ATATURK UNIVERSITY PUBLICATIONS

Research in Agricultural Sciences

Formerly: Atatürk University Journal of Agricultural Faculty

Official journal of Atatürk University Agricultural Faculty

Volume 56 • Issue 3 • September 2025

EISSN 2979-9686
dergipark.org.tr/agricultureatauni

Research in Agricultural Sciences

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Research in Agricultural Sciences

AIMS AND SCOPE

Research in Agricultural Sciences is a scientific, open access, online-only periodical published in accordance with independent, unbiased, and double-blinded peer-review principles. The journal is official publication of the Atatürk University Faculty of Agriculture and published tri-annually on January, May and September. The publication languages of the journal is Turkish.

Research in Agricultural Sciences aims to contribute to the science by publishing high quality publications in all fields of agricultural sciences. The journal publishes original articles, compilations, technical notes and letters to the editor.

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Research in Agricultural Sciences is currently indexed in Web of Science-Zoological Record, Scopus, DOAJ, CABI, EBSCO, ProQuest, MIAR, CNKI, CAB Abstract, Gale Cengage, and TÜBİTAK ULAKBİM TR Dizin.

All expenses of the journal are covered by the Atatürk University. Processing and publication are free of charge with the journal. No fees are requested from the authors at any point throughout the evaluation and publication process. All manuscripts must be submitted via the online submission system, which is available at https://dergipark.org.tr/en/pub/agricultureatuni. The journal guidelines, technical information, and the required forms are available on the journal's web page.

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Adaptation of Some Corn Genotypes from Different Variety Groups to Erzurum Plain Conditions

Farklı Çeşit Gruplarına ait Bazı Mısır Genotiplerinin Erzurum Ovası Koşullarına Adaptasyonu

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ABSTRACT

Selection of variety with high potential yield and adaptability is one of the most effective ways to increase corn production. This research was carried out according to the randomized complete blocks experimental design with 10 corn genotypes (five sweet corn, four flint corn, and one dent corn) in 2022 and 2023 years under Erzurum conditions. The differences among the genotypes were significant in terms of all the characteristics investigated, except plant number per hectare. As average of years, the days to silking of the genotypes was between 63.3-78.0 days, days to maturity for fresh ear harvest 98.2-110.0 days, plant number per hectare 86969-89585, ear number per plant 1.10-1.83, chlorophyll value (SPAD unit) 45.2-55.6, maximum quantum yield at PSII (Fv/Fm) 0.716-0.784, green mass yield 75337-108544 kg/ha, kernel number per ear 231.9-692.0, fresh ear yield 15312-25465 kg/ha, grain protein content 10.4-16.2 %. The highest green mass yield was obtained from Simpatico-KWS, the highest fresh ear yield from Khan F_1, the highest kernel protein content from Challenger F_1 and Karaçam genotypes. Only silage or corn for fresh consumption can be produced in Erzurum Plain conditions due to the short vegetation period and low average temperatures. Crow damage during the germination-emergence period and the first frost in autumn may a risk for corn production.

Keywords: Dent corn, Protein, Flint corn, Sweet corn, Yield

ÖZ

Potansiyel verimi ve adaptasyon kabiliyeti yüksek çeşit seçimi mısır üretimini artırmanın en etkili yollarından biridir. Erzurum koşullarında 2022 ve 2023 yıllarında şansa bağlı tam bloklar deneme planına göre yürütülen bu araştırmada 10 mısır genotipi (beş tatlı mısır, dört sert mısır, bir atdişi mısır) kullanılmıştır. Dekara bitki sayısı dışında, incelenen karakterler bakımından genotipler arasında önemli farklar belirlenmiştir. Yılların ortalaması olarak genotiplerin koçan püskülü çıkış süreleri 63,3-78,0 gün, taze koçan hasadı için olum süreleri 98,2-110,0 gün, dekara bitki sayıları 8696,9-8958,5, bitkide koçan sayıları 1,10-1,83, SPAD klorofil değerleri 45,2-55,6, PSII maksimum enerji verimleri (Fv/Fm) 0,716-0,784, hasıl verimleri 7533,7-10854,4 kg/da, koçandaki tane sayıları 231,9-692,0, taze koçan verimleri 1531,2-2546,5 kg/da, tane protein oranları ise %10,4-16,2 arasında değişmiştir. En yüksek hasıl verimi Simpatico-KWS, en yüksek taze koçan verimi Khan F_1, en yüksek tane protein oranı ise Challenger F1 ve Karaçam genotiplerinden elde edilmiştir. Erzurum Ovası koşullarında vejetasyon süresinin kısa ve ortalama sıcaklıkların düşük olması nedeniyle sadece silajlık veya taze tüketim amaçlı mısır üretilebilir. Çimlenme-çıkış dönemindeki karga zararı ve sonbahardaki ilk donlar mısır üretimi için risk oluşturabilir.

Anahtar Kelimeler: Atdişi mısır, Protein, Sert mısır, Tatlı mısır, Verim

Received Date:	11.04.2025
Revision Request Date:	17.05.2025
Last Revision Date:	22.05.2025
Accepted Date:	04.06.2025
Publication Date:	26.09.2025

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Cite this article: Öztürk, A., Stansluos, A.A.L., Kartay, H., & Hacımüftüoğlu, F. (2025). Adaptation of Some Corn Genotypes from Different Variety Groups to Erzurum Plain Conditions. *Research in Agricultural Sciences, 56*(3), 186-199.

Introduction

Corn is a multi-purpose crop that is widely used in animal nutrition, human nutrition and industry. Worldwide, it ranks second after wheat with a cultivation area of 208 234 140 ha among cultivated plants, its production is 1 241 557 811 tons, and its kernel yield is 5960 kg/ha. Corn, which ranks third after wheat and barley with a cultivation area of 958 017 ha in Türkiye, has a production of 9 000 000 tons and a grain yield of 9390 kg/ha (Anonymous, 2023a). The cultivation area of corn in Erzurum province is 150 ha and its yield is 1970 kg/ha (Anonymous, 2024). In the world, 61% of the corn produced is used as animal feed, 19% as industrial raw material, 15% as direct human food, 4% as losses, and 1% as seed (Garcia-Lara & Sena-Saldivar, 2019). When the latest data are compared with the data of the year 2000, the amount of corn production has increased by 210% in the world and 391% in Türkiye (Anonymous, 2023a). Despite that, since the increasing need could not be met, Türkiye imported 3 561 000 tons of corn and products against 1 270 000 tons of exports in the 2021/22 marketing year, and our sufficiency rate is 76.6% (Anonymous, 2023b).

The corn species includes seven different groups of varieties: dent corn, flint corn, sweet corn, popcorn, flour corn, waxy corn and pod corn, which are separated from each other according to their endosperm structure. Dent corn, which is widely used in animal nutrition and industry, meets most of the world's corn production. Flint corn, which is the most used in bread making, ranks second in the production share. Popcorn, which is known for its thick grain pericarp and hard endosperm structure and is generally used as a snack, ranks third in Türkiye in terms of cultivation area. Sweet corn, which ranks fourth in terms of cultivation area, is used in human nutrition as fresh, canned or frozen with higher kernel sugar, protein and vitamin content than other groups (İdikut et al., 2016; Öztürk et al., 2019; Sönmez et al., 2013). In corn, where genetic diversity is very rich, many research has been carried out to determine the rapidly increasing number of varieties with high adaptation and yield in certain ecologies. The first research on the adaptation of corn varieties to Erzurum conditions was carried out by Tosun (1967), the green mass yield was lower in the early varieties and the average of the varieties was determined as 36100 kg/ha, and M-202 variety was recommended for the region. Tosun (1970) determined the plant height as 84.2-173.2 cm, cob length as 9.8-19.4 cm, cob weight as 32.0-115.3 g, number of cobs per hectare between 17500-66620 and the dry straw yield between 3175-6450 kg/ha in 18 sweet corn varieties under Erzurum conditions and he found that Golden Midget and North Starr varieties with early and high cob number promising. Ergin (1974) investigated the effect of plant density (50000, 60000, 75000, 100000 plants/ha), nitrogen (0, 90, 180, 270 kg/ha) and phosphorus (0, 70, 140 kg/ha) doses on M-202 corn variety under Erzurum conditions, and the highest grain and green mass yields obtained from 100000 plants/ha, 270 kg N/ha and 70 kg P/ha treatments. Öztürk and Akkaya (1996) conducted a study with 25 corn varieties and suggested early and relatively high-yielding Inra 260 and Inra 380 varieties as silage for Erzurum Plain conditions. Bulut et al. (2008) examined the adaptation of 17 corn varieties to Erzurum conditions, the green mass yields of the varieties ranged between 61035-65500 kg/ha, dry matter yields ranged between 13763-17744 kg/ha, crude protein yield ranged between 905-996 kg/ha, and DK-440 and DK-585 varieties were recommended as silage. Öztürk et al. (2008) investigated the effect of plant density (83000, 91000, 100000, 125000, 143000 plants/ha) on silage production in DK-440 and DKC-4604 corn varieties and determined the ideal density as 125000 plants/ha in Erzurum.

In recent years, the cultivation area and economic value of sweet corn have been increasing. Sweet corn varieties have high yield potential and can also be grown in environments with limited vegetation periods, such as Erzurum, due to their short maturity period. The remaining parts after the cob harvest are also a valuable crop and silage material (Arslan & Williams, 2015). In the research carried out with 11 sweet corn varieties in Erzurum conditions, marketable ear yield according to varieties was 3205-16858 kg/ha, fresh kernel yield was 2412-11855 kg/ha, kernel protein ratio was 11.3-16.5%, and green mass yield was 35458-49406 kg/ha, and Signet F_1 and Challenger F_1 varieties were recommended for the region (Stansluos et al., 2020a). Local corn populations are valuable as a potential gene source in breeding programs for possible new needs in the feed and food industry, especially changes in environmental factors (Drinic et al., 2012). For this reason, emphasis is placed on collecting, identifying, and protecting local populations. In a study conducted on 196 local genotypes belonging to the Black Sea Region, 84 of the genotypes were found to belong to the flint corn, 64 dent corn, and 48 popcorn groups, plant grain yield was determined between 16.99-197.73 g, grain oil content was 2.22-6.41%, grain protein content was 8.88-16.42%, and local genotypes were defined as a rich gene source (Öner, 2011). In the research carried out with 18 local corn populations and two registered varieties of Trabzon province, the grain yield was determined between 3193-11671 kg/ha, and grain protein content varied between 9.89-14.50%, and the highest protein contents were determined in Köprübaşı, Çaykara and Tonya landraces (Öztürk & Büyükgöz, 2021).

In order to meet the increasing demand for corn in different variety groups, such as dry grain, fresh kernel or silage purposes, it is necessary to develop varieties with high adaptability, yield and nutritional value as well as to expand their production. The conditions of Erzurum Plain, where the altitude is high, the vegetation period is short and the average temperature is low, make corn production for grain purposes risky, and allow corn cultivation for silage or fresh consumption by using early varieties. In this study, the adaptation of a total of 10 corn genotypes, including five sweet corn varieties, one dent corn, and four flint corn landraces to the conditions of Erzurum Plain was examined.

Methods

Materials

This research was carried out in 2022 and 2023 years at Erzurum, Atatürk University Plant Production Application and Research Center trial area. The 10 corn genotypes, some traits of which are presented in Table 1, were used as plant material, ammonium sulfate, triple superphosphate and potassium sulfate were used as fertilizer sources, groundwater and drip irrigation system were used.

During the growing period, less rainfall fell in 2022 and more in 2023 compared to the long-term average (Table 2). During the trial years, June received more rainfall than in long-term average, and August and September received less rainfall. In both years, the average temperatures in May, June and July were lower than in long-term average, and the average temperature in August was higher. Physical and chemical analyses of samples taken from 0-30 cm depth of the experimental area soil were carried out according to the methods described by Dane and Topp (2018) and Sparks et al. (2020). It was determined that the soils had clay-loam textured in

Table 1
Some traits of the corn genotypes used in the research

Genotypes	Company / Origin	Traits
Argos F_1	Semillas Fito Tarım	Sweet corn, super-sweet, maturity period 80-90 days, kernel color is yellowish golden
Baron F_1	May Tohum	Sweet corn, super-sweet, very early, plant height 190-195 cm, kernel color is dark yellow
Challenger F_1	BAYER-Seminis	Sweet corn, super-sweet, maturity period 80-85 days, plant height 170-180 cm, kernel color is yellow
Khan F_1	May Tohum	Sweet corn, super-sweet, early, plant height 190-200 cm, kernel color is dark yellow
Signet F_1	Monsanto Gıda ve Tarım	Sweet corn, sugary enhanced, maturity period 60–65 days, plant height 150–160 cm, kernel color is yellow
Simpatico-KWS	KWS Türk Tarım Ticaret	Dent corn, FAO 400 grub, for silage, early and with high silage yield, ear rate and quality
Taşören landrace	Çaykara-Taşören village	Flint corn, kernel color is yellow, cultivation altitude is 815 m
Karaçam landrace	Çaykara-Karaçam village	Flint corn, kernel color is yellow, cultivation altitude is 1350 m
Ormanüstü landrace	Maçka-Ormanüstü village	Flint corn, kernel color is yellow, cultivation altitude is 1000 m
Sayraç landrace	Tonya-Sayraç village	Flint corn, kernel color is yellow, cultivation altitude is 950 m

Table 2
Some climate data of the research area during 2022 and 2023 with the long-term mean (LTM: 1990-2021)[1]

Months	Total rainfall (mm)			Average temperature (°C)			Average relative humidity (%)			Maximum temperature (°C)		Minimum temperature (°C)	
	2022	2023	LTM	2022	2023	LTM	2022	2023	LTM	2022	2023	2022	2023
May	89.3	97.0	90.4	9.1	10.4	11.6	67.3	64.3	59.8	24.1	22.5	-3.8	-4.1
June	80.4	63.0	39.8	15.9	14.8	16.2	62.8	66.5	53.7	29.2	25.9	2.5	2.0
July	5.2	55.6	24.2	19.4	18.2	20.3	48.1	57.0	46.5	34.2	31.8	3.1	4.0
August	0.0	4.4	26.3	21.9	21.3	20.8	36.2	42.1	44.7	33.7	36.2	1.6	6.4
September	8.8	3.3	26.4	15.5	16.4	15.9	42.6	46.3	47.9	32.3	31.0	-3.5	1.9
Total	183.7	223.3	207.1										
Mean				16.4	16.2	17.0	51.4	55.2	50.5				

[1]Taken from the annual climate observations of Erzurum Meteorology Regional Directorate

both years, aggregate stability value was between 25.1-27.5%, slightly saline (EC: 0.16-0.19 ds/m), less calcareous (1.05-1.37%), slightly alkaline reaction (pH: 7.54-8.13), organic matter content (1.63-2.09%) and available phosphorus amount (28.0-34.8 kg/ha) were low, and available potassium amount (819-981 kg/ha) was high (Taşova & Akın, 2013).

Methods

The first tillage was done in fall, the seedbed was prepared with cultivator + rake cultivation in spring, and the sowing was carried out manually and by quarry on May 16, 2022, and June 3, 2023. In this research, which was carried out in 3 replications according to randomized complete block design, each plot consisted of five rows of plants with a length of 5.0 m. Two seeds were planted at a depth of 3-4 cm using a row marker, with a row spacing of 50 cm and an intra-row of 20 cm (targeted density 100000 plants/ha), and the seeds were covered with soil. When the emerging seedlings had 3-4 leaves, thinning was done so that one seedling remained in each hill, and the first weeding were done manually by hoe. The plots were fertilized at 200 kg N/ha, 100 kg P_2O_5/ha and 150 kg K_2O/ha in order to minimize the limiting effects of NPK deficiency. 40% of the nitrogen and all of the phosphorus and potassium were sprinkled in the plots before sowing and mixed with the soil, while the remaining part of the nitrogen was sprinkled in rows when the plants were about 40 cm height the throat was filled. Soil moisture content was monitored by gravimetric method, and 493 mm of water was applied to each plot in equal amounts during the growing period in 2022 and 361 mm in 2023. Depending on the variety, the plants were harvested between August 22 and September 3 in 2022, and between September 10 and September 22 in 2023. In determining the harvest time, the recommended kernel moisture content for sweet corn was based on the date when it decreased to 73±1% (Okumura et al., 2013), two rows edge effects were left from the side rows and row ends of the plots, the plants in the remaining 6.3 m^2 area were harvested with a sickle from a 10 cm height from the soil surface, and the yield was determined by weighing immediately. The edge effect plants were used to check whether kernels reached grain harvest maturity.

In each plot, the number of days from sowing date to the date of 50% silking and maturity (kernel moisture content 73% ±1%) was determined. Plant density was calculated at the harvesting time by counting the plants (excluding tillers) in the harvesting area. Randomly, 10 plants were chosen to measure the plant height from the soil surface to the tip of the tassel, first ear height from the soil surface to the node where the first ear emerged, and the number of leaves per plant by counting the leaves with at least 50% green leaf blade. During silking period, chlorophyll value (SPAD unit) was measured by averaging the readings made with a chlorophyll meter (Model SPAD 502, Minolta, Japan) at the bottom, middle and the tip of the leaf blade at the node where the first ear emerged, and the maximum quantum yield at PSII (Fv/Fm) was measured by averaging the measurements made with the portable chlorophyll fluorescence system (Handy Pea, Hansatech Instruments Kink's Lynn, UK) on the same leaf blades and in the same parts (Guo et al., 2021). Immediately after harvest, all the ears were separated from the husks and those holding at least 50% of the kernels were counted, the value obtained was divided by the number of plants within the harvesting area and the number of ear per plant was calculated. The ears were weighed, and the yield of fresh de-husked ear was determined. Randomly, 10 ears were selected, the ear diameter was measured from the middle part using an electronic caliper, and the ear length was measured from the place where the lowest kernel at the bottom to the place where the end kernel at tip. The number of kernel rows and the number of kernels per row were determined from the same ears, and the number of kernels per ear was calculated from the two values. The grain protein content was determined by the Kjeldahl method using the multiplication factor of % N × 6.25 in fresh kernel samples (Okumura et al., 2014). Variance analysis of the data was performed with the RStudio (2020) statistical analysis program, and the differences between the means were compared using Duncan multiple comparison test.

Results and Discussion

In both trial years, due to crow damage during the germination and emergence periods, a full seedling establishment could not be achieved, and the targeted plant density could not be reached in any of the plots. Aphid pests were observed in the plants in two years, and there was no plant loss due to lodging or breakage. The first frosts occurred on September 10, 2022 (-1.1˚C) and October 18, 2023 (-0.9˚C). In the first year, in all genotypes, edge-effect plants that were still at the beginning of the physiological maturity period died due to the first frost. In the second year, it was observed that the edge effect plants reached physiological maturity (the husks turned yellow and a black layer was formed where the kernel was attached to the ear) in all genotypes.

Significant differences were determined among corn genotypes in terms of the traits examined, except for the number of plants per hectare (Tables 3-5). Year effect was insignificant for maturity period, number of leaves per plant, chlorophyll value, maximum quantum at PSII, ear diameter and grain protein content, but significant for other traits. The fact that the temperatures of June, July and August were more favorable for corn in 2022 shortened the silking

Table 3
Mean values of corn genotypes for days to silking, days to maturity, plant height, first ear height and leaf number per plant[1]

	Days to silking (day)	Days to maturity (day)	Plant height (cm)	First ear height cm)	Leaf number per plant
Year (Y)					
2022	68.9^{b}	106.1	233.1^{a}	83.7^{a}	10.9
2023	71.8^{a}	106.0	222.8^{b}	71.2^{b}	11.2
Mean	70.6	106.0	227.9	77.5	11.0
Genotype (G)					
Argos F_1	71.3^{c}	106.7^{bcd}	203.2^{d}	59.4^{d}	11.6^{b}
Baron F_1	70.0^{c}	107.2^{bc}	201.1^{de}	69.0^{c}	11.1^{bc}
Challenger F_1	72.2^{c}	106.8^{bcd}	199.5^{de}	55.2^{de}	11.4^{bc}
Khan F_1	78.0^{a}	110.0^{a}	206.3^{d}	62.7^{cd}	10.7^{bcd}
Signet F_1	66.3^{d}	98.2^{f}	189.5^{e}	50.8^{e}	9.6^{e}
Simpatico-KWS	71.7^{c}	106.2^{cde}	267.4^{a}	102.5^{b}	14.8^{a}
Çaykara-Taşören	74.8^{b}	107.8^{abc}	274.7^{a}	119.3^{a}	11.3^{bc}
Çaykara-Karaçam	71.7^{c}	108.8^{ab}	268.8^{a}	103.5^{b}	10.5^{cd}
Maçka-Ormanüstü	63.3^{e}	104.0^{e}	220.7^{c}	49.9^{e}	9.2^{e}
Tonya-Sayraç	66.7^{d}	104.5^{de}	248.3^{b}	102.3^{b}	10.1^{de}
Interaction (G × Y)					
Argos F_1 × Y1	68.3^{g-j}	106.7	209.2^{c-f}	62.9^{gh}	10.8^{d-g}
Argos F_1 × Y2	74.3^{cd}	106.7	197.1^{efg}	55.9^{ghi}	12.3^{c}
Baron F_1 × Y1	69.7^{f-i}	107.7	201.3^{d-g}	75.3^{ef}	11.3^{cde}
Baron F_1 × Y2	70.3^{e-h}	106.7	200.9^{d-g}	62.7^{gh}	10.9^{c-f}
Challenger F_1 × Y1	69.7^{f-i}	106.7	200.7^{d-g}	57.2^{ghi}	11.1^{cde}
Challenger F_1 × Y2	74.7^{bcd}	107.0	198.3^{efg}	53.2^{ghi}	11.6^{cde}
Khan F_1 × Y1	77.3^{abc}	109.7	211.0^{cde}	64.8^{fg}	11.1^{cde}
Khan F_1 × Y2	78.7^{a}	110.3	201.5^{d-g}	60.6^{gh}	10.3^{e-i}
Signet F_1 × Y1	65.7^{jkl}	98.7	190.2^{fg}	56.8^{ghi}	9.7^{f-i}
Signet F_1 × Y2	67.0^{hij}	97.7	188.8^{g}	44.7^{i}	9.5^{ghi}
Simpatico-KWS × Y1	71.3^{d-g}	105.7	283.5^{a}	109.2^{c}	15.9^{a}
Simpatico-KWS × Y2	72.0^{def}	106.7	251.3^{b}	95.7^{d}	13.7^{b}
Çaykara-Taşören × Y1	72.0^{def}	108.0	276.3^{a}	113.0^{bc}	10.7^{d-h}
Çaykara-Taşören × Y2	77.7^{ab}	107.7	273.0^{a}	125.7^{a}	11.8^{cd}
Çaykara-Karaçam × Y1	70.0^{e-h}	109.0	287.0^{a}	124.1^{ab}	9.3^{hi}
Çaykara-Karaçam × Y2	73.3^{de}	108.7	250.7^{b}	83.0^{e}	11.7^{cd}
Maçka-Ormanüstü × Y1	63.0^{l}	104.3	223.2^{c}	51.8^{hi}	9.0^{i}
Maçka-Ormanüstü × Y2	63.7^{kl}	103.7	218.1^{cd}	48.0^{i}	9.4^{hi}
Tonya-Sayraç × Y1	67.0^{hij}	104.3	248.2^{b}	122.0^{ab}	9.7^{f-i}
Tonya-Sayraç × Y2	66.3^{ijk}	104.7	248.4^{b}	82.7^{e}	10.4^{d-h}
Sources of variation			*F* values[2]		
Year (Y)	26.64***	0.04	15.55***	53.44***	2.85
Genotype (G)	33.88***	64.75***	65.51***	95.06***	27.45***
G x Y	2.67*	0.20	2.60*	9.18***	4.75***
CV (%)	2.55	1.78	4.42	8.55	6.59

[1] The means marked with the same letter are not different from each other.
[2] *F* values marked with * and *** are significant at the probability level of 0.05 and 0.001, respectively.

