025>
- Coşkun G, Şahin Ö, Aytekin İ (2023). Robotik Sağımda Sürü Yönetimi. *Turkish Journal of Agricultural Research* 10(3), 361-371. <https://doi.org/10.19159/tutad.1339586>
- Dado RG, Allen MS. (1995). Intake limitations, feeding behavior, and rumen function of cows challenged with rumen fill from dietary fiber or inert bulk. *Journal of Dairy Science* 78(1), 118-133.
- Demir B, Öztürk İ (2010). Robotlu sağım sistemleri. *Alinteri Journal of Agriculture Science* 19(2), 21-27.
- Erdman RA, Varner M (1995). Fixed yield responses to increased milking frequency. *Journal of Dairy Science* 78(5), 1199-1203.
- Eyduran, E. (2020). ehaGoF: Calculates Goodness of Fit Statistics. R package version 0.1.0. <https://CRAN.Rproject.org/package=ehaGoF>
- Gisi DD, DePeters EJ, Pelissier CL. (1986). Three times daily milking of cows in California dairy herds. *Journal of Dairy Science* 69(3), 863-868.
- Grzesiak W, Zaborski D (2012). Examples of the use of data mining methods in animal breeding. Data mining applications in engineering and medicine 303-324.
- Hart KD, McBride BW, Duffield TF, DeVries TJ. (2013). Effect of milking frequency on the behavior and productivity of lactating dairy cows. *Journal of Dairy Science* 96(11), 6973-6985.
- Himu HA, Raihan A (2024). An overview of precision livestock farming (PLF) technologies for digitalizing animal husbandry toward sustainability. *Global Sustainability Research* 3(3), 1-14.
- IBM Corp. Released (2015). IBM SPSS Statistics for Windows, Version 23.0. Armonk, NY: IBM Corp.
- Isık AH, Alakus F, Eskicioğlu ÖC (2021). Hayvancılıkta robotik sistemler ve yapay zeka uygulamaları. *Düzce Üniversitesi Bilim ve Teknoloji Dergisi* 9(6), 370-382.
- Jacobs JA, Siegford JM (2012). Invited review: The impact of automatic milking systems on dairy cow management, behavior, health, and welfare. *Journal of Dairy Science* 95(5), 2227-2247.

- Ji B, Banhazi T, Phillips CJ, Wang C, Li B (2022). A machine learning framework to predict the next month's daily milk yield, milk composition and milking frequency for cows in a robotic dairy farm. *Biosystems Engineering* 216, 186-197. <https://doi.org/10.1016/j.biosystemseng.2022.02.013>
- Johansen F, Buijs S, Arnott G (2025). Social rank and personality are associated with visit frequency in dairy cows learning to use an automatic milking system. *Animal* 19(3), 101446. <https://doi.org/10.1016/j.animal.2025.101446>
- Johnston C, DeVries TJ. (2018). Associations of feeding behavior and milk production in dairy cows. *Journal of Dairy Science* 101(4), 3367-3373.
- Kass GV (1980). An exploratory technique for investigating large quantities of categorical data. *Journal of the Royal Statistical Society: Series C (Applied Statistics)* 29(2), 119-127.
- Kruip TAM, Morice H, Robert M, Ouweltjes W. (2002). Robotic milking and its effect on fertility and cell counts. *Journal of Dairy Science* 85(10), 2576-2581.
- Maimon OZ, Rokach L (2014). Data mining with decision trees: theory and applications (Vol. 81). World Scientific.
- Mathijs E (2004). Socio-economic aspects of automatic milking. In Automatic milking, a better understanding. Wageningen Academic. (pp. 46-55).
- Morgan JN, Sonquist JA (1963a). Problems in the analysis of survey data, and a proposal. *Journal of the American Statistical Association* 58, 415-434.
- Morgan JN, Sonquist JA (1963b). Some Results from a Non-Symmetrical Branching Process that Looks for Interaction Effects. *Proceedings of the Social Statistics Section, American Statistical Association* 8, 40-53.
- R Core Team (2020). R: A language and environment for statistical computing. Vienna, Austria: R Foundation for Statistical Computing. Retrieved from <https://www.R-project.org/> (access date: 25.11.2024).
- Rodenburg J (2017). Robotic milking: Technology, farm design, and effects on work flow. *Journal of Dairy Science* 100(9), 7729-7738. <https://doi.org/jds.2016-11715>
- Simões Filho LM, Lopes MA, Brito SC, Rossi G, Conti L, Barbari M (2020). Robotic milking of dairy cows: a review. *Semina: Ciências Agrárias* 41(6), 2833-2850.
- Tangirala S (2020). Evaluating the impact of Gini index and information gain on classification using decision tree classifier algorithm. *International Journal of Advanced Computer Science and Applications* 11(2), 612-619.
- Topal M, Aksakal V, Bayram B, Yaganoglu AM (2010). An analysis of the factors affecting birth weight and actual milk yield in Swedish red cattle using regression tree analysis. *The Journal of Animal and Plant Sciences* 20(2), 63-69.
- Tse C, Barkema HW, DeVries TJ, Rushen J, Pajor EA (2018). Impact of automatic milking systems on dairy cattle producers' reports of milking labour management, milk production and milk quality. *Animal* 12(12), 2649-2656. <https://doi.org/10.1017/S1751731118000654>
- Wei T, Simko VR (2021). Package "corrplot": Visualization of a Correlation Matrix (Version 0.92). Package Corrplot for R Software.
- Zaborski D, Ali M, Eyduran E, Grzesiak W, Tariq MM, Abbas F, Waheed A, Tirink C. (2019). Prediction of selected reproductive traits of indigenous Harnai sheep under the farm management system via various data mining algorithms. *Pakistan Journal of Zoology* 51(2), 421.
- Zhang Y, Chi G, Zhang Z (2018). Decision tree for credit scoring and discovery of significant features: an empirical analysis based on Chinese microfinance for farmers. *Filomat* 32(5), 1513-1521.



Silybum marianum (L.) Gaertner: A Review of Its Traditional Uses, Phytochemistry and Pharmacology

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HIGHLIGHTS

- Giving information about the history, geographical distribution, and botanical characteristics of milk thistle.
- The use of milk thistle in both traditional and modern medicine.
- Chemical composition, biological activity, and pharmacological use of milk thistle.

Abstract

Silybum marianum (L.) Gaertn., commonly known as "milk thistle", Asteraceae family, is a plant that has adapted to diverse soil and environmental conditions across all continents. Originally grown in Southern Europe and Asia, it is now found worldwide. Milk thistle has been used for medicinal purposes for over 2000 years, primarily for treating liver disease such as cirrhosis and hepatitis, as well as protecting the liver from toxic substances. The therapeutic effects of milk thistle are attributed to the flavonoid complex silymarin, which is most abundant in the ripe seeds (achenes) of the plant. Pharmacological studies have shown that this plant has antioxidant, anti-inflammatory, antitumor, hepatoprotective, and liver regenerative effects. All parts of the plant are also used medicinally. In addition, Milk thistle has essential uses, including the food industry as a supplement, food use as fresh or fried vegetables, livestock feeding, the cosmetic industry, bioenergy production, biocidal activity, and phytoremediation.

Keywords: Milk thistle, *Silybum marianum* (L.) Gaertn.; silymarin; traditional medicine use; chemical composition; biological activity

1. Introduction

Milk thistle [*Silybum marianum* (L.) Gaertner] has a long history of medicinal use that dates back over 2000 years. The ancient Greek physician Dioscorides was one of the first to document the use of milk thistle for the treatment of snake bites, while Pliny the Elder noted its application for the removal of bile when mixed with honey. During the Middle Ages, it gained prominence as a remedy for liver conditions and as an antidote for liver toxins (Post-White et al. 2007).

Milk thistle is an annual or biennial herbaceous plant belonging to the Asteraceae family. In general, rosette leaves emerge in the first year, and in the second year, the stem grows to a height of 30-150 cm between the rosette leaves (Demirezer et al. 2007). The plant is distributed in the Mediterranean countries, North Africa,

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Asia Minor, and Southern Russia (WHO monographs 2002). It is also widespread in many parts of the European continent, North and South America, and is found in the wild in Australia. It is widespread in the western, northern, and southern regions of our country. Additionally, it can be found up to 700 meters on roads, field edges, and empty fields in Türkiye (Davis 1975; Zeybek and Haksel 2010).