Table 4

Mean values of corn genotypes for ear number per plant, chlorophyll value, PSII maximum energy yield, plant number per hectare and green mass yield[1]

	Ear number per plant	Chlorophyll value (SPAD unit)	PSII maximum energy yield (Fv/Fm)	Plant number per hectare	Green mass yield (kg/ha)
Year (Y)					
2022	1.50[a]	51.2	0.763	89,058[a]	87,462[a]
2023	1.39[b]	52.6	0.760	86,578[b]	82,883[b]
Mean	1.45	51.9	0.761	87,818	85,173
Genotype (G)					
Argos F_1	1.10[c]	52.5[a]	0.778[ab]	87,674	78,383[ef]
Baron F_1	1.10[c]	53.6[a]	0.716[d]	88,237	91,350[b]
Challenger F_1	1.12[c]	54.6[a]	0.773[abc]	87,156	81,844[de]
Khan F_1	1.13[c]	55.6[a]	0.758[bc]	88,060	81,870[de]
Signet F_1	1.39[b]	45.2[b]	0.783[a]	87,058	76,314[f]
Simpatico-KWS	1.78[a]	53.7[a]	0.757[c]	87,586	108,544[a]
Çaykara-Taşören	1.67[a]	47.3[b]	0.778[ab]	87,112	87,233[bc]
Çaykara-Karaçam	1.67[a]	51.7[a]	0.725[d]	89,585	87,125[bc]
Maçka-Ormanüstü	1.70[a]	53.1[a]	0.784[a]	86,969	75,337[f]
Tonya-Sayraç	1.83[a]	51.7[a]	0.757[d]	88,747	83,726[cd]
Interaction (G × Y)					
Argos F_1 × Y1	1.20	53.2	0.780[ab]	89,570	82,532
Argos F_1 × Y2	1.00	53.0	0.776[abc]	85,777	74,233
Baron F_1 × Y1	1.17	53.4	0.724[ef]	88,475	91,882
Baron F_1 × Y2	1.03	53.9	0.712[f]	88,000	90,820
Challenger F_1 × Y1	1.20	54.7	0.789[a]	90,311	86,747
Challenger F_1 × Y2	1.03	54.4	0.757[bcd]	84,000	76,939
Khan F_1 × Y1	1.17	55.9	0.781[ab]	88,564	83,206
Khan F_1 × Y2	1.10	55.4	0.736[def]	87,556	80,534
Signet F_1 × Y1	1.51	44.5	0.788[ab]	88,782	80,052
Signet F_1 × Y2	1.27	46.0	0.779[abc]	85,333	72,577
Simpatico-KWS × Y1	1.69	52.5	0.749[cde]	89,837	111,616
Simpatico-KWS × Y2	1.87	54.9	0.765[abc]	85,333	105,472
Çaykara-Taşören × Y1	1.70	44.6	0.790[a]	88,889	89,942
Çaykara-Taşören × Y2	1.63	50.0	0.766[abc]	85,333	84,523
Çaykara-Karaçam × Y1	1.73	51.3	0.729[def]	89,837	87,636
Çaykara-Karaçam × Y2	1.60	52.1	0.721[ef]	89,333	86,614
Maçka-Ormanüstü × Y1	1.77	52.4	0.775[abc]	88,160	77,276
Maçka-Ormanüstü × Y2	1.63	53.8	0.794[a]	85,777	73,398
Tonya-Sayraç × Y1	1.89	49.5	0.721[ef]	88,160	83,735
Tonya-Sayraç × Y2	1.77	54.0	0.793[a]	89,333	83,718
Sources of variation			*F* values[2]		
Year (Y)	7.35*	3.41	0.48	7.26*	21.99***
Genotype (G)	24.02***	6.99***	12.94***	0.34	39.05***
G x Y	0.82	0.78	6.22***	0.79	1.20
CV (%)	10.72	5.80	2.11	4.06	4.44

[1] The means marked with the same letter are not different from each other.

[2] *F* values marked with * and *** are significant at the probability level of 0.05 and 0.001, respectively.

Table 5

Mean values of corn genotypes for ear length, ear diameter, kernel number per ear, fresh ear yield, and grain protein content[1]

	Ear length (cm)	Ear diameter (mm)	Kernel number per ear	Fresh ear yield (kg/ha)	Grain protein content (%)
Year (Y)					
2022	17.1^{b}	47.1	475.3^{b}	22,274^{a}	13.9
2023	17.7^{a}	47.0	508.4^{a}	20,215^{b}	14.2
Mean	17.4	47.0	491.8	21,245	14.1
Genotype (G)					
Argos F_1	20.9^{ab}	47.7^{c}	692.0^{a}	24,712^{b}	15.9^{a}
Baron F_1	16.5^{d}	50.6^{a}	678.9^{a}	23,710^{a}	10.9^{e}
Challenger F_1	20.5^{b}	48.0^{bc}	678.3^{a}	24,577^{a}	16.2^{a}
Khan F_1	21.5^{a}	49.1^{abc}	675.5^{a}	25,465^{a}	14.5^{c}
Signet F_1	18.1^{c}	48.0^{bc}	591.7^{b}	23,318^{a}	12.7^{d}
Simpatico-KWS	18.3^{c}	50.5^{a}	628.9^{b}	25,195^{a}	10.4^{e}
Çaykara-Taşören	13.1^{f}	41.7^{d}	232.7^{c}	16,252^{b}	15.1^{bc}
Çaykara-Karaçam	16.0^{de}	50.2^{ab}	272.3^{c}	16,315^{b}	16.2^{a}
Maçka-Ormanüstü	13.6^{f}	42.7^{d}	236.3^{c}	15,312^{b}	15.7^{ab}
Tonya-Sayraç	15.4^{e}	41.6^{d}	231.9^{c}	17,591^{b}	13.0^{d}
Interaction (G × Y)					
Argos F_1 × Y1	18.9^{ef}	46.7^{cd}	678.8	26,083	15.6
Argos F_1 × Y2	22.8^{a}	48.7^{abc}	705.2	23,340	16.2
Baron F_1 × Y1	16.6^{gh}	51.3^{a}	640.7	24,061	10.9
Baron F_1 × Y2	16.3^{gh}	49.8^{abc}	717.1	23,358	10.9
Challenger F_1 × Y1	19.8^{de}	46.7^{cd}	637.1	26,077	16.0
Challenger F_1 × Y2	21.2^{bc}	49.3^{abc}	719.4	23,078	16.4
Khan F_1 × Y1	20.9^{cd}	47.0^{bcd}	633.1	26,400	14.1
Khan F_1 × Y2	22.2^{ab}	51.2^{a}	717.9	24,530	14.9
Signet F_1 × Y1	17.9^{f}	47.9^{a-d}	600.4	25,385	13.1
Signet F_1 × Y2	18.3^{f}	48.2^{a-d}	583.0	21,253	12.3
Simpatico-KWS × Y1	18.1^{f}	50.7^{ab}	622.9	25,571	10.6
Simpatico-KWS × Y2	18.4^{f}	50.4^{abc}	634.9	24,818	10.1
Çaykara-Taşören × Y1	13.1^{i}	41.7^{ef}	223.5	16,538	14.8
Çaykara-Taşören × Y2	13.1^{i}	41.7^{ef}	242.0	15,964	15.4
Çaykara-Karaçam × Y1	16.2^{gh}	50.9^{a}	276.7	16,907	16.0
Çaykara-Karaçam × Y2	15.8^{gh}	49.5^{abc}	267.9	15,725	16.3
Maçka-Ormanüstü × Y1	13.8^{i}	44.9^{de}	218.9	15,293	15.4
Maçka-Ormanüstü × Y2	13.5^{i}	40.6^{f}	253.7	15,331	15.9
Tonya-Sayraç × Y1	15.6^{gh}	42.8^{ef}	220.5	20,429	12.9
Tonya-Sayraç × Y2	15.2^{h}	40.3^{f}	243.2	14,754	13.2
Sources of variation			*F* values[2]		
Year (Y)	11.64**	0.04	14.38***	17.36***	2.34
Genotype (G)	118.45***	21.14***	244.19***	29.97***	100.31***
G x Y	5.95***	2.61*	1.75	1.35	1.41
CV (%)	3.85	2.11	6.89	9.01	3.79

[1] The means marked with the same letter are not different from each other.

[2] *F* values marked with *, ** and *** are significant at the probability level of 0.05, 0.01 and 0.001, respectively.

period, increased plant height, first ear height and ear number per plant. In the second year, the greater crow damage reduced the number of plants, and accordingly, lower green-mass and fresh ear yields were obtained. The reactions of genotypes to environmental factors were different in terms of silking days, plant height, first ear height, number of leaves per plant, maximum quantum yield at PSII, ear length and ear diameter, and "genotype × year" interactions were significant.

Days to Silking and Days to Maturity

Days to silking of maize genotypes ranged between 63.0-77.3 days in 2022 and 63.7-78.7 days in 2023. In two years, the Ormanüstü landrace was the earliest in terms of days to silking and the Khan F_1 variety the latest, however, the "genotype × year" interaction was significant due to the different responses of other genotypes to environmental factors (Table 3). Days to silking may vary according to growing techniques such as genetic structure, environmental factors and sowing date. Days to silking was between 69.8-74.4 days in Eskişehir conditions in sweet corn genotypes (Sönmez et al., 2013), 76.17-90.67 days in Erzurum conditions (Stansluos et al., 2020a). It was determined between 57-85 days in Samsun conditions (Öner, 2011) and 52.7-66.5 days in Trabzon conditions (Öztürk & Büyükgöz, 2021) in local corn genotypes. In this study, the relationships between days to silking and days to maturity (r=0.69), number of leaves per plant (r=0.45) and ear length (r=0.47) were positive and significant (Table 6). The mean days to maturity of genotypes ranged from 98.2 days to 110.0 days. The shortest maturity period was observed in Signet F_1 variety, followed by the Ormanüstü and Sayraç landraces. Khan F_1 and Karaçam genotypes were the latest to reach maturity for fresh ear. Significant differences among maize genotypes in terms of days to maturity were also observed in previous studies, ranging between 105.7-120.2 days in Erzurum conditions (Stansluos et al., 2020a), 82.5-106.5 days in Slovakia conditions (Baratova et al., 2016), and 83.0-87.0 days in İzmir conditions (Kantarcı et al., 2016). The relationship between days to maturity and SPAD value was found to be positive and significant (r=0.58).

Plant Height and First Ear Height

In 2022 and 2023, the plant heights of the corn genotypes ranged between 190.2-287.0 cm and 188.8-273.0 cm, and the first ear height ranged between 51.8-124.1 cm and 44.7-125.7 cm, respectively (Table 3). The shortest plant height was measured in Signet F_1 variety in the two years, and the longest plant height was measured in Karaçam landrace in 2022 and Taşören landrace in 2023 year. The shortest first ear height was determined in Ormanüstü and Signet F_1 genotypes, and the tallest in Karaçam and Taşören landraces. Generally, landraces had taller plant height and first ear height, followed by the Simpatico-KWS variety, and sweet corn varieties taking the last ranks. Plant height and first ear height can vary significantly according to genetic structure, environmental factors, and cultivation techniques (Arteaga et al., 2016; Beyene et al., 2005). Previous research has also shown that sweet corn (Sönmez et al., 2013; Stansluos et al., 2020a) and local maize (Öner, 2011; Öztürk & Büyükgöz, 2021) genotypes were found to be significantly different in terms of plant height and first ear height. The first ear height was also higher in genotypes with long plant height. It was determined that plant height was positively correlated with first ear height (r=0.90), ear number per plant (r=0.76), green mass yield (r=0.56) and negatively correlated with fresh ear yield (r=-0.50), ear length (r=-0.55) and kernel number per ear (r=-0.63). Similar to plant height, the first ear height is also positively correlated with the ear number per plant (r=0.63), green mass yield (r=0.56) and negatively correlated with ear length (r=-0.44) and kernel number per ear (r=-0.50) (Table 6).

Number of Leaf per Plant and Number of Ear per Plant

As an average of the years, the number of leaves of the genotypes per plant varied between 9.2 and 14.8, and the number of leaves was the least in the Ormanüstü landrace and the highest in Simpatico-KWS variety in two years. However, the order of other genotypes in terms of the number of leaves differed according to the years and the interaction of "genotype × year" was found to be important (Table 3). The ear number per plant varied between 1.10 and 1.83. The Sayraç landrace had the highest ear number per plant, followed by the Simpatico-KWS variety. The lowest number of ear per plant was determined in Agros F_1 and Baron F_1 sweet corn varieties (Table 4). Due to their different responses to genetic makeup and environmental factors, significant differences can be seen between maize genotypes in terms of the number of leaves and cobs per plant. The number of leaves per plant was related to light retention, photosynthesis rate, and yield (Li et al., 2016), while the number of leaves in this study was similar to that of sweet corn (Sönmez et al., 2013; Stansluos et al., 2020a) and local maize (Öner, 2017; Öztürk & Büyükgöz, 2021) are close to the previously reported values for genotypes. In this study, a positive and significant (r=0.75) relationship was determined between the number of leaves and green mass yield. Maize genotypes with a higher number of leaves are more suitable for silage (Subedi & Ma, 2005) and the Simpatico-KWS variety for silage has attracted attention with this feature.

Although hybrid corn varieties usually have a well-developed ear per plant, high ear counts have been detected in Simpatico-KWS and Signet F_1 varieties. In this study, the ear number per plant determined in sweet corn

Table 4
Correlation coefficients among the traits investigated of the corn genotypes (n=20)

	SD[1]	MD	PH	FEH	LNPP	ENPP	SPAD	Fv/Fm	PNPD	GMY	EL	ED	KNPE	FEY
MD	0.69***	-												
PH	0.10	0.32	-											
FEH	0.22	0.34	0.90***	-										
LNPP	0.45*	0.29	0.31	0.28	-									
ENPP	-0.40	-0.17	.76***	0.63**	-0.01	-								
SPAD	0.29	0.58**	-0.16	-0.24	0.29	-0.31	-							
Fv/Fm	-0.25	-0.38	-0.16	-0.34	-0.12	0.07	-0.18	-						
PNPD	-0.22	0.19	0.26	0.23	-0.04	0.18	-0.03	-0.11	-					
GMY	0.18	0.31	0.56**	0.56**	0.75***	0.34	0.15	-0.32	0.34	-				
EL	0.47*	0.16	-0.55**	-0.44*	0.28	-0.70***	0.40	0.00	-0.14	-0.09	-			
ED	0.34	0.21	-0.24	-0.16	0.37	-0.45*	0.25	-0.54**	0.04	0.34	0.61**	-		
KNPE	0.35	0.05	-0.63**	-0.50*	0.39	-0.78***	0.34	-0.07	-0.15	0.12	0.84***	0.69***	-	
FEY	0.05	0.03	-0.50*	-0.30	0.40	-0.58**	0.25	-0.05	0.06	0.27	0.78***	0.60**	0.91***	-
GPC	0.15	0.26	-0.04	-0.16	-0.38	-0.15	0.06	0.27	-0.03	-0.63**	0.05	-0.28	-0.28	-0.36

[1] SD: silking days; MD: maturity days; PH: plant height; FEH: first ear height; LNPP: leaf number per plant; ENPP: ear number per plant; SPAD: chlorophyll value; Fv/Fm: PSII maximum energy yield; PNPD: plant number per hectare; GMY: green mass yield; EL: ear length; ED: ear diameter; KNPE: kernel number per ear; FEY: fresh ear yield; GPC: grain protein content. Correlation coefficients marked with *, ** and *** are significant at the probability level of 0.05, 0.01 and 0.001, respectively.

varieties is close to the values determined by Eşiyok and Bozokalfa (2005) between 1.10-1.14 and lower than the values determined by Sönmez et al. (2013) between 1.56-1.96. The number of ear per plants belonging to local populations is close to the results of Öner (2017) and higher than the results of Öztürk & Büyükgöz (2021). It was determined that the number of ear per plant was negatively and significantly related to fresh ear yield (r=-0.58), ear length (r=-0.70), ear diameter (r=-0.45) and number of kernels per ear (r=-0.78).

Chlorophyll Value (SPAD units) and Maximum Quantum Yield at PSII (Fv/Fm)

Chlorophyll values (SPAD unit) of maize genotypes ranged from 45.2 to 55.6. The highest value was measured in the Khan F_1 variety, followed by the Challenger F_1 and Simpatico-KWS varieties. The lowest values were measured in the Signet F_1 and Taşören genotypess, and these genotypes had significantly lower chlorophyll values than the others (Table 4). The measured chlorophyll values were higher than the values reported by Tunalı et al. (2012) as 40.3-46.3 in maize varieties and consistent with the values reported by Wang et al. (2019) between 43.1 and 66.3. Chlorophyll value is one of the main chloroplast elements for photosynthesis, and leaf chlorophyll content is positively correlated with the rate of photosynthesis (Guo et al., 2008). Leitao et al. (2023) pointed out that there is a positive and significant relationship between chlorophyll value and kernel yield in corn. In this study, the correlation coefficients between the SPAD value and the other traits examined were not significant. Wang et al. (2019) identified a very weak and insignificant relationship between chlorophyll value and kernel yield in 55 maize genotypes, similar to our results.

The maximum quantum yield (Fv/Fm) is considered as an indicator of PSII potential quantum activity and as a measure of plant photosynthesis ability (Maxwell & Johnson, 2000) and is normally between 0.75-0.85 (Bolhar-Nordenkampf et al., 1989; Sayar et al., 2008). The Fv/Fm values of the genotypes ranged from 0.721 to 0.790 in 2022 and from 0.712 to 0.794 in 2023, and the genotype × year interaction was significant due to different responses to changing environmental conditions in terms of the Fv/Fm value (Table 4). Simpatico-KWS, Ormanüstü, and Sayraç genotypes had higher Fv/Fm values in 2023, while the other seven genotypes had higher Fv/Fm values in 2022. According to the average of the years, the highest Fv/Fm values were measured in Ormanüstü and Signet F_1, and the lowest Fv/Fm values were measured in Baron F_1 and Karaçam genotypes. In previous studies, significant differences were determined between maize genotypes in terms of maximum energy yield, and relatively high Fv/Fm values were measured according to our findings, between 0.770-0.844 by Özdemir & Sade (2019) and 0.780-0.830 by Badr & Brüggemann (2020). The Fv/Fm value was significantly correlated only with ear diameter (r=-0.54) (Table 6).

Number of Plants per Hectare and Green Mass Yield

The number of plants per hectare is one of the most important determinants of yield, and the ability to reach the target plant density is an important feature for high yields. In this study, the targeted plant density (100000 plants/ha) could not be reached in any genotype, and the plant density decreased significantly in 2023 as plant losses due to crow damage in the germination-emergence period were higher (Table 4). Due to the decrease in kernel starch ratio in sweet corn varieties, the germination and emergence rate may be lower than in dent corn and flint corn varieties (Azanza et al. 1996; Szymanek et al. 2006). However, in this study, the differences between genotypes in terms of the number of plants per hectare at harvesting time were not significant. The number of plants per hectare varied between 86969 and 89585 according to genotypes, and the lowest and highest values were determined in the Ormanüstü and Karaçam landraces, respectively. High yields can be achieved with an establishment of optimum plant number per unit area, their management and protection until harvest (Mathukia et al., 2014). Since the plant density at harvest is also affected by environmental factors, environmental factors should be taken into consideration as well as the biological characteristics of the seed in the calculation of seeding rate.