The large spiny leaves of the plant display white spots that resemble milk, which is the basis for the English name "Milk Thistle" (Baytop 1999). Another reason why it is called Milk Thistle comes from the belief that the white liquid veins and white spots were formed when the milk of Mary, who breastfed Jesus Christ, dripped on the leaves of this plant (Baser 2008). The botanical name of this plant is *Silybum marianum* (L.) Gaertner and its synonym is "*Carduus marianus* L.". This plant is commonly referred to by several names, including "Marian thistle, wild artichoke, variegated thistle, St. Mary's thistle, crown of Jesus, holy thistle, Venus thistle, heal thistle, and wand of God's grace" (Tenney 1995; Baytop 1999). The names known in Turkish are "akkız, devediken, deve kengeri, kengel, kibbun, meryemana diken, sütlü kengel, şevkülmeryem, uslu kenger" etc. names (Baytop 1999; Demirezer et al. 2007).

Milk thistle, due to its significant chemical composition, serves as an important herbal raw material in both traditional and modern medicine applications, making it a subject of ongoing scientific research. This article aims to provide an overview of the significant information on the biology and chemistry of milk thistle, its historical and current uses, the industries where it is supplied as raw material, and its role in traditional and modern medicine.

2. Taxonomic Classification and Botanical Characteristics

Milk thistle belongs to the family Asteraceae (commonly known as the daisy family), within the subfamily Carduoideae and the tribe Cardueae, and is identified under the genus *Silybum* with the species name *Silybum marianum* (L.) Gaertn. (Sharma and Singh 2023). Milk thistle is one of the plants that does not require specific cultivation conditions; however, its growth is favored by a humid and warm climate as well as fertile soil (Sowińska and Szpunar 2022). The plant resembles a thistle in appearance (Fig. 1f) and is between 30 and 100 cm in height. The stem is longitudinally striate, long and slender, softly hairy, and sparsely. The leaves are hairless, pale green with white speckled spots along the veins, and distinctly toothed and spiny. White spots on rosette leaves (Fig. 1b, c) are due to calcium carbonate accumulation (Zeybek and Haksel 2010). Basal leaves are triangular, lobed, ovate, stalked, and measure 9-26 x 5-12 cm. The upper leaves are simple, ovate-lanceolate in shape. The involucre is 2.5-4 x 2-4 cm in size, with the outer phyllaries recurved and spiny, broadly expanded at the base, the inner ones erect, and the innermost ones lanceolate and not appendaged. The brownish achenes are black-striped and measure 7 x 3 mm. The achenes are topped with white-colored pappus hairs (approximately 15 mm in length) (Fig. 1a), which play a crucial role in the dispersal and wind-borne transportation of the fruit (Ceylan 1994; WHO monographs 2002; Demirezer 2011). The flower color of this plant is purple, light pink, and white (Çelik 2009) (Fig. 1d,e). Additionally, as a honey plant, it attracts insects, particularly bees and butterflies. Depending on the region or climate, flowering occurs between April and May or July and August (Davis 1975; Demirezer et al. 2007), and the achenes, source of valuable substances such as flavonolignans, ripen around September and October (Sowińska and Szpunar 2022).

3. Traditional and Pharmacological Uses

Silybum marianum (L.) Gaertn. is native to the Mediterranean region and has a long history of use in traditional medicine. The achenes, leaves, and roots have been utilized for the treatment of various health conditions since ancient times. The Roman naturalist Pliny the Elder was the first to note its medicinal properties, observing that when mixed with honey, the plant increased bile flow, thus linking it to the treatment of liver diseases. During the early Christian period, the plant was dedicated to the Virgin Mary and became known as the Marian thistle. Used for over two millennia, it was described in *Planta Medica* as the "blessed plant from past to future" (Ceylan 1994; Zeybek and Haksel 2010). By the Middle Ages, it was widely recognized that the achenes of the plant had positive therapeutic effects on the liver (Çelik 2009). According

to Baytop (1999), the fruits of *Silybum marianum* are traditionally ground into a powder and mixed with honey in Türkiye. This mixture is used as a remedy for liver disorders, gallbladder disorders, and digestive system issues.



Figure 1. The botanical parts of the milk thistle: (a) achenes and pappus on the seed; (b) the plant seedling; (c) white spots on the rosette leaf; (d, e) flowers of milk thistle; (f) herbaceous plant.

Culinary use of the plant is as follows: the young stems of the Mary's thistle can be peeled and eaten raw or cooked, and they are often used in salads or pickled. Additionally, the fresh leaves, stems, roots, and flower buds of milk thistle can be boiled, and the resulting juice or tea is consumed for its nutritional and medicinal benefits (Marceddu et al. 2022; Herbazest 2024). According to the recipe provided by Demirezer (2021), two teaspoons (5 g) of the plant are added to boiling water, steeped for 10-15 minutes, and then consumed. However, the active ingredient of the plant, silymarin, is not present in this tea as it is poorly water-soluble. Pharmacologically, the above-ground parts of the plant are used as a diuretic (Kroll et al. 2007), antioxidant (Abenavoli et al. 2010), antipyretic, rheumatic pain reducer, and sedative, while the seeds regenerate liver cells (Flora et al. 1998), increase milk secretion, and additionally exhibit effects such as antiviral, antitumor, and anti-inflammatory (Demirezer et al. 2007; Eren and Sar 2020; Sowińska and Szpunar 2022).

4. Chemical Composition of The Milk Thistle

The most notable component of *Silybum marianum* is silymarin (1.5-3%), which belongs to the flavonolignans. The chemical formula of silymarin is $C_{25}H_{22}O_{10}$. Silymarin consists of subcomponents such as silybin (silibinin A and B), isosilybin, silychristin, and silydianin. The mature seeds are the part used as a drug in pharmacology, while all parts of the plant are traditionally used; in short, silymarin is found in the seeds of the plant and not in other organs such as the leaves, stems, and flowers (Gruenwald et al. 2004; Kren and Walterova 2005; Tanker et al. 2007; Kocaman and Dabak 2015). In addition to these, the plant contains several other essential chemical constituents, including flavonoids, fixed oils, polyenes, sterols, organic acids, and small amounts of mucilage substances (Zeybek and Haksel 2010). The flavonoids present in *Silybum marianum* include apigenin, luteolin, kaempferol, quercetin, naringenin, and taxifolin. The steroids identified in the plant consist of beta-sitosterol and beta-sitosterol glucosides. Fumaric acid (3.3%) is one of the organic acids found in the plant. The seeds of *Silybum marianum* contain 20-30% fixed oil, which is particularly rich in unsaturated fatty acids such as linoleic acid and oleic acid. Furthermore, the seeds serve as a source of vitamin E, phytosterols, and proteins (Gruenwald et al. 2004; Çelik 2009; European Pharmacopoeia 2011).