As average of the varieties, 87462 kg/ha and 82883 kg/ha of green mass yields were obtained in 2022 and 2023 years respectively, and the green mass yield decreased significantly in 2023 due to the decrease in plant density (Table 4). The green mass yield of corn genotypes ranged between 75337-108544 kg/ha, and significant differences were determined between the genotypes. The highest green mass yield was obtained from the Simpatico-KWS variety, followed by the Baron F_1 sweet corn variety. The lowest yields were obtained by Ormanüstü and Signet F_1 genotypes. Since corn is an important silage crop, genotypes that can be used for both food and fodder purposes may be more valuable. Green mass yield can vary according to plant density, fertilization, irrigation and other cultivation techniques, as well as environmental and genetic factors. In this study, green mass yields obtained from sweet corn varieties are considerably higher than those ranging from 21553 to 29093 kg/ha in Karaman conditions (Eser, 2014), 33639 to 35886 kg/ha in Kahramanmaraş conditions (İdikut et al., 2016) and 35458 to 49406 kg/ha in Erzurum conditions (Stansluos et al., 2020a). It was determined that the correlation between green mass yield and grain protein content was negative and significant (r=-0.63). The correlation coefficient between the SPAD value and green mass yield was not significant (r=0.15).

Ear Length, Ear Diameter and Number Kernels per Ear

The ear lengths of the genotypes ranged between 13.1-20.9 cm in 2022 and 13.1-22.8 cm in 2023. The shortest ears were measured in Taşören landrace in both years, the longest ears Khan F_1 and Challenger F_1 in the first year and Argos F_1 and Khan F_1 in the second year (Table 5). Ear length is an important yield component with a high degree of heritability and is positively correlated with grain yield (Lucchin et al., 2003; Ruiz de Galarreta & Alvarez, 2001). In this study, hybrid varieties formed longer ears than landraces. The ear lengths of sweet corn varieties were less than the values reported by Sönmez et al. (2013) as 21.9-23.8 cm and close to the values reported by Stansluos et al. (2020b) as 16.1-19.8 cm. It can be stated that the ear lengths of landraces are close to the results reported by Lucchin et al. (2003) and Öztürk and Büyükgöz (2021). The correlations between ear length and ear diameter (r=0.61), kernel number per ear (r=0.84) and fresh ear yield (r=0.78) were positive and significant (Table 6).

The ear diameters of the genotypes varied between 41.7-51.3 mm in 2022 and 40.3-51.2 mm in 2023. As average of the years, it was determined that the ear diameter was the largest in Baron F_1 and Simpatico-KWS varieties, and the smallest was in Sayraç and Taşören landraces (Table 5). Ear diameter is a trait that can vary according to genetic structure, environmental factors and cultivation techniques, and affects kernel yield through the number of kernel rows per ear and the number of kernels per ear. In terms of ear diameter, significant differences among genotypes have also been identified in sweet corn (Sönmez et al., 2013; Stansluos et al., 2020b) and in maize landraces (Öztürk & Büyükgöz, 2021; Ruiz de Galarreta and Alvarez, 2001). In this study, the landraces generally had smaller ear diameters than the hybrids varieties, and positive and significant correlations were determined between the ear diameter and kernel number per ear (r=0.69) and fresh ear yield (r=0.60) (Table 6).

As an average of the trial years, the number of kernels per ear of genotypes varied between 231.9 and 692.0. The kernel number per ear was highest in Argos F_1 and Baron F_1 cultivars, and the lowest in Sayraç and Taşören landraces (Table 5). The hybrids were significantly superior to landraces in terms of the number of kernel rows per ear and kernel number per ear. Kernel number per ear is one of the most important component of yield in corn (Bagrintseva, 2015) and in this study, it was positively and strongly correlated (r=0.91) with fresh ear yield. In previous studies, significant differences between genotypes in terms of this trait were determined, and Öztürk & Büyükgöz (2021) and Stansluos et al. (2020a) reported similar results to our findings in corn landraces and in sweet corn varieties, respectively.

Fresh Ear Yield and Grain Protein Content

While fresh ear yield was 22274 kg/ha in 2022, it decreased significantly in 2023 due to the decrease in plant density and became 20215 kg/ha (Table 5). On average, fresh ear yields of corn genotypes ranged from 15312 to 25465 kg/ha. Significant differences between genotypes were identified, with all hybrid varieties yielding higher fresh ear yield than landraces. The highest fresh ear yield was obtained from the Khan F_1 variety, but the differences between it and other hybrid varieties were not significant. The Ormanüstü landrace had the lowest fresh ear yield and the differences between it and other landraces were found to be insignificant. Fresh ear yield is related to plant density, number of ear per plant, kernel number per ear and kernel weight, and may vary according to genotype, environmental factors and cultivation technique. In this study, fresh ear yields obtained from sweet corn varieties were higher than fresh ear yields from other studies, 12410 to 16100 kg/ha in İzmir (Bozokalfa et al. 2004), 10590 to 16370 kg/ha in Şanlıurfa (Öktem & Öktem, 2006), 13840 to 18620 kg/ha in Karaman (Eser, 2014), 11620 to 12450 kg/ha in Brazil (Okumura et al., 2014), 16190 to 19330 kg/ha in Sakarya (Uçak et al., 2016), 16330 to 18500 kg/ha in Tekirdağ (Özerkişi, 2016), and 9440 to 18790 kg/ha in Erzurum (Stansluos et al., 2020a). This result is thought to be mainly due to the fact that the plant density in this study was higher than in the studies listed.

The average grain protein contents of maize genotypes ranged from 10.4% to 16.2%. The Challenger F_1 sweet corn variety and the Karaçam landrace had the highest grain protein content, followed by the Argos F_1 and Ormanüstü genotypes. The lowest grain protein contents were determined in Simpatico-KWS and Baron F_1 varieties (Table 5). Protein content, which is the most important measure of kernel quality in corn, may vary significantly according to genetic structure, environmental factors and cultivation techniques. Sönmez et al. (2013) pointed out that sweet corn kernel contains higher protein than other variety groups, and Ünlü et al. (2018) drew attention to the wide variation in terms of grain protein content and biochemical properties in corn landraces in Türkiye. In previous studies conducted with sweet corn varieties, grain protein contents were determined between 11.6-20.5% (Goldman & Tracy, 1994) and 9.7-13.3% (Alan et al., 2014), and our results are consistent within these findings. In the studies conducted on corn landraces, protein content in dry grain were determined between 8.88-16.00% (Öner, 2011) and 11.02-14.50% (Öztürk & Büyükgöz, 2021).

Conclusion and Recommendations

In this study, plant number per hectare of corn genotypes was 86969-89585, the number of kernels per ear was 231.9-692.0, green-mass yield was 75337-108544 kg/ha, fresh ear yield was 15312-25465 kg/ha, and the kernel protein content was 10.4-16.2%. The highest green-mass yield was obtained from Simpatico-KWS, number of kernels per ear was obtained from Argos F_1, fresh ear yield was obtained from Khan F_1, and kernel protein content was obtained from Challenger F_1 and Karaçam genotypes. The Simpatico-KWS variety for silage has attracted attention with its high and stable yield in two years. It can be said that the Khan F_1, Argos F_1 and Challenger F_1 varieties can be preferred for fresh consumption. Considering the maturity days, the Signet F_1 variety may be the first choice for the Erzurum region. Despite the global warming process, it has been confirmed once again that only silage or corn for fresh consumption can be produced in Erzurum Plain conditions due to the short vegetation period and low average temperatures. After fresh cob harvest, genotypes with superior feed value of the remaining plant parts may be more advantageous in local conditions.

Peer-review: Externally peer-reviewed.
Ethics Committee Approval: This study does not require ethics committee approval.
Author Contributions: Concept – A.Ö.; Design – A.Ö.; Supervision – A.Ö., A.A.L.S., H.K., F.H.; Resources – A.Ö., A.A.L.S., F.H.; Materials – A.Ö., A.A.L.S., F.H.; Data Collection and/or Processing – A.A.L.S., H.K. F.H; Analysis and/or Interpretation – A.Ö., A.A.L.S., F.H.; Literature Search – A.Ö., A.A.L.S., H.K., F.H.; Writing Manuscript – A.Ö., A.A.L.S.; Critical Review – A.Ö., A.A.L.S.
Conflict of Interest: The authors have no conflicts of interest to declare.
Financial Disclosure: The authors declared that this study has received no financial support.

Hakem Değerlendirmesi: Dış bağımsız.
Etik Komite Onayı: Bu çalışma için etik kurul onayına gerek yoktur.
Yazar Katkıları: Fikir - A.Ö.; Tasarım - A.Ö.; Süpervizyon - A.Ö., A.A.L.S., H.K., F.H.; Kaynaklar - A.Ö., A.A.L.S., F.H.; Materyaller - A.Ö., A.A.L.S., F.H.; Veri Toplama ve/veya İşleme - A.A.L.S., H.K. F.H; Analiz ve/veya Yorumlama - A.Ö., A.A.L.S., F.H.; Literatür Taraması - A.Ö., A.A.L.S., H.K., F.H.; Makale Yazımı - A.Ö., A.A.L.S.; Eleştirel İnceleme - A.Ö., A.A.L.S.
Çıkar Çatışması: Yazarlar, çıkar çatışması olmadığını beyan etmiştir.
Finansal Destek: Yazarlar bu çalışmanın herhangi bir finansal destek almadığını beyan etmişlerdir.

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ATATURK UNIVERSITY PUBLICATIONS

Research Article *Araştırma Makalesi* DOI: 10.17097/agricultureatauni.1710484

The Role of Spatial Familiarity in Visual Perception: An Investigation in Protected Landscapes in Cappadocia

Görsel Algıda Mekânsal Aşinalığın Rolü: Kapadokya'daki Korunan Peyzaj Alanlarında Bir İnceleme

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ABSTRACT

Visual perception is one of the main elements that shape the visitor experience in tourism and recreation activities. The Cappadocia Region, where natural and cultural landscape elements form a unique integrity, has a strong visual appeal at the universal level in this respect. In this study, the perceptual effects of different landscape types of Cappadocia on individuals were examined; the role of individual variables such as spatial familiarity, settlement and visit history on perception was evaluated.

Methodologically, the study consisted of (1) photographing the characteristic landscapes of the region, (2) selecting photographs with diverse content, (3) administering a questionnaire to 120 participants in order to evaluate these images in terms of scenic beauty, tranquility, attractiveness and excitement, and (4) statistically analyzing the data.

The findings revealed that Cappadocia has a strong aesthetic and emotional impact on the participants with its natural landscapes as well as its cultural landscape elements. However, it was also found that locals evaluated certain landscapes more positively and that spatial familiarity and emotional connection created significant differences in the perception of "tranquility" and "beauty". Moreover, individuals who had visited the region before, developed a deeper and more meaningful perception of some images.

The results point to the importance of developing holistic planning strategies that are sensitive to user profiles and consider perceptual differences in areas with unique landscapes such as Cappadocia. They also emphasize the need to integrate visual perception into tourism planning and promotion processes.

Keywords: Cultural heritage, Natural heritage, Nevşehir, Tourism destination, Visual landscape quality

ÖZ

Görsel algı, turizm ve rekreasyon faaliyetlerinde ziyaretçi deneyimini şekillendiren temel unsurlardan biridir. Doğal ve kültürel peyzaj öğelerinin özgün bir bütünlük oluşturduğu Kapadokya Bölgesi, bu açıdan evrensel düzeyde güçlü bir görsel çekiciliğe sahiptir. Bu çalışmada, Kapadokya'ya ait farklı manzara türlerinin bireyler üzerindeki algısal etkileri incelenmiş; özellikle mekânsal aşinalık, yerleşim yeri ve ziyaret geçmişi gibi bireysel değişkenlerin algı üzerindeki rolü değerlendirilmiştir.

Yöntemsel olarak çalışma; (1) bölgenin karakteristik peyzajlarının fotoğraflanması, (2) içerik bakımından çeşitlilik taşıyan 21 fotoğrafın seçilmesi, (3) bu görsellerin manzara güzelliği, huzur vericilik, ilgi çekicilik ve heyecan vericilik boyutlarında değerlendirilmesi amacıyla 120 katılımcıya anket uygulanması ve (4) verilerin istatistiksel olarak analiz edilmesi aşamalarını içermektedir.

Bulgular, Kapadokya'nın doğal peyzajları başta olmak üzere kültürel peyzaj öğeleriyle de katılımcılar üzerinde güçlü bir estetik ve duygusal etki yarattığını ortaya koymuştur. Bununla birlikte, yerel halkın belirli manzaraları daha olumlu değerlendirdiği ve mekânsal aşinalık ile duygusal bağın özellikle "huzur" ve "güzellik" algısı üzerinde anlamlı farklar yarattığı saptanmıştır. Ayrıca, bölgeyi daha önce ziyaret eden bireylerin bazı görsellere yönelik daha derinlikli ve anlamlı bir algı geliştirdiği belirlenmiştir. Sonuçlar, Kapadokya gibi özgün peyzajlara sahip alanlarda, kullanıcı profillerine duyarlı ve algısal farklılıkları gözeten bütüncül planlama stratejilerinin geliştirilmesinin önemine işaret etmektedir. Ayrıca, görsel algının turizm planlama ve tanıtım süreçlerine entegre edilmesinin gerekliliğini vurgulamaktadır.

Anahtar Kelimeler: Kültürel miras, Doğal miras, Nevşehir, Turizm Destinasyonu, Görsel peyzaj kalitesi

Received Date:	31.05.2025
Revision Request Date:	11.07.2025
Last Revision Date:	17.07.2025
Accepted Date:	19.07.2025
Publication Date:	26.09.2025

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Cite this article: Aklıbaşında, M. (2025). The Role of Spatial Familiarity in Visual Perception: An Investigation in Protected. *Research in Agricultural Sciences, 56*(3), 200-211.

Introduction

Perception is the process by which an individual makes sense of the stimuli in his or her environment. The dimension of this process related to the sense of sight is characterized as the visual perception (Çakcı & Çelem, 2009). Visual perception is a multifaceted phenomenon that covers the processes of interpreting and making sense of visual stimuli coming from the environment. Visual perception, which is the first process of receiving visual information from the environment, emerges as a result of the interaction of physical and social factors (Alpak et al., 2018). The most quickly recognized element in the perceptual definition of a space is the physical characteristics of the space. Although spatial components consist of similar elements in different spaces, the form, scale, color, texture and formal relationships of these elements differentiate the environmental experience and perceptual reactions of the individual to that space (Ardıçoğlu, 2024). How people perceive environmental stimuli depends not only on physical sensations but also on their life stories, cultural backgrounds, past experiences and levels of knowledge. Therefore, the same visual stimulus may take on different meanings for different individuals (Kahraman & Anıktarı, 2023; Yılmaz & Kaya, 2023). Since the aesthetic and psychological perception of the environment directly affects user experience, spatial belonging and environmental interaction, it is one of the main elements that should be considered in spatial planning and design processes.

In this context, studies examining how environmental stimuli are perceived by individuals have particularly focused on the concept of visual environmental quality. Visual quality has been the subject of research since the 1960s in order to reveal the objective and subjective dimensions of environmental aesthetic evaluation (Frank et al., 2013; Gobster et al., 2019). Visual landscape is a variable and multi-layered structure that is shaped by the individual's visual evaluation process of environmental elements and includes both physical features and perceptions based on aesthetic appreciation (Kiper & Ateş, 2023). Visual landscape quality is the evaluation of the aesthetic value created by environmental elements such as topographic structure, plant diversity, presence of water elements, harmony of colors, historical and cultural elements, natural life and geological forms as a whole (Polat et al., 2022). Visual quality analyses aim to measure how the environment is perceived aesthetically, functionally and psychologically, allowing of an understanding of emotional and cognitive interaction (Arriaza et al., 2004; Daniel, 2001; Zhao et al., 2024). In this context, visual quality analyses not only determine the aesthetic value of the environment, but also stand out as a powerful tool for understanding individuals' relationships with the environment, sense of belonging and spatial preferences.

Landscape quality assessment is not only an effective subfield of environmental perception studies, but also a fundamental element of environmental planning and management processes (Ak & Yılmaz, 2016, Sarı & Karaşah, 2015). The use of visual quality analyses in tourism planning enables the identification of the qualities of natural and cultural landscape elements in a region that are most appreciated and preferred by users. This is of strategic importance for planning touristic activities based on or influenced by visual experience (Aklıbaşında & Bulut, 2018).

Based on this conceptual basis, this study analyzes the Cappadocia Region, which is one of the most important tourism centers worldwide and has not been extensively studied in terms of visual perception. Nevşehir is the center of the Cappadocia Region and tourism activities are concentrated in Uçhisar, Ortahisar, Göreme, Ürgüp, Avanos, Derinkuyu and Kaymaklı settlements called Rocky Cappadocia. The region is one of the places where the world's most characteristic surface features are formed due to volcanism, tectonism and erosion. The volcanic erosions called fairy chimneys in geomorphology have an important tourism attraction power with their valuable surface features in terms of shape, color, density and size, and with settlements created by carving the slopes, underground and inside the fairy chimneys in the region (Dirik, 2009). Cappadocia draws attention as one of the rare areas on earth where history, nature, geography and culture are intertwined. The unique traces left by many important civilizations since the periods before Christ have enriched the cultural texture of Cappadocia and transformed the region into a unique heritage area (Akpınar & Koç, 2023). This visual diversity offers a rich opportunity to investigate not only the aesthetic values of Cappadocia, but also individuals' perceptions of these values. This study is significant as it comprehensively addresses the visual and perceptual values of the Cappadocia Region, which has special characteristics in terms of tourism and nature conservation.

Individual differences are recognized as one of the main determinants of perception in visual landscape assessments. In this context, individuals' level of familiarity with a landscape and their previous experiences can significantly affect their perception of visual quality. In this study, it is aimed to visually analyze the landscapes offered by different natural and cultural landscape components in the Cappadocia Region through people's perceptions and to examine the effects of spatial familiarity on visual perception. Although there are various findings on the effect of familiarity and experience on visual perception (Mangone et al., 2021; Petrova et al., 2015; Purcell, 2025; Strumse, 1996; Tang et al., 2025; Tenerelli et al., 2017; Tessema et al., 2021) in the literature, this relationship has been addressed in a limited way, especially in natural, cultural and visually unique areas such as Cappadocia. In this respect, it is thought that this study will make an important contribution both regionally and to the visual perception literature.

Methods

Materials

Ethics committee approval was obtained from Nevşehir Hacı Bektaş Veli University Scientific Research and Publication Ethics Committee (Date:05.02.2025, Number:2025.01.25) The research area consists of Uçhisar, Göreme, Ortahisar, Ürgüp and Avanos settlements of Nevşehir province, which is the center of the Cappadocia Region. Their distances to Nevşehir city center are: Uçhisar 16.6 km, Avanos 19.4 km, Göreme 20.4 km, Ortahisar 23.8 km and Ürgüp 28.6 km (Figure 1). The region has unique landscapes blended with its unique geological and geomorphological structure as well as its deep-rooted historical and cultural background. The main material of the study consists of photographs taken from the main tourism attraction areas, scenic viewpoints and road routes.

Method

The research sought answers to the following questions:

-Does familiarity with a place affect visual assessment of its natural and cultural features?

-How does having visited a place before affect people's evaluations in visual perception analysis through photographs?

-Do people differ in their perceptual approach to landscapes different from the landscape character they are familiar with?

In this direction, the research method consists of (1) photographing the natural and cultural landscape features of the region by conducting a field study, (2) analyzing the natural and cultural landscape features of the photographs taken and determining the photographs to be used in the survey, (3) preparation and implementation of the survey form, (4) analysis and interpretation of the data obtained.

Field work: Fieldwork was carried out at different times during June-September 2024 in the research area. 3000 photographs were taken including Uchisar Castle and its surroundings, Güvercinlik Valley, Göreme balloon take-off area, Göreme Open Air Museum and its surroundings, Aşıklar Hill, Love Valley, Three Beauties (Üç Güzeller), traditional housing texture in the center of Ürgüp, Devrent Valley, Zelve Open Air Museum, Paşabağlar Ruins, Kızılçukur Valley, Ortahisar castle and its surroundings and characteristic landscapes on the road routes. Photographs were taken with semi-professional cameras on bright and rain-free days.

Figure 1.