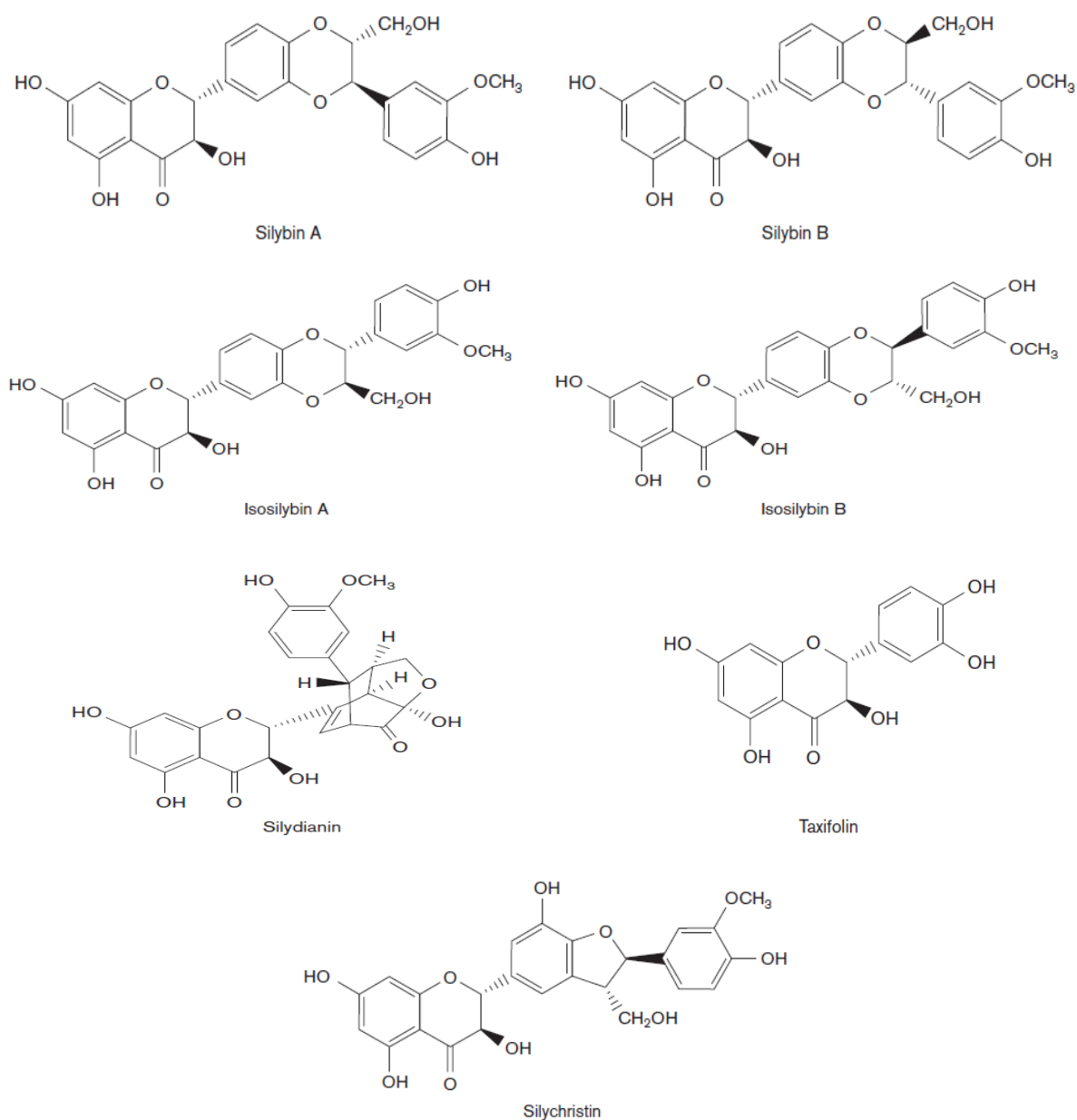


Figure 2. Chemical structure of some components of *Silybum marianum* (Mastron et al. 2015).

5. Uses of Milk Thistle in Cosmetics

Milk thistle, particularly its active compound silymarin, has gained attention in cosmetology due to its antioxidant, anti-inflammatory, and skin-protective properties (Kucharska et al. 2024). Studies have shown that silymarin can suppress oxidative stress and reduce damage caused by skin aging and UV radiation (Kim et al. 2023). For example, milk thistle oil is effective in improving the texture and resilience of chemically damaged hair, which also indicates its potential use in hair care products (Kim and Jeon 2023). Additionally, silymarin has been found to prevent UVB-induced skin cell damage (Emadi et al. 2022) and reduce melanin spots (Feher et al. 2011). These findings demonstrate that milk thistle can be utilized both protectively and reparatively in anti-aging creams, sunscreens, and hair care formulations. Consequently, the oil extracted from the achenes of *Silybum marianum* and its active component, silymarin, are recognized as valuable raw materials in the field of cosmetics.

6. Uses of Milk Thistle in Phytoremediation, Biomass and Biodiesel Production

S. marianum has significant potential for phytoremediation and biomass production due to its ability to grow and thrive in soils contaminated with heavy metals (Zheljazkov and Nikolov 1996). Its tolerance to heavy metals such as cadmium, chromium, lead, copper, manganese, and zinc (Domínguez et al. 2017) makes it a valuable plant for both environmental remediation and bioenergy production (Rady et al. 2018; Elateeq et al. 2020). Additionally, the oil extracted from *S. marianum* seeds is considered a suitable resource for bioenergy production, despite requiring a two-step process due to its high free fatty acid content. This process reduces the free fatty acid level in the oil, enabling its conversion into biodiesel (Ahmad et al. 2014).

7. Use in Animal Feeding

Milk thistle has the potential to enhance milk yield and meat quality in animals by reducing metabolic and oxidative stress due to its flavonolignan content (Krizova et al. 2011; Marceddu et al. 2022). However, its digestibility and energy value are lower compared to many commonly used feed plants (Özinan et al. 2017), and adverse characteristics such as nitrate toxicity are among the factors limiting its use in animal nutrition (Rady et al. 2018). Therefore, the potential benefits of *S. marianum* in animal feeding should be carefully evaluated, considering its method of application and dosage.