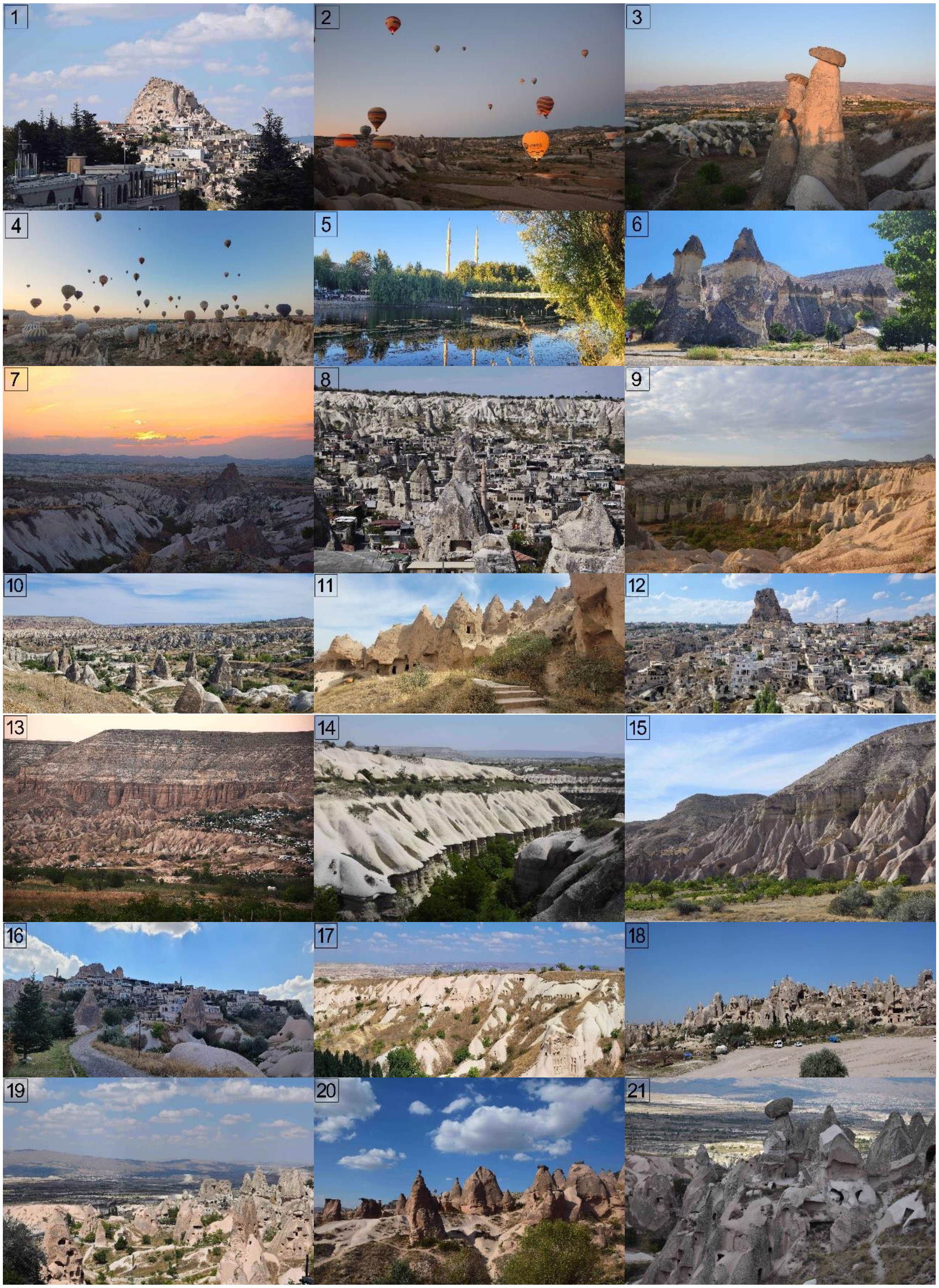
Location of the research area

Determination of the photographs to be used in the analysis: The photographs were transferred to the computer environment and grouped according to the settlement where they were taken. Among these, 21 photographs with high image quality and different qualities in terms of landscape elements were selected (Figure 2).

Questionnaire study: The main group of the survey consisted of the students of Nevşehir Hacı Bektaş Veli University, Department of Landscape Architecture. Accordingly, the number of questionnaires was calculated by the following formula (Yazıcıoğlu & Erdoğan, 2007), which is used when the number of individuals in the population is known.

Figure 2.

Photographs subjected to perceptual analysis



$$n = \frac{Nt^2pq}{d^2(N-1)+t^2pq}$$

N: Number of individuals in the target group

n: Number of individuals to be sampled

p: Probability of occurrence of the event under investigation

q: Probability that the event under investigation will not occur

t: The theoretical value found in the t-table at a given significance level

d: Accepted margin of error

Based on 130 students actively studying in the department, it was determined that the sample size should be 98 with a 5% margin of error, 95% confidence interval and 50% frequency of occurrence. Accordingly, the questionnaire was administered to 100 volunteer students. In addition, in order to include the views of non-students in the study and to make comparisons with the responses of the main group, a total of 120 people were surveyed including an additional group of 20 participants who are not students.

The questionnaire consists of two parts, including questions to determine the individual characteristics of the participants and their perceptions of the selected photographs. In the first part, the participants were asked about their gender, age, province of residence and whether they had visited the region where the photographs were taken. In the second part, the participants were asked to rate 21 photographs on a 5-point Likert scale (Strongly disagree: 1 point, Disagree: 2 points, Undecided: 3 points, Agree: 4 points and Strongly agree: 5 points).

Analysis of questionnaires*:* Survey data were transferred to SPSS 22.0 program and frequency analysis was performed. Percentage distributions regarding the individual characteristics of the participants, the percentages of the options marked and the average scores in the perceptual parameters were presented. Chi-Square analysis was conducted to determine whether the participants' perceptions of the photographs differed according to their permanent residence addresses and the status of visiting the region. As a result of the analysis, cross tabulations were created on the basis of each factor with a significant difference. By comparing the percentage distributions of the options marked by the groups through these tables, the differences and the Likert option with the highest percentage difference were determined.

Results

Participant Profile and General Evaluation

A total of 120 people, 85 women and 35 men, participated in the survey. 77.5% of the participants were between the ages of 18-24, 7.5% between25-34, 9.2% between35-44, and 5.8% between 45-55. According to their permanent residence address, 15% of the participants were students and locals residing in Nevşehir, while 85% were university students from 43 different provinces of Turkey (45% from coastal cities). The class distribution of the students is as follows: 34 were first-year students, 23 were second-year students, 27 were third-year students and 16 were fourth-year students. 76.5% of participants from different provinces stated that they had visited the Cappadocia Region before, 18.6% stated that they had partial knowledge of the region from television and social media, and 4.9% stated that they were not familiar with the region.

General Evaluation of the Photographs

The participants' responses to the photographs in terms of scenic beauty, tranquility, attractiveness and excitement were converted into scores and the mean scores are presented in Table 1. According to the mean scores, the scenic beauty (min. 3,73 - max. 4,68), tranquility (min. 3,21 - max. 4,50) and attractiveness (min. 3,51 - max. 4,47) of all images of the Cappadocia Region were found to be quite high. Although the excitement parameter had a lower mean score (min. 3.18 - max. 4.43) than the other parameters, the majority of the images were found to be exciting.

In terms of scenic beauty, the highest scores were given to photographs with no.P4 ($\bar{X}$=4.68), P2 ($\bar{X}$=4.65) and P7 ($\bar{X}$=4.58), respectively. In terms of peacefulness, P2 stood out ($\bar{X}$=4.50), followed by P7 ($\bar{X}$=4.40) and P4 ($\bar{X}$=4.38). Similarly, P2 ($\bar{X}$ =4,47), P4 ($\bar{X}$ =4,43) and P7 ($\bar{X}$ =4,32) were found to be the most interesting images; this ranking was in parallel with the level of excitement (P2:$\bar{X}$ =4,43; P4:$\bar{X}$ =4,41; P7:$\bar{X}$ =4,15). When these photographs were analyzed, it was seen that people are highly impressed by the landscapes created by the balloons, which had become the symbol of the region, together with their characteristic surface shapes. In addition, the fact that the photographs taken especially at sunset and sunrise were at the top of the participants' appreciation showed that the unique natural landscape features of the region become more attractive with warm color transitions. The analysis revealed that the level of appreciation for the natural and cultural landscape features of the region is high, especially natural landscapes are more

Table 1.

Mean scores of the photographs in perceptual parameters

Photograph Number	Scenic beauty	Tranquility	Attractiveness	Excitement
	$\overline{X}$±SD	$\overline{X}$±SD	$\overline{X}$±SD	$\overline{X}$±SD
P1	3.92±1.142	3.28±1.195	3.79±1.144	3.52±1.100
P2	4.65±0.706	4.50±0.799	4.47±0.888	4.43±0.867
P3	4.23±1.000	3.88±1.204	4.21±1.012	3.93±1.146
P4	4.68±0.661	4.38±0.972	4.43±0.923	4.41±0.884
P5	4.39±0.748	4.25±0.843	4.06±1.007	3.90±1.072
P6	4.28±0.970	3.85±1.010	4.07±0.985	3.88±1.104
P7	4.58±0.785	4.40±0.920	4.32±0.953	4.15±1.074
P8	3.90±1.191	3.34±1.260	3.88±1.142	3.55±1.256
P9	4.31±0.951	4.11±0.968	4.21±0.943	4.04±1.126
P10	4.02±1.115	3.58±1.112	3.74±1.149	3.54±1.202
P11	4.10±1.040	3.79±1.122	4.03±1.041	3.82±1.159
P12	4.00±1.069	3.52±1.077	3.88±1.017	3.51±1.152
P13	4.12±1.094	3.58±1.261	3.92±1.199	3.72±1.304
P14	4.20±1.074	3.81±1.125	4.08±1.070	3.69±1.121
P15	4.18±1.021	3.80±1.050	3.93±1.030	3.71±1.148
P16	3.97±0.987	3.54±1.092	3.83±1.064	3.31±1.158
P17	3.73±1.137	3.31±1.143	3.51±1.145	3.18±1.188
P18	3.95±1.083	3.43±1.248	3.88±1.164	3.64±1.269
P19	4.16±.979	3.58±1.185	3.92±0.992	3.44±1.172
P20	4.09±1.037	3.69±1.106	4.00±1.045	3.78±1.104
P21	4.04±1.103	3.21±1.236	3.91±1.069	3.43±1.207

prominent in this respect. At the same time, participants found natural landscapes to be more peaceful than landscapes containing cultural fabric. However, it is noteworthy that a photograph of the Kızılırmak surroundings (P5) was considered the most peaceful among the cultural landscapes.

Assessments Related to the Familiarity Factor

Regarding the role of familiarity in visual perception, the relationship between the place of residence of the participants and their previous visits to the Cappadocia Region was questioned. In the statistical analysis, it was determined that the answers of the participants living in coastal cities with quite different characteristics in terms of geographical characteristics did not differ from those living in other regions. However, it was observed that the answers of those living in Nevşehir and those who had visited the region before differed positively.

It was determined that there was a statistically significant difference ($p<.05$) between those who reside in Nevşehir and those who do not in the landscape beauty evaluations of photographs numbered P2, P9, P10, P16, P17, P18, P19 and P21 (Table 2). In terms of landscape beauty, it was observed that participants residing in Nevşehir gave higher scores to cultural landscapes than other participants. This difference is especially evident in P16 (p=.044), P17 (p=.042), P18 (p=.042), P19 (p=.039) and P21 (p=.030) images of traditional settlement texture, rock carvings used as pigeon nests and fairy chimneys used for settlement in the past.

Table 2.

Analysis results for photographs with statistically significant differences in landscape beauty evaluations

Photograph number	Place of residence	Place of residence x Scenic beauty					X^2	*p*
		Strongly disagree	Disagree	Neutral	Agree	Strongly agree		
P2	0	2.0%	0.0%	2.0%	25.5%	70.6%	9.901	.014
	1	0.0%	0.0%	11.1%	0.0%	88.9%		
P9	0	2.0%	2.9%	13.7%	31.4%	50.0%	8.694	.045
	1	5.6%	0.0%	0.0%	11.1%	83.3%		
P10	0	3.9%	6.9%	20.6%	29.4%	39.2%	10.618	.019
	1	0.0%	11.1%	5.6%	5.6%	77.8%		
P16	0	2.0%	5.9%	23.5%	38.2%	30.4%	8.960	.044
	1	0.0%	5.6%	16.7%	11.1%	66.7%		
P17	0	4.9%	9.8%	25.5%	34.3%	25.5%	9.000	.042
	1	5.6%	11.1%	0.0%	33.3%	50.0%		
P18	0	4.9%	6.9%	19.6%	37.3%	31.4%	8.922	.042
	1	0.0%	0.0%	11.1%	16.7%	72.2%		
P19	0	2.9%	2.0%	18.6%	34.3%	42.2%	9.074	.039
	1	0.0%	5.6%	16.7%	5.6%	72.2%		
P21	0	3.9%	8.8%	13.7%	32.4%	41.2%	9.609	.030
	1	0.0%	0.0%	27.8%	5.6%	66.7%		

0: Participants residing outside Nevşehir, 1: Participants residing in Nevşehir

However, significant differences were also found in the evaluations of natural landscapes of both group. In particular, the responses of those living in Nevşehir were concentrated at the highest level of evaluation, especially in the wide-angle valley images (P9 and P10), in which fairy chimneys and undulating surface shapes on the slopes are concentrated. This may be attributed to the fact that local people who are familiar with the region can more easily perceive complex compositions with more landscape elements.

On the other hand, although both groups gave high scores to P2, which was taken from the balloon take-off area at sunrise and under relatively dark weather conditions, participants residing outside Nevşehir were more positive. This twilight image, in which balloons stand out more prominently than landforms, suggests that balloons constitute a more attractive element in the perception of the landscape for participants unfamiliar with the region.

In the evaluation made according to the level of finding the photographs "tranquil", statistically significant differences ($p<.05$) emerged between the participants living in Nevşehir and those not living in Nevşehir in the images numbered P1, P7, P8, P14, P15, P17 and P18 (Table 3). When the crosstabs are examined, it is seen that participants living in Nevşehir preferred the 'strongly agree' option more frequently in P1, P8, P14, P17 and P18 photographs compared to those who do not live in Nevşehir. In photograph P7, while both groups exhibited a positive approach, it is noteworthy that those who live in Nevşehir chose the 'strongly agree' option more often, while those who do not live in Nevşehir chose the 'agree' option more often. In the P15 image, it was determined that participants who do not live in Nevşehir were more likely to be undecided than those who live in Nevşehir. When the photographs are evaluated holistically, it can be said that local people perceive undulating surface forms and settlement silhouettes as more tranquil than other participants.

When the relationship between place of permanent residence and "attractiveness" responses was analyzed, a statistically significant difference was found only in photographs P15 and P17 ($p<.05$) (Table 4). In both photographs, those living in Nevşehir gave more positive responses. This difference is due to the fact that those living in Nevşehir chose the 'strongly agree' option in P17 and those not living in Nevşehir chose the 'undecided' option in P15. The findings suggest that the P17 photograph of the rock-carved pigeon nests, which give Güvercinlik Valley its name, was found to be more interesting by the people of the region, whereas these details escaped the attention of the participants outside the region. At the same time, since pigeon nests are part of the local cultural landscape, they may carry nostalgic or cultural meanings for local people. Similarly, image no.P15, which features undulating surface forms formed by erosion processes, was found to be more interesting by those living in Nevşehir, while participants outside the region were more ambivalent about this image.

When the responses to the excitement parameter were analyzed according to the place of permanent residence, a statistically significant difference was found in photographs numbered P12, P15 and P17 ($p<.05$) (Table 5). While the answers given by the participants residing in Nevşehir to these photographs were concentrated in the "agree" and "strongly agree" options, it was observed that the answers of the participants living outside the region were mostly concentrated in the "undecided" or negative options, especially for the images numbered P12 and P17.

The fact that these photographs, which were found more interesting by the locals, were also found more exciting points to a possible relationship between interest and excitement. In particular, the prominent silhouette of Ortahisar Castle in photograph P12 and the layered appearance of the rock-carved traditional structures integrated with the topography were effective in the excitement of this scene for the local participants.

Table 3.

Analysis results for the photographs showing a statistically significant difference in terms of tranquility

Photograph number	Place of residence	Place of residence x Tranquility					X^2	p
		Strongly disagree	Disagree	Neutral	Agree	Strongly agree		
P1	0	7.8%	17.6%	35.3%	26.5%	12.7%	15.809	.001
	1	16.7%	0.0%	22.2%	11.1%	50.0%		
P7	0	2.0%	3.9%	3.9%	34.3%	55.9%	9.417	.032
	1	5.6%	0.0%	11.1%	5.6%	77.8%		
P8	0	7.8%	17.6%	34.3%	19.6%	20.6%	8.861	.048
	1	16.7%	5.6%	11.1%	22.2%	44.4%		
P14	0	2.9%	9.8%	23.5%	34.3%	29.4%	11.476	.013
	1	5.6%	16.7%	11.1%	5.6%	61.1%		
P15	0	2.9%	4.9%	30.4%	36.3%	25.5%	9.817	.028
	1	11.1%	5.6%	5.6%	27.8%	50.0%		
P17	0	7.8%	13.7%	37.3%	30.4%	10.8%	12.581	.007
	1	11.1%	11.1%	11.1%	22.2%	44.4%		
P18	0	9.8%	16.7%	23.5%	31.4%	18.6%	9.829	.031
	1	5.6%	0.0%	27.8%	16.7%	50.0%		

0: Participants residing outside Nevşehir, 1: Participants residing in Nevşehir

Table 4.

Analysis results for the photographs showing a statistically significant difference in terms of attractiveness

Photograph number	Place of residence	Place of residence x Attractiveness					X^2	p
		Strongly disagree	Disagree	Neutral	Agree	Strongly agree		
P15	0	1.0%	7.8%	22.5%	35.3%	33.3%	10.186	.025
	1	11.1%	5.6%	0.0%	44.4%	38.9%		
P17	0	3.9%	18.6%	21.6%	41.2%	14.7%	13.017	.006
	1	11.1%	11.1%	5.6%	22.2%	50.0%		

0: Participants residing outside Nevşehir, 1: Participants residing in Nevşehir

The study also analyzed whether there is a difference in the perceptual evaluations of those who have visited Cappadocia before among the participants who do not reside in Nevşehir. The findings show that the fact that the participants have visited the region before does not have a significant effect on their evaluations in terms of scenic beauty and attractiveness.

However, a statistically significant difference was found only in photograph P1 in terms of being found peaceful (*p*=.020) (Table 6). P1 is an image of Uçhisar Castle, which is considered to be the largest fairy chimney in Cappadocia, and the traditional settlement texture on its skirts. This area is one of the most visited touristic spots in the region, and it is understood that the participants' previous experiences of this place reflected positively on their perceptions of tranquility.

There was a statistically significant correlation ($p<.05$) between the participants' having visited the Cappadocia Region and their finding photos P7 and P13 exciting (Table 7). Both images were taken from Kızılçukur Valley during sunset and represent one of the most visited areas of the region. Kızılçukur Valley stands out with its red-colored tuff rocks on the slopes, white undulating surface forms in the valley and the impressive view it offers to watch the sunset. The results show that this color contrast and visual impact evoke a sense of excitement in visitors.

Table 5.

Analysis results for the photographs showing a statistically significant difference in terms of excitement

Photograph number	Place of residence	Place of residence x Excitement					X^2	*p*
		Strongly disagree	Disagree	Neutral	Agree	Strongly agree		
P12	0	4.9%	10.8%	36.3%	27.5%	20.6%	9.034	.042
	1	11.1%	16.7%	11.1%	16.7%	44.4%		
P15	0	2.9%	11.8%	24.5%	34.3%	26.5%	9.311	.037
	1	16.7%	5.6%	5.6%	27.8%	44.4%		
P17	0	7.8%	21.6%	34.3%	25.5%	10.8%	17.439	.001
	1	16.7%	11.1%	0.0%	33.3%	38.9%		

0: Participants residing outside Nevşehir, 1: Participants residing in Nevşehir

Table 6.

The relationship between the participants' previous visits to Cappadocia and their finding the images tranquil

Photograph number	Visit	Visiting Cappadocia x Tranquility					X^2	*p*
		Strongly disagree	Disagree	Neutral	Agree	Strongly agree		
P1	0	4.2%	12.5%	50.0%	33.3%	0.0%	10.991	.020
	1	10.4%	15.6%	29.2%	21.9%	22.9%		

0: Participants who have not visited the Cappadocia Region, 1: Participants who have visited the Cappadocia Region

Table 7.

The relationship between the participants' previous visits to Cappadocia and their finding the images exciting

Photograph number	Visit	Visiting Cappadocia x Excitement					X^2	*p*
		Strongly disagree	Disagree	Neutral	Agree	Strongly agree		
P7	0	4.2%	4.2%	29.2%	29.2%	33.3%	10.456	.022
	1	2.1%	9.4%	6.3%	28.1%	54.2%		
P13	0	12.5%	12.5%	37.5%	8.3%	29.2%	9.050	.047
	1	8,3%	8,3%	15,6%	28,1%	39,6%		

0: Participants who have not visited the Cappadocia Region, 1: Participants who have visited the Cappadocia Region

Discussion

This study aimed to examine the impact of different natural and cultural landscapes of the Cappadocia Region on people's perceptions; participant evaluations were analyzed especially in the dimensions of scenic beauty, tranquility, attractiveness and excitement. The findings revealed that both natural and cultural landscape elements of Cappadocia created a strong visual and emotional impact on the participants. This finding shows parallelism with the findings of Mangone et al. (2021) and Petrova et al. (2015) that landscapes with distinctive features can be strongly preferred regardless of familiarity or geographical origin. This suggests that some specific landscapes may have some universal (transcultural, common) concepts about landscape aesthetics.

However, it was observed that participants liked natural landscapes more than cultural landscapes. Among the cultural landscapes, images with dominant natural elements (rivers and trees) received the highest scores in terms of scenic beauty and tranquility. As a matter of fact, it is emphasized in the literature that water surface and vegetation cover are elements that both increase visual quality (Bulut & Yılmaz, 2009; Irmak & Yılmaz, 2010; Sezen et al., 2015) and create psychologically tranquil effects (Chang, 2004; Sakıcı, 2023).

When the natural and cultural landscape components and the characteristics of the images were evaluated, it was observed that the photographs of hot air balloons, fairy chimneys and unique surface shapes, which are symbolic elements of the region, especially those taken at sunrise or sunset, received the highest scores in aesthetic perception. The visual composition formed by light, texture and geomorphological structure was decisive in the aesthetic evaluations of the participants. This finding coincides with the literature that light and color changes in the atmosphere at sunrise and sunset (Smalley & White, 2023), the presence of effective color (Özhancı, 2021), topographic structure and geological formations (Tessema et al., 2021) strengthen the perception of landscape.

In the analyses to determine the familiarity effect in the perceptual evaluations of the participants, the place of residence (both the perception of local people towards the environment and the view of foreign landscapes of individuals living in different regions) and the experience of visiting the region were taken into consideration. In this context, the responses of individuals from coastal settlements with different geographical characteristics from the Central Anatolia Region, where the research area is located, were evaluated. The findings show that there is no significant relationship between the participants' city of residence and their perceptions of Cappadocia.

On the other hand, the data obtained in the context of permanent residence revealed that local people familiar with Cappadocia perceived the landscapes more detailed, spatially meaningful and positive. This positive perception was particularly evident in the dimensions of scenic beauty and tranquility. For example, participants residing in Nevşehir rated cultural landscapes higher than other groups, suggesting that both visual familiarity and cultural ties influence perceptual evaluation. This supports the findings of Petrova et al. (2015) on the influence of cultural background on landscape perception.

Six of the eight images with statistically significant differences in landscape beauty evaluations belong to cultural landscapes (settlement texture, rock-carved structures and fairy chimneys with cultural traces), while two of them belong to wide-angle natural landscapes. In particular, images with complex surface forms and wide valleys were rated higher by participants familiar with the region, suggesting that these individuals have more detailed visual discriminations. This finding is consistent with the findings of Tenerelli et al. (2017) on the role of individual and environmental variables in the evaluation of aesthetic services. It is understood that in order for visual complexity to be transformed into aesthetic value, the observer must have information about the environment.

The effects of spatial familiarity are manifested not only in aesthetic judgments, but also in environmental preferences and psychological processes. According to the findings of the study, local people are more likely to find images more tranquil than other participants. This effect is particularly evident in undulating surface forms and traditional settlements. The results reveal that environmental familiarity has the potential to create a sense of tranquility in individuals.

Two images (P15 and P17) showed significant differences in the parameters of tranquility, attractiveness and excitement according to place of residence. The physical characteristics (color, texture, form) and cultural traces of these images created a multidimensional perception on local participants. It can be explained by the fact that the local people see such landscapes as a source of tranquility and find them exciting and intriguing through the cultural and historical layers they contain. This reveals that the sense of spatial belonging can be integrated into aesthetic perception. Indeed, Li et al. (2023) have stated that tourists' perceptions are influenced by natural and cultural landscapes, while the perceptions of local people are shaped by their familiarity with their surroundings.

The visit history variable had a limited effect on visual perception. Only one image in terms of tranquility and two images in terms of excitement gained special meaning depending on the visit history. This suggests that some spatial experiences may leave deep and long-lasting emotional traces in individuals.

As a result, both environmental factors (light, color, topography, landscape diversity) and individual/cultural variables (place of residence, familiarity, cultural connection) were effective in the perceptual evaluation of the natural and cultural landscapes of the Cappadocia Region. The region has been found to be highly visually appealing, particularly due to the combination of hot air balloons and geomorphological formations, as well as the impressive sunsets and sunrises. Visual perception is an important component of tourism and recreation activities. In this context, the findings provide important scientific-based clues for tourism planning and presentation strategies in Cappadocia. Integrating individuals' perceptual tendencies and different perspectives into planning processes, especially in areas with special protection status, will contribute to a more effective and inclusive management approach. Therefore, considering that local people and visitors may have different perspectives, the protection of local values and the enhancement of the visitor experience should be ensured in a balanced manner.

Peer-review: Externally peer-reviewed.
Ethics Committee Approval: Ethics committee approval was obtained from Nevşehir Hacı Bektaş Veli University Scientific Research and Publication Ethics Committee (Date: 05.02.2025, Number:2025.01.25)
Informed Consent: Verbal consent was obtained from the participants.
Conflict of Interest: The author have no conflicts of interest to declare.
Financial Disclosure: This study was supported by Research Fund of the Nevşehir Hacı Bektaş Veli University (Project Number: HDP24F02).

Hakem Değerlendirmesi: Dış bağımsız.
Etik Komite Onayı: Etik kurul onayı Nevşehir Hacı Bektaş Veli Üniversitesi Bilimsel Araştırmalar ve Yayın Etik Kurulu'ndan (Tarih: 05.02.2025, Sayı:2025.01.25) alınmıştır.
Katılımcı Onamı: Katılımcılardan sözlü onam alınmıştır.
Çıkar Çatışması: Yazar çıkar çatışması olmadığını beyan etmiştir.
Finansal Destek: Bu çalışma Nevşehir Hacı Bektaş Veli Üniversitesi Bilimsel Araştırma Projeleri Koordinasyon Birimince desteklenmiştir (Proje Numarası: HDP24F02).

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ATATÜRK ÜNİVERSİTESİ YAYINLARI
ATATURK UNIVERSITY PUBLICATIONS

Research Article *Araştırma Makalesi* DOI: 10.17097/agricultureatauni.1716924

First Record of *Dreissena caputlacus* (Schütt, 1993) and *Dreissena polymorpha gallandi* (Locard, 1893) in Çamlıgöze Dam Lake (Sivas, Türkiye) and Evaluation of Some Biometric Parameters

Çamlıgöze Baraj Gölü'nde (Sivas, Türkiye) *Dreissena caputlacus* (Schütt, 1993) ve *Dreissena polymorpha gallandi* (Locard, 1893)'nin İlk Kaydı ve Bazı Biyometrik Parametrelerin Değerlendirilmesi

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ABSTRACT

In this study, the presence and biometric characteristics of *Dreissena caputlacus* (Schütt, 1993) and *Dreissena polymorpha gallandi* (Locard, 1893) populations were determined in Çamlıgöze Dam Lake. Shell length (SL), shell height (SH), shell width (SW) data of individuals collected in the study area were used with a digital caliper; The weights of individuals (W) were determined using precision scales. The means of SL, SW, SH and W in *D. caputlacus* and *D. polymorpha gallandi* were determined as 22.66±4.33 and 30.03±3.17 mm, 15.88±4.16 and 14.54±1.46 mm; 13.37±2.85 and 14.51±1.41 mm; 94±1.12 and 3.29±0.95 g, respectively. According to principal component analysis, there was a strong relationship between SH, SW, SL and W for both species. For *D. caputlacus* and *D. polymorpha gallandi*, 82.283% and 94.502% of the total variance was explained by two principal components. *D. caputlacus* and *D. polymorpha gallandi* populations from Çamlıgöze Dam Lake were reported for the first time in this study.

Keywords: Çamlıgöze dam lake, *Dreissena caputlacus, Dreissena polymorpha gallandi*

ÖZ

Bu çalışmada, Çamlıgöze Baraj Gölü'nde dağılım gösteren *Dreissena caputlacus* (Schütt, 1993) ve *Dreissena polymorpha gallandi* (Locard, 1893) türlerinin varlığı ve biyometrik özelliklerinin belirlenmesi amaçlanmıştır. Çalışma alanında toplanan bireylere ait kabuk uzunluğu (KU), kabuk yüksekliği (KY), kabuk genişliği (KG) verileri dijital kumpas ile; bireylerin ağırlıkları (A) hassas terazi kullanılarak belirlenmiştir. *D. caputlacus* ve *D. polymorpha* gallandi'de KU, KG, KY ve A ortalamaları sırasıyla 22,66±4,33 ve 30,03±3,17 mm; 15,88±4,16 ve 14,54±1,46 mm; 13,37±2,85 ve 14,51±1,41 mm; 1,94±1,12 ve 3,29±0,95 g olarak belirlenmiştir. Temel bileşenler analizine göre, her iki tür için kabuk yüksekliği, kabuk genişliği, kabuk uzunluğu ve ağırlık arasında güçlü bir ilişki olduğu belirlenmiştir. *D. caputlacus* ve *D. polymorpha gallandi* için toplam varyansın %82,283 ve %94,502'luk kısmının iki temel bileşen tarafından açıklanmıştır. Çamlıgöze Baraj Gölü'nden *D. caputlacus* ve *D. polymorpha gallandi* populasyonları bu çalışma ile ilk kez rapor edilmiştir.

Anahtar Kelimeler: Çamlıgöze baraj gölü, *Dreissena caputlacus, Dreissena polymorpha gallandi*

Received Date:	25.06.2025
Revision Request Date:	27.07.2025
Last Revision Date:	05.08.2025
Accepted Date:	12.08.2025
Publication Date:	26.09.2025

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Cite this article: Kara, C., Kutluyer Kocabai, F., Kocabaş, M., Bozali, N., & Gürlek, M. E. (2025). First Record of *Dreissena caputlacus* (Schütt, 1993) and *Dreissena polymorpha gallandi* (Locard, 1893) in Çamlıgöze Dam Lake (Sivas, Türkiye) and Evaluation of Some Biometric Parameters. *Research in Agricultural Sciences, 56*(3), 212-216

Introduction

Anatolia has an important position in the paleoarctic region in terms of biological resources, as it is a peninsula rich in species diversity. Although Türkiye does not have large internal water resources, it has a rich habitat and species diversity due to paleogeographic developments and hydrogeographic connections. However, this situation is also suitable for exotic and invasive species (Yıldırım et al. 2019; 2023).

Species belonging to the genus Dreissena are among the most common invasive invertebrates in Türkiye's inland waters. In addition to the suitability of many inland waters for this genus, fishing activities and the lack of adequate controls have allowed individuals of this genus to easily invade new areas. Although there is a consensus on the invasiveness of Dreissena, there are different opinions about which species of Dreissena are invasive (Geldiay & Bilgin, 1973; Yıldırım et al., 2019; Yıldız et al., 2018).

In recent molecular phylogenetic studies, *Dreissena* has been divided into three subgenera: *Dreissena, Pontodreissena* and *Carinodreissena*. These include *Pontodreissena*, *D. caputlacus* and *D. rostriformis* species. *D. caputlacus* is widespread in Türkiye. The subgenus Carinodreissena includes the taxa D. carinata and D. blanci; both live in ancient lakes on the Balkan Peninsula. However, there is no record of its distribution in Türkiye. The subgenus *Dreissena* is represented by two subspecies: *D. polymorpha anatolica* and *D. polymorpha gallandi*. *D. polymorpha anatolica* is endemic to lakes in southern Türkiye near the northern Mediterranean coast. *D. polymorpha gallandi* is of Pontocaspian origin and is known to be widely distributed in most of Eurasia and North America (Gelembiuk et al., 2006). In studies conducted in Türkiye to date*, D. caputlacus, D. p. anatolica* and *D. p. gallandi* taxa have been reported to be widespread (Gürlek et al., 2019).

Çamlıgöze Dam Lake is located in Suşehri district of Sivas province. The dam lake was built between 1987 and 1998 for irrigation, energy production and flood control. The lake area is 5 km^2 and the maximum depth is 30 m. The average annual energy production in the lake is 102 GWh/year (Aydoğar, 2004; Dirican & Musul, 2009). This study is the first scientific report on the population of *D. caputlacus* (Schütt, 1993) and *D. p. gallandi* (Locard, 1893) living in Çamlıgöze Dam Lake and some of their biometric characteristics.

Methods

D. caputlacus (n: 30) and *D. p. gallandi* (n: 60) used in the study were sampled from Çamlıgöze Dam Lake (Sivas) (x: 424471.02 y: 4455477.23) (x,y coordinate: WGS_1984_UTM_Zone_37N (6°) (Figure 1) in August 2024.

Metal framed scoops and shovels were used in suitable places to collect samples; rakes were used for screening and individuals were collected by hand from sand and silt areas up to 1 m water depth. In addition, samples were collected by diving in deeper areas (at depths of 10-15 m) (Figure 2), and then the samples were stored in styrofoam boxes at +4°C. Identification of the collected species was performed by comparing them with descriptions and drawings of different *Dreissena* species available in the literature (Yıldırım et al., 2023).

Shell measurements [shell length (SL), shell height (SH) and shell width (SW))] were made with a digital caliper (±0.01 mm) (Figure 3), and weight (W) measurements were made with a precision scale (±0.001 g). The formula W=a*Lb and its logarithmic transformation (log(W)=a+b*log(L)) were used to calculate length-weight relationships.

Microsoft Excel® was used to analyze and process the data. Principal component analysis (PCA) was performed using PAST4.03 software to explore the relationships between the variables

Figure 1.
Çamlıgöze Dam Lake.

Figure 2.
Sample collection.

Figure 3.
a. Dreissena caputlacus b. Dreissena polymorpha gallandi.

Results and Discussion

D. caputlacus was described from Adıyaman Gölbaşı Lake and it was characteristically known with transverse stripes on it (Schütt, 1993). As a feature of the Family, there is no tooth protrusion on the hinge that keeps the shells together, there is an elastic hinge bond that connects the shells together. It is one of the endemic mussel species of Türkiye. It has also been determined that the species is widespread in Menzelet Dam Lake, Almus Dam Lake (Tokat) and Kartalkaya Dam Lake (Kahramanmaraş) while it was previously known in the Seyhan River, Seyhan Dam, Sır Dam Lake, Kurtağılı Dam Lake (Yozgat), Probably the center of evolution of the species is Gölbaşı Lake, which is the type locality. For the higher temperatures, living examples of the species can only be found in the coastal zone during the summer months. However, quite dense and large populations of the species are found in lakes and ponds that have hydrogeographic connections with Gölbaşı Lake. They show a biofouling effect in energy production systems, especially in the Ceyhan dam lake (Yıldırım et al., 2023). *D. polymorpha gallandi* is found in regions close to the sea (Marmara and Black Sea) in Türkiye. Although they are very similar to the nominal subspecies *D. polymorpha polymorpha*, they differ in their zoogeographical features and thinner and more shaped structures. In current study, the presence of *D. caputlacus* and *D. polymorpha gallandi* in Çamlıgöze Dam Lake (Sivas, Türkiye) was revealed for the first time.

In this study, the mean of SL, SW, SH and W in *D. caputlacus* and *D. polymorpha gallandi* were determined as 22.66±4.33 and 30.03±3.17 mm; 15.88±4.16 and 14.54±1.46 mm; 13.37±2.85 and 14.51±1.41 mm; 1.94±1.12 and 3.29±0.95 g. respectively. Akkuş et al. (2019) reported in their study in Van Province Sarımehmet Dam Lake that the largest shell length and weight values in *D. polymorpha* were 43.74 mm and 9.85 g. Kocabaş and Kutluyer Kocabaş (2021) reported that the mean of SL, SW, SH and W in *D. polymorpha* population obtained from Demirköprü Dam Lake was 30.48±5.40, 14.48±2.33, 14.72±3.02 and 5.19±0.94 (2.38-7.47 g), respectively. In this study, the highest values of SL and W were determined as 36.34 mm and 4.96 g. The decrease of water level in Çamlıgöze Dam Lake has negatively affected the living environments of mussels, so it is expected that the W values will be reduced as a result of the presence of nutrients in the environment and changing water parameters (Akkuş et al., 2019). The mechanisms underlying the introduction of *Dreissena polymorpha* (zebra mussel) into the dam ecosystem remain uncertain; however, anthropogenic vectors are strongly implicated. This invasive bivalve species, which sustains itself by filtering suspended particulate matter and nutrients from the water column, may have been inadvertently transported via aquaculture-related activities (Haltiner et al., 2023; Karatayev et al., 2015; Yıldırım et al., 2023). Specifically, the use of boats for the translocation of cultured fish between aquatic systems is considered a probable pathway for its spread (Akkuş et al., 2019; Bobat et al., 2002; Schall, 2019). A precedent for such introduction exists in the case of North American freshwater ecosystems, where zebra mussels were first introduced through the discharge of ballast water from transoceanic vessels (Bobat et al., 2004). Moreover, the species' capacity to survive extended periods in moist, non-submerged environments further enhances its potential for passive dispersal across regions (Bobat et al., 2002; Bobat et al., 2004; DSİ, 2005).

Kocabaş and Kutluyer (2021) used Bartlett's test and KMO to verify the usefulness of Principal component analysis (PCA) and reported that PCA was useful in summarizing the correlation matrix (KMO=0.79). and Bartlett's test data were determined to be significant (p=.000; p<.001) in *D. polymorpha* population in Demirköprü Dam Lake. They determined that 94.379% of the total variance in *D. polymorpha* was explained by two principal components and there was a strong relationship among SL, SW, SH and W. Similarly, in this study, 82.283% of the total variance in

D. polymorpha gallandi and 94.502% in *D. caputlacus* were explained by two principal components, useful in summarizing the correlation matrix ($KMO_{D. polymorpha gallandi}$=0.711; $KMO_{D. caputlacus}$=0.83) and Bartlett's test data were determined to be significant (*p*=.000; *p*<.001). Therefore, PCA was useful, and the variables are interrelated. In addition, there was a strong relationship among SL, SW, SH and W for both species (Figures 4 and 5).

Figure 4.
Principal components analysis of variables [Shell length (SL), Shell height (SH), Shell width (SW) and Weight (W)]; D. polymorpha gallandi.

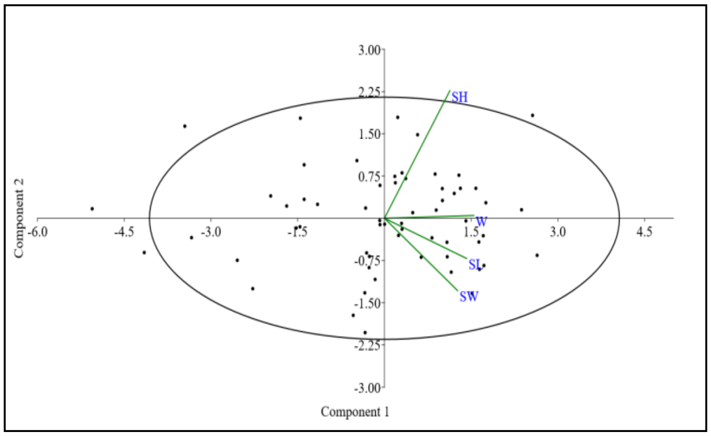
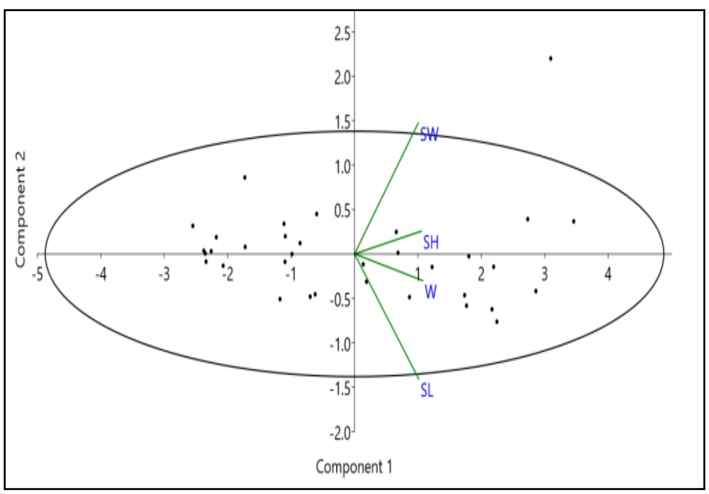


Figure 5.
Principal components analysis of variables [Shell length (SL), Shell height (SH), Shell width (SW) and Weight (W)]; D. caputlacus.



Kocabaş and Kutluyer (2021) reported that there was a strong correlation between shell length-shell width, shell length-shell height, shell width-shell height, shell width-weight and shell height-weight in *D. polymorpha*. In this study, there was a strong correlation between shell length-shell width and shell length-weight in the D. polymorpha gallandi (Table 1). In *D. caputlacus*, there was a strong correlation between shell length-shell width, shell length-shell height, shell length-weight, shell width-shell height, shell width-weight and shell height-weight (Table 2).

Table 1.
Correlation matrix between measured parameters for D. p. gallandi. parameters for D. caputlacus.

Variables	SL	SW	SH	W
SL		0.521	0.368	0.749
SW	0.521		0.310	0.579
SH	0.368	0.310		0.558
W	0.749	0.579	0.558	

Table 2.
Correlation matrix between measured parameters for D. caputlacus.

Variables	SL	SW	SH	W
SL		0.727	0.807	0.880
SW	0.727		0.834	0.829
SH	0.807	0.834		0.916
W	0.880	0.829	0.916	

Conclusion and Recommendations

In conclusion, habitat and physiological conditions can influence the shell calcification process and morphometric parameters during maturation, growth and reproduction, as well as the growth, morphology and relative proportions of Mollusca shells. This finding regarding the reporting of *D. caputlacus* and *D. polymorpha gallandi* in Çamlıgöze Dam Lake indicates the presence of a stable population for the native Mollusk fauna of this species. Invasion of dam areas by zebra mussels will pose a major problem for the reproductive migration of fish species in the environment. Therefore, it is necessary to prevent transporting of the zebra mussel from Çamlıgöze Dam to other streams and lakes by taking precautions.