8. Conclusions

The studies have shown that all parts of *Silybum marianum* (L.) Gaertn. are also used medicinally. Additionally, milk thistle has essential applications, including use in the food industry (e.g., as a dietary supplement and fresh or fried vegetables), livestock feeding, the cosmetic industry, bioenergy production, and phytoremediation. The low soil and climate selectivity, combined with its biological and agronomic characteristics, make milk thistle a reliable alternative for low-input agriculture in sustainable farming systems. In addition, the thorny structure of the plant, the fact that the seeds do not ripen at the same time, and the differences in flowering/ripening stages are issues that need to be studied. In addition, despite its widespread use by the public, it is often confused with other thorny plants because consumers are not fully aware of the botanical differences. Therefore, more genetic, and agronomic research should be conducted on this plant, and reliable field studies are needed to determine appropriate planting, harvesting, and post-harvest treatments to different production targets to increase its production.

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References

- Abenavoli L, Capasso R, Milic N, Capasso F (2010). Milk thistle in liver diseases: past, present, future. *Phytotherapy Research* 24(10), 1423-1432.
- Ahmad M, Zafar M, Sultana S, Azam A, Khan MA (2014). The optimization of biodiesel production from a novel source of wild non-edible oil-yielding plant *Silybum marianum*. *International Journal of Green Energy* 11, 589-594.
- Baytop T (1999). Türkiye’de bitkiler ile tedavi (geçmişte ve bugün) ilaveli ikinci baskı, Nobel Tıp Kitabevleri, İstanbul.
- Başer KHC (2008). Devedikeni *Silybum marianum* (L.) Gaertner. *Bağbahçe* 16, 22-23.

- Ceylan A (1994). Tıbbi Bitkiler III. Ege Üniv. Ziraat Fak. Yay., No:500, İzmir. p. 136-144.
- Çelik SA (2009) A study on the determination of silymarin and fixed oil components in the seeds of milk thistle (*Silybum marianum* (L.) Gaertner) grown under Konya ecological conditions. Master Thesis, Selcuk University (Unpublished), Türkiye.
- Davis PH (1975). Flora of Turkey and the East Aegean Islands, Vol.5. Edinburgh: Edinburgh University Press.
- Demirezer LÖ, Ersöz T, Saracoğlu İ, Şener B (2007). Tedavide kullanılan bitkiler. Ankara: Medikal & Nobel Tıp Kitabevi, Ankara.
- Demirezer LÖ (2011). FFD monografıları tedavide kullanılan bitkiler. Medikal Network Nobel Kitabevi. 2. Baskı. Ankara.
- Demirezer LÖ (2021). Tıbbi çay reçeteleri. Hayy Kitap, 2. Baskı. İstanbul.
- Domínguez MT, Montiel-Rozas MM, Madejón P, Diaz MJ, Madejón E (2017). The potential of native species as bioenergy crops on trace-element contaminated Mediterranean lands. *Science of the Total Environment* 590, 29–39.
- Elateeq AA, Sun Y, Nxumalo W, Gabr AMM (2020). Biotechnological production of silymarin in *Silybum marianum* L.: a review. *Biocatalysis and Agricultural Biotechnology* 29, 1-16.
- Emadi S, Ghasemi F, Mohammadi M (2022). Protective effects of silymarin against UVB-induced oxidative damage in human skin cells. *International Journal of Cosmetic Science* 44(1), 56-64.
- Eren BH, Şar S (2020). Meryemana dikenli bitkisi: farmakolojik ve folklorik bir değerlendirme. *Lokman Hekim Dergisi* 10 (1), 23-27.
- European Pharmacopoeia (2011). 7th Edition, Council of Europe, Strasbourg, France.
- Fehér P, Vecsernyés M, Fenyvesi F, Váradi J, Kiss T, Újhelyi Z, Nagy K, Bácskay I (2011). Topical application of *Silybum marianum* extract. *Arad Medical Journal* 14, 5–8.
- Flora K, Hahn M, Rosen H, Benner K (1998). Milk thistle (*Silybum marianum*) for the therapy of liver disease. *American Journal of Gastroenterology* 93(2), 139-143.
- Gruenwald J, Brendler T, Jaenicke C (2004). PDR for herbal medicines. 3rd Ed. Montvale, NJ: Thomson Healthcare, p.566-569.
- Herbazest (2024). "Milk thistle". <https://www.herbazest.com/herbs/milk-thistle> (access date: 02.10.2024).
- Kim J, Lee YN, Lee J, Lee SG, Kim H, Choi YS, Draelos ZD, Kim J (2023). Efficacy and safety of silymarin containing antioxidant serum as an adjuvant treatment of mild-to-moderate acne vulgaris: a prospective, open-label pilot study. *Journal of Cosmetic Dermatology* 22, 561–568.
- Kim J, Jeon H (2023). The effects of silymarin on oxidative stress and UV-induced skin damage. *Journal of Dermatological Science* 45(2), 123-130.
- Kocaman N, Dabak DÖ (2015). Hepatoprotektif bir ajan: Silymarin. *Fırat Tıp Dergisi* 20(3), 128-132.
- Kren V, Walterova D (2005). Silybin and silymarin-new effects and applications. *Biomed Papers* 149(1), 29-41.
- Krizova L, Watzkova J, Trinacty J, Richter M, Buchta M (2011). Rumen degradability and whole tract digestibility of flavonolignans from milk thistle (*Silybum marianum*) fruit expeller in dairy cows. *Czech Journal of Animal Science* 56, 269–278.
- Kroll DJ, Shaw HS, Oberlies NH (2007). Milk thistle nomenclature: why it matters in cancer research and pharmacokinetic studies. *Integrative Cancer Therapies* 6(2), 110-119.
- Kucharska E, Sarpong R, Bobkowska A, Ryglewicz J, Nowak A, Kucharski L, Muzykiewicz-Szymanska A, Duchnik W, Pelech R (2024). Use of *Silybum marianum* extract and bio-ferment for biodegradable cosmetic formulations to enhance antioxidant potential and effect of the type of vehicle on the percutaneous