Peer-review: Externally peer-reviewed.
Ethics Committee Approval: Since the species included in the study is an invertebrate, approval from the Local Animal Research Ethics Committee is not required.
Author Contributions: Concept –C.K.; Design- C.K.; Supervision- C.K.; Resources- C.K.; Data Collection and/or Processing- C.K., F.K.K., M.K., N.B.; Analysis and/or Interpretation- C.K., F.K.K., M.K., M.E.G.; Literature Search- F.K.K., M.K.; Writing Manuscript- F.K.K., M.K., N.B., M.E.G.
Conflict of Interest: The authors have no conflicts of interest to declare.
Financial Disclosure: This research was funded by Scientific Research Project Coordination Unit of Karadeniz Technical University (Project number: FBA-2023-10937).

Hakem Değerlendirmesi: Dış bağımsız.
Etik Komite Onayı: Çalışmada yer alan tür, omurgasız olduğundan Hayvan Araştırmaları Yerel Etik Kurulu onayı gerekmemektedir.
Yazar Katkıları: Fikir- C.K.; Tasarım- C.K.; Denetleme- C.K.; Kaynaklar- C.K.; Veri Toplanması ve/veya İşlemesi- C.K., F.K.K., M.K., N.B.; Analiz ve/ veya Yorum- C.K., F.K.K., M.K., M.E.G.; Literatür Taraması- F.K.K., M.K.; Yazıyı Yazan- F.K.K., M.K., N.B., M.E.G.
Çıkar Çatışması: Yazarlar çıkar çatışması olmadığını beyan etmiştir.
Finansal Destek: Bu araştırma, Karadeniz Teknik Üniversitesi Bilimsel Araştırma Projeleri Koordinasyon Birimi tarafından finanse edilmiştir (Proje numarası: FBA-2023-10937).

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ATATÜRK ÜNİVERSİTESİ YAYINLARI
ATATURK UNIVERSITY PUBLICATIONS

Research Article *Araştırma Makalesi* DOI: 10.17097/agricultureatauni.1665941

Guava Fruit Disease Classification Using Deep Learning and Machine Learning Models

Derin Öğrenme ve Makine Öğrenmesi Modelleri Kullanarak Guava Meyvesi Hastalıklarının Sınıflandırılması

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ABSTRACT

This study presents a classification approach for guava fruit diseases using both deep learning and machine learning models. InceptionV3 was employed to extract image features, which were subsequently classified using models such as artificial neural networks support vector machines, k nearest neighbors, random forest, and decision tree. The performance of the models was evaluated in terms of accuracy, F1 score, precision, and recall. Experimental results demonstrate that SVM and ANN achieved the highest performance, with SVM reaching 0.9974 across all metrics and ANN achieving 0.9958. The kNN model also performed well with an accuracy of 0.9924, while random forest and decision tree obtained lower accuracies of 0.9612 and 0.9209, respectively. Confusion matrix analysis further confirmed the superiority of SVM and ANN, with minimal misclassifications across anthracnose, fruit fly, and healthy guava categories. These findings highlight the effectiveness of deep learning-based feature extraction combined with SVM and ANN classifiers for reliable and accurate detection of guava fruit diseases.

Keywords: Agricultural technology, Deep learning, Guava disease classification, Machine learning

ÖZ

Bu çalışma, guava meyvesi hastalıklarının sınıflandırılmasına yönelik olarak derin öğrenme ve makine öğrenmesi modellerini bir arada kullanan bir yaklaşım sunmaktadır. Görüntü özelliklerinin çıkarılması için InceptionV3 kullanılmış, elde edilen bu özellikler yapay sinir ağları, destek vektör makineleri, en yakın k-komşu, rastgele orman ve karar ağacı gibi modeller aracılığıyla sınıflandırılmıştır. Modellerin performansı doğruluk, F1 skoru, kesinlik ve duyarlılık ölçütleri açısından değerlendirilmiştir. Deneysel sonuçlar, en yüksek başarımın SVM ve ANN modelleri tarafından elde edildiğini göstermektedir. Buna göre SVM tüm metriklerde 0,9974, ANN ise 0,9958 değerine ulaşmıştır. kNN modeli de 0,9924 doğruluk ile yüksek bir performans sergilerken, rastgele orman ve karar ağacı modelleri sırasıyla 0,9612 ve 0,9209 doğruluk oranlarına ulaşmıştır. Karışıklık matrisi analizi de SVM ve ANN'in üstünlüğünü doğrulamış, antraknoz, meyve sineği ve sağlıklı guava kategorilerinde minimal yanlış sınıflandırmalar gözlemlenmiştir. Bu bulgular, derin öğrenme tabanlı özellik çıkarımının SVM ve ANN sınıflandırıcıları ile birleştirilmesinin, guava meyvesi hastalıklarının güvenilir ve yüksek doğrulukla tespiti için etkin bir yöntem olduğunu ortaya koymaktadır.

Anahtar Kelimeler: Tarım teknolojisi, Derin öğrenme, Guava hastalığı sınıflandırması, Makine öğrenmesi

This work is an extended version of our conference paper titled "Classification of Guava Diseases Using Features Extracted from Squeezenet with Adaboost and Gradient Boosting", presented at the 4th International Conference on Frontiers in Academic Research.

Received Date:	26.03.2025
Revision Request Date:	03.08.2025
Last Revision Date:	18.08.2025
Accepted Date:	01.09.2025
Publication Date:	26.09.2025

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Cite this article: Kilci, O., & Koklu, M. (2025). Guava Fruit Disease Classification Using Deep Learning and Machine Learning. *Research in Agricultural Sciences, 56*(3), 217-226.

Introduction

Guava is a tropical fruit native to Mexico, Central America and northern South America. Rich in nutrients such as antioxidants, vitamin C, lycopene, potassium and fiber, guava is beneficial for skin health and helps increase fertility. It is native to Central America and South America and grows naturally in Brazil, Mexico and the Caribbean. Today, it has a wide production area in different continents such as Asia, Africa and Oceania.

It is also an agriculturally and commercially important crop, widely used as juice, jam and food supplements. However, the guava plant is threatened by various fungal, bacterial and viral diseases. These diseases cause deformations of leaves, fruits and stems, leading to reduced productivity and economic losses. Traditional disease diagnosis methods are time-consuming and often require expert supervision. For disease diagnosis and classification, image processing and machine learning techniques have been widely used in agriculture. With the advancement of technology, image processing and machine learning methods have become important tools for early detection of such diseases. To classify guava plant diseases, various machine learning algorithms were utilized. In particular, analyzing visual data for early detection of guava diseases is an important step in reducing production losses. The goal of the study is to improve the treatment of diseases in agriculture. The novelty of this study lies in the integration of a lightweight deep learning architecture InceptionV3 with high-performing traditional classifiers ANN and SVM. This hybrid approach has been scarcely explored in the literature for guava disease detection and contributes significantly in terms of efficiency and accuracy.

Related Works

Mostafa et al. (2021) utilized computer vision and deep learning for guava disease diagnosis, enhancing data with color histogram equalization and unsharp masking, and applying 360° image augmentation. They classified using AlexNet, SqueezeNet, GoogLeNet, ResNet-50, and ResNet-101, with ResNet-101 achieving 97.74% accuracy.

Asim et al. (2023) used machine vision and machine learning techniques to classify 12 different guava varieties. They extracted 47 multiple features including histogram, texture and spectral features and selected 18 features with the best search algorithm. They applied instant base identifier, random forest and meta bagging classifiers and tested IBI with 93.00%, RF with 90.03% and meta bagging with 82.75% accuracy. They obtained the highest accuracy rate with IBI.

Almutiry et al. (2021) developed an image processing framework for the detection of major diseases in guava plants. They selected four different guava plant diseases: anthracnose, algal blotch, fruit flies and style fly rot. Image processing techniques were applied using feature extraction with Local Binary Pattern (LBP) and dimensionality reduction with Principal Component Analysis (PCA). The bagged tree classifier provided 95.7%, 95.9%, 94%, 95.7% and 100% accuracy rates for anthracnose, algal blotch, style fly rot, and fruit flies, respectively.

Doutoum et al. (2023) developed a deep learning-based method for detecting and predicting guava leaf diseases. The study used 1834 leaf samples to model four different pre-trained Convolutional Neural Network (CNN) architectures. A 94.93% accuracy rate was obtained for the EfficientNet-B3 model. Detection and control of disease in guava leaves was found to be feasible using the model.

Jain et al. (2023) developed a deep learning model to detect diseases in guavas. The model was trained on 6000 images using CNN and Long Short-Term Memory (LSTM) algorithms. It could detect leaf spot, guava rust, and guava cancer in guava fruit Testing showed 98.26% accuracy for guava cancer, with 95.90% accuracy for other cancers.

Toptas and Guven (2024) developed a deep learning-based classification system for guava fruit. GoogleNet, Vgg19, ResNet50 and DenseNet201 were used as pre-trained CNNs. They used the k-fold-stratified method and 80:20 separation to train and test 2309 images. DenseNet201 was found to be the most accurate model with 96.58% success.

Farisqi and Prahara (2022) applied a mask region-based convolutional neural network (R-CNN) based method to automatically detect and classify guava fruits. The study developed a computer vision system for segmenting and classifying four different guava species commonly found in Indonesia. Their dataset consisted of 616 training, 264 validation, and 200 test data. The proposed method achieved 90% mAP, 88% mAR, and 89% F1 Score. It was shown that the model could detect and classify guava fruit accurately.

Al Haque et al. (2019) developed a computer vision-based system to detect guava disease. Images of diseases like anthracnose, fruit rot, and fruit canker were collected from various parts of Bangladesh. They used three different the best CNN model had an accuracy of 95.61 based on three different CNN models.

Table 1 presents a compilation of previous methods for the classification of guava and various plants. The table includes the datasets used, the methods and techniques applied, and the accuracy rates obtained. The number of images and the number of classes used in each study varies. In previous research, different deep learning methods have been tried for the classification of guava and other plant groups, and their accuracy rates have been reported. In the future, it is recommended to apply different artificial intelligence approaches to achieve higher accuracy rates.

Table 1.
Sucess of Different Methods in Plant Classification

Methods	Dataset Type	Dataset Class	Accuracy	Reference
DenseNet	Guava leaf	5 classes 527 images	98.76%	(Kaur et al., 2024)
Inception CNN	Guava leaf	4 classes 120 images	85%	(Foo et al., 2024)
CNN, AI	Guava fruit and leaf	7 classes 5281 images	Class-4: 93.52%, Class-7: 65.72%	(Chouhan et al., 2024)
Inception CNN	Guava fruit	4 classes 166 images	94.11%	(Putra & Prabowo, 2024)
SqueezeNet	Guava	4 classes 3784 images	95.6%	(Kilci & Koklu, 2024)
CNN	Guava fruit and leaf	4 classes 306 images	74.73%	(Ahmed et al., 2024)
CNN	Guava wilt	3 classes 1420 images	95.17%	(Mirjat et al., 2024)
Hybrid CNN (Efficient Net + DenseNet)	Guava leaf	4 classes	94.7%	(Rana et al., 2024)
CNN	Mango, African almond, Guava, Avocad, Cashew	5 classes 1000 images	91%,	(Irhebhude et al., 2024)
SVM	Onobrychis fruit	4 classes 448 images	99.6%	Kızgın et al., 2023
AlexNet-based CNN	Guava fruit	5 classes 612 images	93%	(Hashan et al., 2024)
Random Forest & CNN	Papaya leaf diseases	6 classes 5080 images	94.44% 96.22%	(Mir et al., 2024)
DenseFusion CNN (DFNet)	Corn and coffee leaf diseases	Corn 4 classes 4188 images Coffe 3 classes 1078 images	Corn: 97.53%, Coffee: 94.65%	(Faisal et al., 2024)
VGGNet-16	Guava ripeness	3 classes 336 images	92%	(Low et al., 2024)
SVM	Guava leaf	3 classes 70 images	98.17%	(Perumal et al., 2021)

To provide a clear overview of the significance and scope of the present study, the main contributions are outlined below:

- A novel framework integrating InceptionV3 based feature extraction with various machine learning classifiers is developed.
- Superior performance of SVM and ANN models is demonstrated in guava disease classification.
- A comparative analysis with traditional models such as random forest and decision tree is provided.

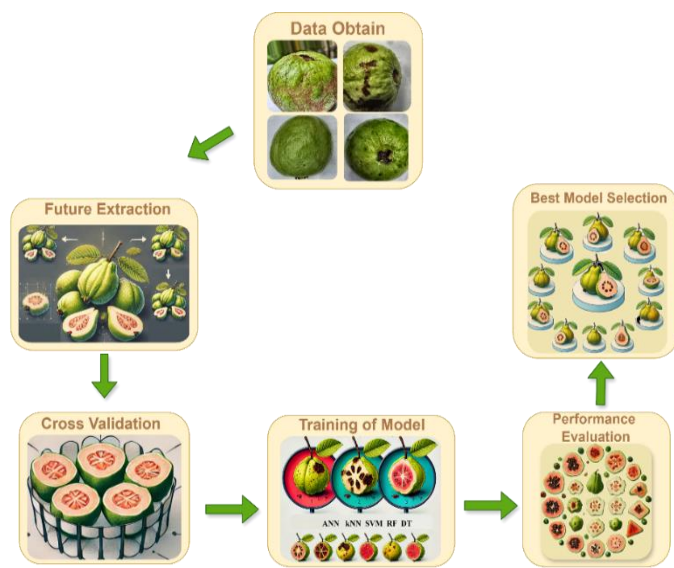
The practical applicability of the model for early disease detection in agricultural settings is emphasized.

Methods

Guava plant diseases were classified using deep learning and machine learning algorithms. The Guava Fruit Disease Dataset was used. First, deep learning models were applied, and the InceptionV3 model was used to extract features. Next, the images were processed and classified into three disease categories using the InceptionV3 model. Finally, a cross-validation method was used to check the model's performance. Five different machine learning algorithms were then used to classify diseases based on the InceptionV3 model. The study's workflow is shown in Figure 1.

Figure 1.

Flow chart for the classification of guava fruit diseases



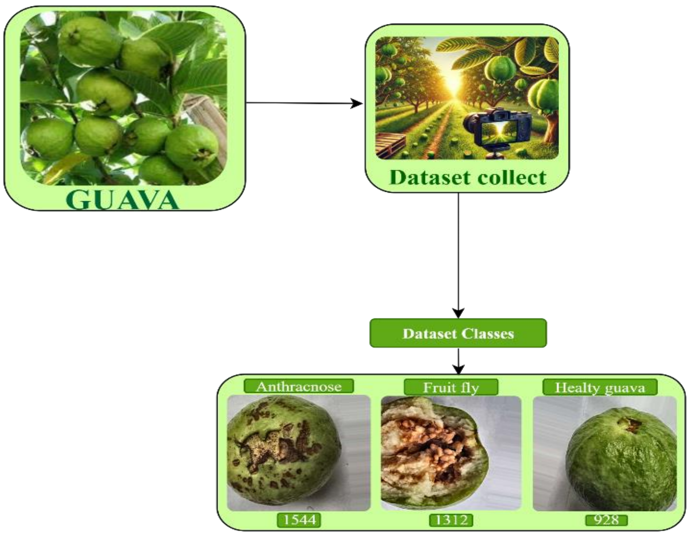
Dataset

This study uses a dataset of 473 RGB images of the plant species *Psidium Guajava*, obtained from the Mendeley data platform. These images were categorized into three different categories; anthracnose (fungal infection), fruit flies (pest damage) and healthy fruits. The dataset contains 1.544 anthracnose, 1.312 fruit flies and 928 healthy fruits images, respectively (Amin, 2024).

In the preprocessing stage, techniques such as sharpening and contrast limited adaptive histogram equalization were applied on the images. Afterwards, data augmentation methods were used to increase the total number of images to 3.784. All images have a resolution of 512 x 512 pixels and are stored in PNG format. The workflow of the dataset preparation process is illustrated in Figure 2.

Figure 2.

Guava fruit disease dataset



InceptionV3

InceptionV3, a renowned deep convolutional neural network, incorporates convolution factorization, auxiliary classifiers for regularization, and batch normalization (Szegedy et al., 2017). This innovative approach enhances computational efficiency, decreases parameter count, and preserves or enhances accuracy by the intentional aggregation of multi-scale features in the inception module (Chollet, 2017; Cinar et al., 2020). These modules enable the network to amalgamate outputs from several convolutional levels (e.g., 1x1, 3x3, and 5x5) to provide a more comprehensive representation of the image (Szegedy et al., 2017). The network necessitates input dimensions of 299x299 pixels, demanding meticulous preparation for compatibility and maximal efficacy (Szegedy et al., 2016). Standardizing input dimensions is crucial as the network's filters and pooling layers are engineered to operate on feature maps derived from this resolution, so assuring uniform information transmission across its deep architecture. In contrast to older, less efficient topologies, the network employs symmetric and asymmetric convolutions to optimize computational cost while maintaining representational efficacy (Larsson et al., 2016). Residual connections and batch normalization layers reduce the architecture's depth, hence enhancing image classification performance (Cinar & Koklu, 2021; Szegedy et al., 2017).

Machine Learning Algorithms

K nearest neighbors

The k nearest neighbor method (kNN) is an easy to use method among supervised learning models for problems such as classification and regression. A kNN classifier new data by analyzing the K nearest neighbors (Koklu & Sabanci, 2016). Euclidean, Manhattan, and other distance measures are used to determine the neighbors, and majority voting is used in classification. A parametric model does not learn during training; it stores and calculates data during prediction but does not learn during training.

Random forest

Random forest (RF) is a machine learning model used to classify and predict data. A majority vote or average is taken for prediction based on an ensemble of decision trees (Kilci et al., 2024). Due to random sampling and feature selection, it is robust to overfitting. Feature importance can be inferred from large and complex datasets using this method (Paul et al., 2018).

Support vector machine

The Support Vector Machine (SVM) is a powerful model for solving linear and non-linear classification problems. Data is classified using a hyperplane that maximizes class margins. Kernel functions are used to transform non-linear data into a higher dimensional space for effective analysis (Kilci & Koklu, 2025b). As a result, SVM are able to solve complex classification problems. Decision boundaries are determined by support vectors The model is also optimized by tolerating misclassifications with the regularization parameter (C) and providing high accuracy (Isik et al., 2024; Yasar & Golcuk, 2025).

Neural networks

An Artificial Neural Network (ANN) is a computer model that mimics the structure of the human brain and makes predictions based on the process of processing data (Sabanci et al., 2015). An input, hidden, and output layer is included in these supervised learning networks. The network learns through each layer by processing information through neurons. The Adam solver and ReLU activation functions are used for training It is often used with high accuracy in complex classification and regression problems to solve problems using artificial neural networks (Kursun et al., 2022).

Decision tree

Decision tree (DT) are machine learning model that divide data by features and create trees based on them. The data is subdivided into subsets based on the internal nodes starting from the root node. In classification, the leaf nodes represent class labels, while in regression, they represent numerical results. A decision tree can be easily understood and visualized thanks to a simple structure, but when they get deeper, overfitting can cause problems (Mienye & Jere, 2024). All machine learning and deep learning models in this study were general hyperparameter settings as follows Table 2.

Table 2.
General hyperparameters of the models used in this study

Model	Hyperparameters
ANN	learning rate = 0.001, batch size = 32, epochs = 50, dropout = 0.5, activation = ReLU, optimizer = Adam
SVM	kernel = RBF, C = 1.0
kNN	k = 5, distance metric = Euclidean
Random Forest	number of trees = 100, max depth = None
Decision Tree	criterion = gini, splitter = best

Cross validation

Cross validation improves the generalization capacity of machine learning models by evaluating their performance. A validation set is developed for each of the K equal subsets (folds) of the data (Browne, 2000). Training data is split from the remaining data. The model is iterated K times, and the overall performance of the model is calculated by averaging the results of each iteration. Tests on different subsets of data reduce the risk of overfitting and improve generalization performance (Tutuncu et al., 2022). Number of sub-folds (k) was selected as 10 in this study.

Confusion matrix and performance measures

A model's performance in a classification problem is measured by the percentage of correct predictions among its predictions. However, this is only an indication of classification success. The accuracy rate alone is often not sufficient to determine whether a model is effective. A confusion matrix is used to analyze classification results. A confusion matrix is used to evaluate classification models (Taspinar et al., 2020). There are four basic values included in this matrix that summarize the correct and incorrect classifications of the model (Isik et al., 2024).

- True Positive (TP): Classification of true positives correctly as positives.
- False Positive (FP): Misclassifying a true negative class as positive.
- The True Negative (TN) class is correctly categorized as negative.
- False Negative (FN): False classification of a true positive class as negative.

Table 3 shows the complexity matrix for binary classification based on these four values (Taspinar et al., 2024). The confusion matrix for multiple classes is shown in Table 3 (Kilci & Koklu, 2025a). This visualization allows to analyze the performance of the classification model in detail and clearly presents the distribution between correct classifications and misclassifications (Gencturk et al., 2024).

Table 3.
Matrix of confusion for binary classes

	Predict	
Actual	TP	FN
	FP	TN

The accuracy, precision, recall, and F1 metrics can be used to evaluate a model's performance. In this study, these metrics are used to measure model performance. Table 4 shows these calculations for binary class datasets. Classification metrics based on general classification and their descriptions are given in Table 5, where the metrics in Table 4 for multiclass data, as in this study, are given in Table 5 (Kilci et al., 2025; Koklu & Ozkan, 2020).

Table 4.
Matrix of confusion for three classes

		Predict		
		Anthrcnose	Fruit fly	Healthy guava
Actual	Anthracnose	TP	FN	FN
	Fruit fly	FP	TP	FN
	Healthy guava	FP	FP	TP

Table 5.
Calculation formulas of binary class metrics

Metrics	Formula
Accuracy	$\frac{TP + TN}{TP + TN + FP + FN}$
Precision	$\frac{TP}{TP + FP}$
Recall	$\frac{TP}{TP + FN}$
F1 Score	$\frac{2TP}{2TP + FP + FN}$

Results

We apply a variety of deep learning and machine learning algorithms to classify disease states of guava fruit in this section. We first embedded images using the InceptionV3 deep learning model to extract features and then classified them using machine learning algorithms such as ANN, kNN, random forests, SVM, decision tree. Table 6 presents metrics such as accuracy, F1 Score, precision, and recall for each model.

Table 6.

Calculation formulas of multiple class metrics

Metrics	Formula
Averaged Accuracy	$\frac{\sum_{i=1}^{1} \frac{tp_i + tn_i}{tp_i + fn_i + fp_i + tn_i}}{l}$
Averaged Precision	$\frac{\sum_{i=1}^{1} \frac{tp_i}{tp_i + fp_i}}{l}$
Averaged Recall	$\frac{\sum_{i=1}^{1} \frac{tp_i}{tp_i + fn_i}}{l}$
Averaged F1 Score	$\frac{2 * \frac{\sum_{i=1}^{1} \frac{tp_i}{tp_i + fp_i}}{l} * \frac{\sum_{i=1}^{1} \frac{tp_i}{tp_i + fn_i}}{l}}{\frac{\sum_{i=1}^{1} \frac{tp_i}{tp_i + fp_i}}{l} + \frac{\sum_{i=1}^{1} \frac{tp_i}{tp_i + fn_i}}{l}}$

tp_i= True Positives for class I; tn_i =True Negatives for class I; fp_i = False Positives for class I; fn_i =False Negatives for class I; l = Total number of classes

SVM and ANN models perform best in Table 7. In particular, the SVM model achieved high performance values such as 0.9974 accuracy, 0.9957 precision, 0.9954 recall and 0.9955 F1 Score. This shows that the SVM model is effective in the classification of guava plant diseases. ANN provided similarly high accuracy and achieved 0.9958 accuracy, 0.9930 precision, 0.9930 recall and 0.9930 F1 Score.

The kNN model also has 0.9924 accuracy. Random forest performed successfully with an accuracy of 0.9612. The decision tree model resulted in lower accuracy rates. The DT model had lower values of 0.9209 accuracy, 0.8794 precision, 0.8767 recall and 0.8780 F1 Score. This means that the decision tree algorithm has limited classification success for this dataset.

Table 8, the SVM model produced 1541 correct predictions in the anthracnose category, 1 fruit fly and 2 healthy guava incorrect predictions. While 1309 correct predictions were made in the fruit fly category, 0 sample was incorrectly classified as anthracnose and 3 samples as healthy guava. In the healthy guava category, there were 919 correct guesses, 0 sample was misclassified as anthracnose, and 9 samples were misclassified as fruit fly.

Table 7.

Performance metrics results for all models

Model	Averaged Accuracy	Averaged Precision	Averaged Recall	Averaged F1 Score
SVM	0.9974	0.9957	0.9954	0.9955
ANN	0.9958	0.9930	0.9930	0.9930
kNN	0.9924	0.9892	0.9864	0.9877
Random Forest	0.9612	0.9409	0.9379	0.9393
Decision Tree	0.9209	0.8794	0.8767	0.8780

Table 8.

Confusion Matrix for Guava Dataset (a: ANN b: SVM c: kNN d: RF e: DT)

a) SVM

Actual \ Predict	Ant	FF	HG
Ant	1541	1	2
FF	0	1309	3
HG	0	9	919

b) ANN

Actual \ Predict	Ant	FF	HG
Ant	1540	1	3
FF	3	1302	7
HG	1	9	918

c) kNN

Actual \ Predict	Ant	FF	HG
Ant	1537	5	2
FF	6	1304	2
HG	7	21	900

d) RF

Actual \ Predict	Ant	FF	HG
Ant	1501	31	12
FF	58	1210	44
HG	21	54	853

e) DT

Actual \ Predict	Ant	FF	HG
Ant	1412	97	35
FF	105	1131	76
HG	39	97	792

Ant: Anthracnose

FF: Fruit fly

HG: Healthy guava

For the ANN model, 1540 correct predictions were made in the anthracnose category, while 1 sample was incorrectly predicted as fruit fly and 3 samples as healthy guava. While there were 1302 correct predictions in fruit fly, 3 samples were misclassified as anthracnose and 7 samples were misclassified as healthy guava. In the healthy guava category, 918 correct guesses were made, 1 sample was incorrectly guessed as anthracnose and 9 samples were incorrectly guessed as fruit fly.

The kNN model correctly predicted 1537 for anthracnose, 1304 for fruit fly and 900 for healthy guava. The most confusion occurred between the anthracnose and fruit fly categories.

The random forest model made 1501 correct predictions for anthracnose, 1210 correct predictions for fruit fly and 853 correct predictions for healthy guava; it made errors especially in fruit fly and healthy guava categories.

The decision tree model made 1412 correct predictions for anthracnose, 1131 correct predictions for fruit fly and 792 correct predictions for healthy guava; however, it made more misclassifications than the other models.

Model accuracy was evaluated using the confusion matrix. A confusion matrix is shown in Table 8 detailing the correct and incorrect classifications for anthracnose, fruit fly and healthy guava categories.

Discussion

Several machine learning and deep learning models were tested for their ability to classify guava fruit diseases based on experimental results. Support vector machine and neural networks provided the highest accuracy rates, reaching 99.74% and 99.58% accuracy rates, respectively. The SVM and ANN are highly reliable models for guava disease detection. kNN model also performed well with 99.24% accuracy. Random forest and decision tree models performed less well than the other models with 96.12% and 92.09% accuracy rates, respectively.

SVM and ANN models have high correct prediction rates for anthracnose, fruit fly, and healthy guava categories when confusion matrices are analyzed. These models minimize error rates due to their low misclassification rates. kNN model were also successful and provided good classification performance, although the number of incorrect predictions was higher than SVM or ANN. In detecting guava diseases, random forest and decision tree models had higher misclassification rates.

As compared with previous studies in literature, the results obtained by Kilci and Koklu show similar trends. Adaptive boosting (AdaBoost) and gradient boosting algorithms were used in Kilci and Koklu's study, resulting in accuracy rates of 82.7% and 95.6%, respectively (Kilci & Koklu, 2024). As compared to gradient boosting, ANN and SVM models perform better than AdaBoost. In classifying guava diseases, deep learning-based methods perform better than traditional machine learning algorithms.

Guava disease detection was most effective with SVM and ANN models. In addition, kNN models showed impressive results and may be a viable alternative in low-cost situations. Compared to other models, random forest and decision tree models performed poorly. Compared to literature studies, deep learning-based methods provide a powerful alternative for guava disease classification and should be prioritized for future research.

This study offers meaningful practical benefits for real-world agricultural use. By designing the model to be compatible with mobile and resource-constrained platforms, it enables farmers to identify guava diseases in their early stages using everyday tools like smartphones. Early detection allows for faster intervention, which can help minimize crop losses and reduce reliance on chemical treatments. Ultimately, the proposed system provides a promising, cost-effective solution that supports smarter, more sustainable farming practices.

Conclusion and Recommendations

Machine learning and deep learning methods are compared for the classification of guava fruit diseases. SVM and ANN models showed the highest classification accuracy in the experiments. Although kNN models also achieved good results, they were not as accurate as ANN and SVM. The performance of the random forest and decision tree models were lower than that of the other models.

The results show that deep learning-based methods are more successful than traditional machine learning methods in detecting guava diseases. In particular, the ANN model proved to be a reliable classifier with high accuracy rates. Comparisons with previous works in the literature show that the proposed methods are competitive and have superior performance compared to existing approaches.

For future studies, it is recommended to increase the generalization capabilities of the models by using larger and more diverse data sets. Furthermore, the application of deeper neural networks and hybrid models can improve accuracy rates. The development of mobile or web-based applications for real-time disease detection may increase the practical use of the model. In addition, model performance can be improved with data augmentation techniques and model decisions can be made more transparent by using explainable artificial intelligence approaches. In conclusion, this study presented an effective method for the detection of diseases of guava fruit.

Data Availability

This study used a dataset from Mendeley (Amin et. Al., 2024), and the data can be obtained through the following link: https://doi.org/10.17632/bkdkc4n835.1

Peer-review: Externally peer-reviewed.

Acknowledgments: This work is an extended version of our conference paper titled “Classification of Guava Diseases Using Features Extracted from Squeezenet with Adaboost and Gradient Boosting”, presented at the 4th International Conference on Frontiers in Academic Research (ICFAR, 2024).

Ethics Committee Approval: Ethics committee approval was not required for this study, as it involves the analysis of plant images (guava diseases) and does not include human or animal subjects, nor data requiring ethical review.

Author Contributions: Concept-K.M; Design- K.O; Supervision-K.M; Resources- K.O; Data Collection and/or Processing- K.O; Analysis and/or Interpretation- K.M; Literature Search- K.O; Writing Manuscript- K.M, K.O; Critical Review- K.M

Conflict of Interest: The authors have no conflicts of interest to declare.

Financial Disclosure: The authors declared that this study has received no financial support.

Hakem Değerlendirmesi: Dış bağımsız.

Etik Komite Onayı: Bu çalışma, yalnızca bitki görüntülerinin (guava hastalıkları) analizi üzerine odaklanmakta olup, insan veya hayvan katılımcı içermediğinden etik kurul onayı gerektirmemektedir.

Yazar Katkıları: Fikir-K.M; Tasarım-K.O; Denetleme-K.M; Kaynaklar-K.O; Veri Toplanması ve/veya İşlemesi-K.O; Analiz ve/veya Yorum-K.M; Literatür Taraması-K.O; Yazıyı Yazan-K.M,K.O; Eleştirel İnceleme-K.M.

Çıkar Çatışması: Yazarlar çıkar çatışması olmadığını beyan etmiştir.

Finansal Destek: Yazarlar, bu çalışma için finansal destek almadığını beyan etmiştir.

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Research Article *Araştırma Makalesi* DOI: 10.17097/agricultureatauni.1584215

Explore the Nematodes Associated with Scarlet Garden Eggplant (*Solanum aethiopicum*) and Implement Soil Amendment for Effective Management

Kırmızı Bahçe Patlıcanı (*Solanum aethiopicum*) İle İlişkili Nematodların İncelenmesi ve Etkili Yönetim için Toprak İlavelerinin Uygulanması

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ABSTRACT

Nematode infections cause severe damage to crops like eggplants. Information on the effects of nematodes on scarlet eggplant is rare. This study investigated the effect of soil amendments on soil nematodes population densities under garden eggplants. The completely randomized block design with replicated treatments was utilized. The trials were conducted in a field infested with four nematode species: *Meloidogyne*, *Hoplolaimus*, *Helicotylenchus,* and *Pratylenchus*. Number of nematodes per plot were extracted, plant height was measured with tape, and number of leaves were counted. Biochar (10 tons ha^{-1} (100%)) excelled in the control of these nematodes, followed by cow dung (100%) and *Bauhinia purpurea* (100%), then cow dung (5 tons ha^{-1} (50%)), and *Bauhinia* sp. (50%). *Hoplolaimus* sp. multiplied or survived most, particularly on biochar (50%) followed by *Pratylenchus* sp. on *Bauhinia* sp. (50%). All treatments had similar nematode populations. At 3 weeks after transplanting (WAT), cow dung 50%, *Bauhinia* sp. 100%, and *Bauhinia* sp. 50% induced the production of taller plants than the control. At 5 WAT, cow dung 50% was the best material for producing taller plants followed by *Bauhinia* sp. 100% and *Bauhinia* sp. 50% then biochar (50 and 100%). At 3 WAT, all organic control agents performed better than control, except for biochar. At 4 WAT, all the organic control agents except biochar 50% performed better than control. Finally, at 5 WAT best control material was cow dung 100% followed by *Bauhinia* sp. (100%), *Bauhinia* sp. (50%), biochar (100%), and cow dung (50%). These amendments are all recommended.

Keywords: African eggplant, Botanicals, Compost, Disease control, Host-parasite interaction

ÖZ

Nematod enfeksiyonları, patlıcan gibi ürünlere ciddi zararlar vermektedir. Nematodların kırmızı patlıcan (scarlet eggplant) üzerindeki etkilerine dair bilgiler sınırlıdır. Bu çalışma, bahçe patlıcanlarında toprak ilavelerinin toprak nematodlarının popülasyon yoğunlukları üzerindeki etkisini araştırmıştır. Çalışmada tekrarlanan uygulamalarla tamamen rastgele blok deneme deseni kullanılmıştır. Denemeler, *Meloidogyne, Hoplolaimus, Helicotylenchus* ve *Pratylenchus* olmak üzere dört nematod türü ile bulaşık bir tarlada yürütülmüştür. Parsel başına nematod sayıları çıkarılmış, bitki boyu şerit metre ile ölçülmüş ve yaprak sayısı sayılmıştır. Biochar (10 ton ha^{-1} (%100)), bu nematodların kontrolünde en etkili olan uygulama olmuştur. Bunu %100 oranında inek gübresi ve *Bauhinia purpurea*, ardından %50 oranında (5 ton ha-1) inek gübresi ve %50 *Bauhinia* sp. takip etmiştir. *Hoplolaimus* sp. en çok çoğalan veya en çok hayatta kalan tür olmuş, özellikle de %50 biochar üzerinde; bunu %50 *Bauhinia* sp. üzerinde *Pratylenchus* sp. izlemiştir. Tüm uygulamalarda benzer nematod popülasyonları gözlenmiştir. Dikimden 3 hafta sonra (WAT), %50 inek gübresi, %100 *Bauhinia* sp. ve %50 *Bauhinia* sp. kontrol grubuna kıyasla daha uzun bitkiler üretmiştir. Dikimden 5 hafta sonra, en uzun bitkileri %50 inek gübresi sağlamış, bunu sırasıyla %100 *Bauhinia* sp., %50 *Bauhinia* sp., ardından %50 ve %100 biochar izlemiştir. Dikimden 3 hafta sonra, biochar hariç tüm organik kontrol ajanları kontrolden daha iyi performans göstermiştir. Dikimden 4 hafta sonra, %50 biochar hariç tüm organik kontrol ajanları kontrol grubundan daha iyi performans göstermiştir. Son olarak, dikimden 5 hafta sonra en iyi kontrol materyali %100 inek gübresi olmuş, bunu %100 *Bauhinia* sp., %50 *Bauhinia* sp., %100 biochar ve %50 inek gübresi izlemiştir. Bu toprak ilavelerinin tamamı önerilmektedir.

Anahtar Kelimeler: Afrika patlıcanı, Botanik, Kompost, Hastalık kontrolü, Konukçu-parazit etkileşimi

Received Date:	02.12.2024
Revision Request Date:	14.06.2025
Last Revision Date:	19.08.2025
Accepted Date:	03.09.2025
Publication Date:	26.09.2025

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Cite this article: Ndifon, E., Lum, A. & Amabo, J. (2025). Explore the Nematodes Associated with Scarlet Garden Eggplant (*Solanum aethiopicum*) and Implement Soil Amendment for Effective Management. *Research in Agricultural Sciences, 56*(3), 227-233.

Introduction

Eggplant is termed the ‘king of vegetables’ in India, South Africa, Malaysia, and Singapore but derided as a ‘poor man's vegetable’ in some climes (Akin-Osanaiye et al., 2024; Bhaskar & Ramesh, 2015). Eggplant, mostly *Solanum aethiopicum* L. 1756, *Solanum melongena* L. 1753, and *Solanum macrocarpon* L. 1771), ranks third amongst the Solanaceae Juss., 1789 after potato and tomato and it is among the top ten global vegetables (FAOSTAT, 2015, 2022; World Population Review, 2025; Wikipedia, 2025). It is rich in fibre, folates, ascorbic acid, vitamins (especially carotene/vitamin B1), pantothenic acid, potassium, nasunin, carbohydrates, protein, iron, and calcium (Aida et al., 2021; Akin-Osanaiye et al., 2024; Sulaiman et al., 2019).

Eggplants are consumed as salad, roasted as a snack, or eaten as a sauce at home or on social/religious occasions (Ndifon et al., 2022). This consumption is attributed to its unique taste, culinary, and health benefits (Bhaskar & Ramesh, 2015). Accordingly, eggplant can improve nutrition, food security, rural development, and sustainable food production, especially in Sub-Saharan Africa (Abolusoro et al., 2013).

The global eggplant yield amounted to 59,312,600 metric tons in 2021-2022. Eggplant production is mostly carried out in five nations including China, India, Egypt, Turkey and Indonesia. These five countries produce about 90% of total global production of eggplant followed by Pakistan, Japan, and Brazil (FAOSTAT, 2012, 2022; Jalal et al., 2017; Uddin et al.; 2023; World population review, 2025; Wikipedia, 2025).

Eggplant production is constrained by biotic and abiotic stresses amongst which are plant-parasitic nematodes (Coyne et al., 2018). Nematodes cause 42-54% and 30-60% yield losses in vegetables and eggplant respectively (Aida et al., 2021). The following nematode genera in order of diminishing frequency: *Meloidogyne* Göldi 1887, *Pratylenchus* Filipjev 1936, *Helicotylenchus* Steiner 1945, *Scutellonema* Steiner and Lehew 1933, *Radopholus* Cobb, 1893, Thorne 1949, and *Tylenchus* Bastian 1865 were associated with eggplant in fields, while the minor nematodes encountered were *Aphelenchoides* Fischer 1894, *Trichodorus* Cobb 1913, *Aphelenchus* Bastian 1865, and *Xiphinema* Cobb 1913 species), *Scutellonema,* and *Tylenchulus* species (Tanimola and Godwin-Egein, 2011).

In Damascus, the presence of *Meloidogyne* species (43.1%) and other nematodes like *Tylenchorhynchus* Cobb 1913, *Pratylenchus, Paratylenchus* Micoletzky 1922, *Helicotylenchus, Ditylenchus* Filipjev 1936, *Rotylenchus* Filipjev 1934, *Longidorus* Micoletzky 1922, *Xiphenema, Aphelenchus, Aphelenchoides,* and *Tylenchus* was reported in eggplant fields (Haider et al., 2006). Moreover, 18 brinjal eggplant varieties out of 30 were susceptible to *M. incognita* race 1 infestation and only one variety (var. Mahy 80) was resistant to the nematode (Gulwaiez & Tabreiz, 2018).

Root-knot nematodes are a significant pest for eggplants across Africa. Effective management strategies include cultural practices like crop rotation with non-host plants, weed control, and soil solarization. Organic and inorganic amendments have also shown promise in reducing nematode populations and improving eggplant growth (Abd-Elgawad, 2021; Abolusoro et al., 2013; Mukasa & Ramathani, 2013; Touré et al, 2021).

It has been vehemently proven that nematode control is best carried out using chemical nematicides (Abolusoro et al., 2013). Nonetheless, the application of synthetic nematicides is frowned upon nowadays due to their effects on humans, animals, and the environment (Aji, 2024; Gulwaiz & Tabreiz, 2018; Ndifon, 2019; Onkendi et al., 2014). Thus, some banned chemical pesticides like methyl bromide are being replaced with eco-friendly agents in the face of climate change, food insecurity, and increasing global population (Oso, 2020).

Soil amendment prepared using plants in the family Brassicaceae Burnett 1835 release glucosinolate/isothiocyanate compounds that can significantly lower nematode populations in the soil (Tian et al., 2020). Significant nematode mortality was observed due to the application of plant extracts from *Tagetes* L. 1753 species and *Melia azedarach* L. 1753 leaves/shoots (Campos et al., 2022; Fekry et al., 2021).

Sources of soil amendments include composted municipal waste, sludge, and organic manure of plant or animal origin like poultry droppings, cow dung, neem cake, plant extracts, and domestic waste (Abolusoro et al., 2013; Aji, 2024; Noling, 2019; Oso, 2020).

The benefits of using these organic materials include improvement of soil’s physical properties like increased water retention, permeability, water infiltration, drainage, aeration, nutrient retention, cation exchange capacity, organic matter content, soil fertility, soil structure, and increased bio-control of nematodes through augmented microbial activity (Noling, 2019; Oso, 2020).

Bio-control of soil pests and pathogens may depend on the type of decomposed material, age of the compost, and biodiversity of the antagonists (Noling, 2019). Moreover, Noling pointed out that in some studies the application of composted municipal wastes up to 120 tons per hectare significantly increased pathogen/nematode population densities as well as plant growth. Both nematode-free and nematode-infested sandy soils lacking organic matter yielded significantly more tomatoes due to the application of soil amendments (Noling, 2019). The stimulatory effect of nematodes on plant growth was observed by Ndifon (2013; 2024).

The findings of Olabiyi et al. (2007) revealed that both decomposed and non-decomposed manure applied as an organic amendment caused a significant reduction in the populations of *Meloidogyne, Helicotylenchus,* and *Xiphinema* species under cowpea resulting in increased growth and yield of the crop. This is a typical finding on soil amendments. The application of amendments is becoming popular amongst many farmers.

Based on the foregoing discourse, this study aimed at thoroughly evaluating the impact of nematodes on garden eggplant (*S. aethiopicum*) and to identify effective soil amendment strategies for their management in the field. Our findings provide valuable insights and solutions for addressing this challenge.