- absorption and skin retention of silybin and taxifolin. *Applied Sciences* 14, 169. <https://doi.org/10.3390/app14010169>
- Marceddu R, Dinolfo L, Carrubba A, Sarno M, Di Miceli G (2022). Milk thistle (*Silybum marianum* L.) as a novel multipurpose crop for agriculture in marginal environments: A review. *Agronomy* 12(3), 729.
- Mastron JK, Siveen KS, Sethi G, Bishayee A (2015). Silymarin and hepatocellular carcinoma. *Anti-Cancer Drugs* 26(5), 475-486.
- Özinan L, Alatürk F, Gökkuş A (2017). Meryemana diken [*Silybum marianum* (L.) Gaertner]’nin silaj olarak kullanım olanakları. *Turkish Journal of Agricultural and Natural Sciences* 4(1), 88-94.
- Post-White J, Ladas EJ, Kelly KM (2007). Advances in the use of milk thistle (*Silybum marianum*). *Integrative Cancer Therapies* (6)2, 104-109.
- Rady MM, Semida WM, Hemida KA, Rady MOA (2018). *Silybum marianum* as a phytoremediator of heavy metals in contaminated soils. *Environmental Science and Pollution Research* 25(3), 1-10.
- Sharma R, Singh R (2023). *Silybum marianum* (Asteraceae): an addition to the weed flora of Delhi, India. *Journal of Economic and Taxonomic Botany* 47(1), 38-41.
- Sowińska M, Szpunar M (2022). *Silybum marianum* – properties and application in medicine – a review. *European Journal of Clinical and Experimental Medicine* 20(3), 266-271. <https://doi.org/10.15584/ejcem.2022.3.3>
- Tanker N, Koyuncu M, Coşkun M (2007). Farmasötik botanik. Ankara Üniversitesi Eczacılık Fakültesi Yayınları No: 93 p.65-72.
- Terney LMH (1995). Milk thistle; a remarkable flavonoid antioxidant and liver protectant. Woodland Publishing INC. USA.
- WHO monographs (2002). World Health Organization monographs on selected medicinal plants. Vol. 2, Geneva. p: 300-311.
- Zeybek U, Haksel M. (2010). Türkiye’de ve dünyada önemli tıbbi bitkiler ve kullanımları. Zade Sağlık Yayınları, Konya 265-270.
- Zheljazkov V, Nikolov S (1996). Accumulation of Cd, Pb, Cu, Mn and Zn by *Silybum marianum* L. grown on polluted soils. *ActaHortic* 426, 297-426. <https://doi.org/10.17660/ActaHortic.1996.426.35>