Methods

Site of the study

This rain-fed experiment (with no supplementary irrigation) was carried out at the Faculty of Agriculture and Veterinary Medicine Teaching and Research Farm at the University of Buea, Cameroon. Buea is located at latitude 4°9'10" N and longitude 9°14'28" E. This area has a mean maximum annual temperature of 26.5-28.0°C and the mean relative humidity is 60%. It is situated at 2100 m above sea level on the slopes of one of the highest mountains in Africa.

Isolation of nematodes from experimental units

Soil samples were collected from the experimental plots in a zigzag pattern. Each composite soil sample (600 ml) was poured into a small bucket. Water was added and stirred till the container was filled to ¾ levels. The soil sample was left for 30 seconds while the soil particles settled. Thereafter a 200 µm and 32 µm set of sieves was used for sieving the suspension.

The last liquid component left in the 32 µm sieve was back-washed into a 500 ml beaker. This collected liquid sample was poured into four 45 ml Eppendorf centrifuge tubes, and 3 g of kaolin was added into each centrifuge tube. The kaolin forms a white lathe thus separating the nematodes from the supernatant. The centrifuge was operated at 3000 revolutions per minute (rpm) for 5 minutes.

The Eppendorf tubes were removed from the centrifuge and the supernatant was poured off. Fifteen millimetres of Zinc sulphate ($ZnSO_4.2H_2O$) was added into the clustered sediment in each tube and the sediment was broken with a spatula. The Zinc sulphate helps in suspending the nematodes. The Zinc sulphate used has a density of 1.16-1.18 and facilitates the floating of any nematodes whose density falls in this range.

The tubes were replaced in the centrifuge. The centrifuge was operated again at 3000 rpm for 4 minutes. The supernatant was poured inside a 200 ml container with water to prevent the nematodes from breaking. The supernatant was poured into a 32 µm sieve and back washed till it reached 100 ml in a beaker.

The nematode suspension was dispensed using 1 ml pipettes onto four slides and the nematodes were counted using a nematode counter under the stereomicroscope. Finally, the number of nematodes per 1000 ml of soil was estimated.

Land preparation

A 100 m^2 flat piece of land was cleared, ploughed, and harrowed with a tractor. The topsoil in the plot was scooped up to about 0.2 m depth and mixed together. The nematode-infested field was small enough for uniform mixing of the topsoil in the plot. The average number of mixed nematodes in the soil was estimated by sampling multiple points till similar populations were obtained.

Planting beds were made manually. The plots in form of beds with a dimension of 2 m x 1 m were raised to a height of 0.2 m. The plots were separated by a 0.5 m wide alleyway between beds. The alleyway between blocks was 1 m wide. The sampling was carried out again when the plots were ready for transplanting to ensure that the nematode populations were similar within plots.

Preparation of the organic manure

The organic manures that were used during the experiment included *Bauhinia purpurea* L. 1953 leaves, cow dung, and corn-stalk biochar. Fresh leaves of *Bauhinia purpurea* were harvested, chopped, and put in a bag for 3 weeks. Water was sprinkled on the leaves to facilitate their decomposition.

The biochar was made from corn stalks using the partial combustion method whereby the stalks were poured into a ground basin and soil lightly poured on the corn stalks. This induced a reduced oxygen level causing pyrolysis to ensue during the combustion process. The cow dung was decomposed for a month by pouring water into the plastic container and stirring the contents for aeration weekly.

Experimental layout

The treatments were laid out using the completely randomized block design and each treatment was replicated thrice. The treatment set included; control, biochar 100%, biochar 50%, *Bauhinia* 100%, *Bauhinia* 50%, cow dung 100%, and cow dung 50%. Each 100% rate received 10 tons ha^{-1} and the 50% rates received 5 tons ha^{-1} of the specific compost. The composts were applied and mixed into the soil to about 0.20 m depth at the time/point of setting up the trial. Fifteen 4 week old eggplant seedlings were transplanted per plot immediately when the plots were ready. The 4 weeks old seedlings were raised on heat steamed soil.

Data collection and analysis

Data collection commenced 21 days after transplanting. Data were collected on the number of nematodes per plot, plant height, and number of leaves. The number of nematodes in the soil was counted five weeks after transplanting (WAT) that is nine weeks after sowing (WAS). The eggplant variety utilized can last 11-13 weeks in the field. Plant height was recorded from four plants in each plot using a flexible tape. The number of leaves was counted weekly.

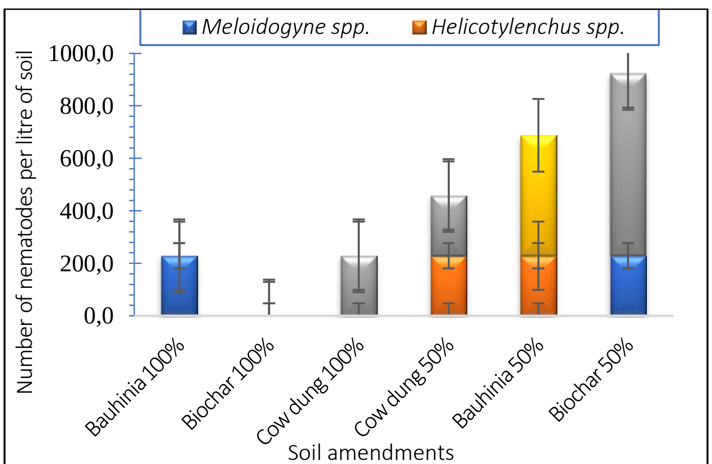
The data were subjected to analysis using the MINITAB statistical package (version 17) and IBM Statistical Package for Social Sciences (IBM SPSS Corp., Armonk, NY, USA) version 25 was used to improve the charts.

Results and Discussion

The effect of soil amendments on the final nematode population densities in the soil at 5 WAT is presented in Figure 1. The results revealed that biochar 100% excelled in the control of the nematodes, followed by cow dung 100% and *Bauhinia* 100%, then cow dung 50%, and *Bauhinia* 50%. *Hoplolaimus* multiplied or survived most on biochar 50%, followed by *Pratylenchus* on *Bauhinia* 50%. All the other treatments had similar nematode populations.

Figure 1.

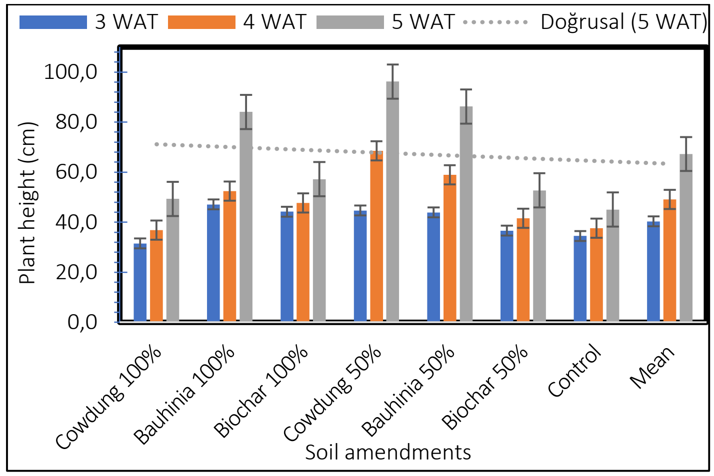
Effects of soil amendments on final nematode population densities in the soil at 5 weeks after transplanting eggplants.



During the early growth stage (3 WAT), cow dung 50%, *Bauhinia sp*. 100%, and *Bauhinia* sp. 50% induced the production of taller plants than the control (Figure 2). Finally, at 5 WAT, cow dung 50% was the best material for producing taller plants followed by *Bauhinia* sp. 100% and *Bauhinia* sp. 50% then biochar (50% and 100%), and so on.

Figure 2.

Effects of soil amendments on plant height at 3, 4, and 5 weeks after transplanting eggplants

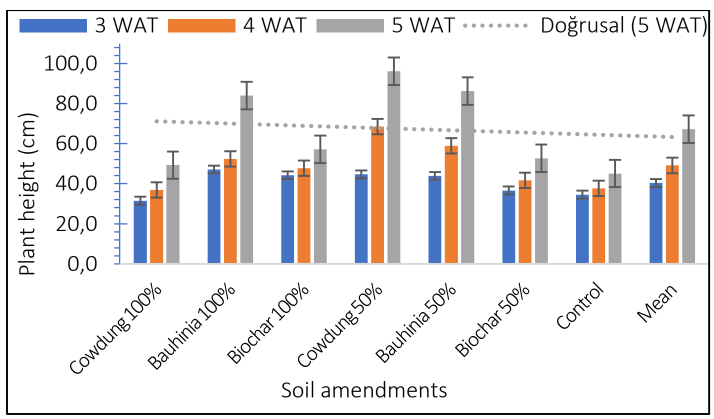


*WAT = weeks after transplanting

Likewise, during early growth (at 3 WAT), all the organic control agents performed better than the control, except for biochar rates (Figure 3). At 4 WAT, all the organic control agents except biochar 50% performed better than the control. Finally, at 5 WAT the best control material was cow dung 100% followed by *Bauhinia* 100%, *Bauhinia* 50%, biochar 100%, and then cow dung 50%.

Figure 3.

Effects of soil amendments on number of leaves at 3, 4, and 5 weeks after transplanting eggplants.



*WAT = weeks after transplanting

At or above 500 *M. incognita* eggs and/or juveniles, a reduction of the shoot height, fruit number, fruit weight, stem girth, flowering, fresh/dry shoot and root weights results which usually climaxes in eggplant yield loss (Sulaiman et al., 2019). Also at or above 500 *Meloidogyne* eggs and/or juveniles, a significant reduction in grapevine growth parameters occurs (Ndifon, 2024).

Chitinous amendments, nitrogenous inorganic fertilizers, manure from animal sources (like poultry droppings/litter), and cover crops constitute excellent soil amendments for improving soil quality and boosting bio-control by microbial antagonists (Noling, 2019). Noling argued that the research findings seem to indicate that the soil amendments are mainly useful as sources of plant nutrients and water availability. This view is not universally acknowledged.

The reproduction factor of *M. incognita* was reduced by 'Nemakey'™ and 'Charge'™ organic soil amendments which culminated in the reduction of the second-stage juveniles by 100% and 81.9% respectively (Jalal et al., 2017). These researchers reported an increase in the quantity of plant growth parameters. Poultry, cow dung, domestic waste, and NPK fertilizer effectively controlled *M. incognita* in the soil (Abolusoro et al., 2013). These findings corroborated the findings of this study.

A significant reduction in the populations of *M. incognita*, *Rotylenchulus reniformis* Linford and Oliveira 1940, *Tylenchorhynchus brassicae Cobb 1913*, and *Helicotylenchus* species were recorded, while plant weight, percent pollen fertility, pod numbers, root nodulation, nitrate reductase activity, and chlorophyll content in leaves increased significantly (Rizvi et al., 2012). The results of this current study were in agreement with the findings by Rizvi.

In tomato fields, marigold and basil plant extracts successfully reduced *M. incognita* populations and increased plant height, plant leaf and fruit yields (Olabiyi, 2008). These typical results confirmed the findings of this present study. To prevent nematode and disease infection 12 tons ha^{-1} organic manure should be applied. Also, live cover-crops and intercropped coniferous crops like mustards - *Brassica juncea (L) Czernajew 1859* kill nematodes (Mukasa and Ramathani, 2018).

Extracts of *Ageratum L* 1753 species severely inhibited *Meloidogyne javanica* in vitro and in vivo. *Ageratum* extract also increased all growth and yield parameters (Mamman, 2023). Some weeds can be effective biopesticides (Fontem et al., 2014) which corroborates the findings of this study herein.

The potential of *Trichoderma harzianum* Rifai 1969 as a biocontrol agent against *M. incognita was assessed on eggplant* (Uddin et al., 2023). Another avenue of nematode control was pointed out by Gaku et al. (2022) whereby *S. melongena* was grafted on *Solanum palinacanthum Dunal 1852* rootstock leading to significant suppression of the reproduction of *M. incognita* even though the yield remained the same. Unfortunately resistance to most nematodes is scarse and can be easily breached. Plant extracts from *Argemone mexicana L. 1753*, *Calotropis procera (Aiton) W.T. Aiton 1811*, *Solanum xanthocarpum Schrad. & Wendl. 1795*, and *Eichhornia echinulata Kunth 1842*) inhibited nematodes and fungi infections in chickpea (*Cicer arietinum L. 1753*) (Rizvi et al., 2012). These plants can be used for preparing soil amendments.

Conclusion

This research examined the nematodes associated with garden eggplant (*Solanum aethiopicum*) and employed soil amendments for the successful management of the nematodes in the field. The efficacy of soil organic amendments including cow dung, *Bauhinia* species, and corn-stalk biochar was demonstrated against four nematodes including *Meloidogyne, Helicotylenchus, Hoplolaimus,* and *Pratylenchus* species. These organic manures were especially effective at the 10-ton ha^{-1} level. The application of organic soil amendments increased the number of plant leaves and shoot height per plant. The crop was subjected to destructive sampling so no yield was recorded but the increase in growth parameters has been positively correlated to increased yield by researchers. The plants remaining in the treated plots after destructive sampling of the inner row plants produced many healthy fruits. These were not scored since the plants were not utilized for data collection from the onset. Finally, corn biochar (100% level) caused a 100% reduction in the population of the nematodes and should be researched more. However, biochar was the least effective agent in indorsing plant growth with time. All the organic materials are recommended for the management of nematodes associated with eggplants, while research on their use continues.

Peer-review: Externally peer-reviewed.

Ethics Committee Approval: Ethics committee approval was not required for this study.

Author Contributions: Concept- EN; Design- EN, AL; Supervision- EN; Resources- EN, AL, JA; Data Collection and/or Processing- EN; Analysis and/or Interpretation- EN; Literature Search- EN; Writing Manuscript- EN, AL, JA; Critical Review- EN, AL, JA

Conflict of Interest: The authors have no conflicts of interest to declare.

Financial Disclosure: The authors declared that this study has received no financial support.

Hakem Değerlendirmesi: Dış bağımsız.

Etik Komite Onayı: Bu çalışma etik kurul onayı gerektirmemektedir.

Yazar Katkıları: Konsept-EN; Tasarım-EN, AL; Denetim-EN; Kaynaklar- EN, AL, JA; Veri Toplama ve/veya İşleme - EN; Analiz ve/veya Yorum-EN; Literatür Taraması-EN; Makaleyi Yazan- EN, AL, JA; Eleştirel İnceleme- EN, AL, JA

Çıkar Çatışması: Yazarlar çıkar çatışması olmadığını beyan etmiştir.

Finansal Destek: Yazarlar, bu çalışma için finansal destek almadığını beyan etmiştir.

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ATATÜRK ÜNİVERSİTESİ YAYINLARI
ATATURK UNIVERSITY PUBLICATIONS

Research Article Araştırma Makalesi DOI: 10.17097/agricultureatauni.1693998

Fuzzy Logic-Based Evaluation of Physicochemical Water Quality Parameters in the Gökırmak River (Türkiye)

Gökırmak Nehri'nin (Türkiye) Fizikokimyasal Su Kalitesinin Bulanık Mantık ile Değerlendirilmesi

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Received Date:	07.05.2025
Revision Request Date:	12.08.2025
Last Revision Date:	23.08.2025
Accepted Date:	16.09.2025
Publication Date:	26.09.2025

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Cite this article: Sönmez, A.Y., Kale, S., Taştan, Y., Özdemir, R.C. & Kadak, A.E. (2025). Fuzzy Logic-Based Evaluation of Physicochemical Water Quality Parameters in the Gökırmak River (Türkiye). *Research in Agricultural Sciences, 56*(3), 234-242.

ABSTRACT

Traditional water quality classification methods rely on fixed threshold values, which limits their ability to reflect the degree of deviation from these boundaries. This rigid approach often results in uncertainties when assessing the ecological status of rivers. Fuzzy logic, in contrast, provides a more flexible framework by incorporating gradual transitions between classes and accounting for the relative importance of parameters. In this study, a fuzzy logic-based classification system was developed to evaluate the water quality of the Gökırmak River (Türkiye) and was compared with the conventional water quality index defined by national standards. Ten physicochemical parameters (temperature, pH, dissolved oxygen, electrical conductivity, nitrate, nitrite, ammonium, phosphate, biochemical oxygen demand, and chemical oxygen demand) were monitored monthly at six stations for one year. The fuzzy logic model was constructed using triangular membership functions and a Mamdani inference system. Model performance was assessed by comparing fuzzy classification results with expert evaluations based on the Surface Water Regulation. The system achieved 90% agreement, calculated as the ratio of consistent classifications to the total number of cases, demonstrating that fuzzy logic can serve as a reliable tool in water quality assessment. The findings highlight that fuzzy logic-based approaches not only reduce classification uncertainties but also provide a decision support framework for sustainable water resource management. Further research should expand the dataset across longer time periods and incorporate retrospective records to improve generalizability.

Keywords: Decision support system, Environmental monitoring, Fuzzy logic, Water pollution, Water quality assessment

ÖZ

Geleneksel su kalitesi sınıflandırma yöntemleri sabit eşik değerlerine dayanmaktadır ve bu durum ölçüm değerlerinin bu sınırların ne kadar uzağında veya yakınında olduğunu yansıtamamaktadır. Bu katı yaklaşım, nehirlerin ekolojik durumunun değerlendirilmesinde belirsizliklere yol açmaktadır. Buna karşılık, bulanık mantık, sınıflar arasında kademeli geçişlere izin vererek ve parametrelerin göreli önemini dikkate alarak daha esnek bir değerlendirme çerçevesi sunmaktadır. Bu çalışmada, Türkiye'deki Gökırmak Nehri'nin su kalitesini değerlendirmek amacıyla bulanık mantık tabanlı bir sınıflandırma sistemi geliştirilmiş ve ulusal standartlarda tanımlanan klasik su kalite indeksi ile karşılaştırılmıştır. On farklı fizikokimyasal parametre (sıcaklık, pH, çözünmüş oksijen, elektriksel iletkenlik, nitrat, nitrit, amonyum, fosfat, biyokimyasal oksijen ihtiyacı ve kimyasal oksijen ihtiyacı) bir yıl boyunca altı istasyonda aylık olarak izlenmiştir. Bulanık mantık modeli üçgensel üyelik fonksiyonları ve Mamdani çıkarım sistemi ile oluşturulmuştur. Modelin performansı, Yüzey Suları Yönetmeliği'ne göre uzman değerlendirmeleri ile karşılaştırılarak test edilmiştir. Sistem, toplam sınıflandırmaların %90'ında uyum sağlamış olup bu oran, bulanık mantık yaklaşımının su kalitesi değerlendirmesinde güvenilir bir araç olduğunu göstermektedir. Bulgular, bulanık mantık tabanlı yöntemlerin sınıflandırma belirsizliklerini azaltmanın yanı sıra sürdürülebilir su kaynakları yönetimi için karar destek aracı sağlayabileceğini ortaya koymaktadır. Daha geniş veri setlerinin ve geçmiş yıllara ait kayıtların dahil edilmesi, yöntemin genellenebilirliğini artırmak için önerilmektedir.

Anahtar Kelimeler: Karar destek sistemi, Çevresel İzleme, Bulanık mantık, Su kirliliği, Su kalite değerlendirmesi

Introduction

Water pollution is among the most pressing environmental challenges of the 21st century, driven largely by population growth, industrialization, and intensive agricultural practices. Freshwater ecosystems, in particular, are increasingly exposed to anthropogenic pressures, threatening both ecological integrity and sustainable resource use (Abdullah et al., 2008). Accurate monitoring and classification of river water quality are therefore crucial for guiding environmental management and policy decisions.

The quality assessment of polluted waters provides important theoretical information not only for determining the effects of pollution elements in waters but also for the sustainability of limited water resources. Several pollution index techniques are employed in water quality assessment, and they define precise limits that show the amount and difference of water pollution at different levels. However, an uncertainty associated with risk appears in quality assessments due to the instability of each water pollutant. The presence of precise limits in uncertainty classification diagrams makes the employment of these diagrams challenging. Due to this uncertainty, environmental researchers have begun to work on advanced evaluation techniques by using fuzzy logic (Sönmez, 2011). Although the use of fuzzy logic, one of the artificial intelligence methods, in the field of water engineering is not very common, it is becoming increasingly widespread.

Traditional water quality assessment approaches, such as those outlined in national standards and international guidelines, are based on assigning water samples to discrete quality classes according to fixed threshold values. While these approaches are widely used, they present several limitations. First, they do not account for the degree of deviation from thresholds, thereby neglecting important nuances in water quality trends. Second, they assume that all measured parameters can be strictly categorized into a single class, which often fails to capture the inherent variability of natural systems (Icaga, 2007). These shortcomings can result in uncertainties and inconsistencies in decision-making.

In response to these challenges, researchers have increasingly turned to advanced computational techniques, particularly fuzzy logic, which provides a more flexible and robust framework for environmental assessment. Fuzzy logic introduces gradual transitions between classes and integrates multiple parameters with weighted significance, reducing uncertainty and improving interpretability (Liou & Lo 2005; Liou et al., 2003; Ludwig & Tulbure, 1996; Sadiq & Rodriguez, 2004; Shen et al., 2005; Wang & Zou, 2008). Recent applications have demonstrated its effectiveness in water quality evaluation across different contexts (Azzirgue et al., 2022; Dewanti & Abadi, 2019; Sönmez et al., 2013). Using fuzzy logic-based quality assessment indices instead of conventional indices will provide more objective results (Sönmez et al., 2018). However, the use of fuzzy logic in Türkiye's river systems remains limited, and no standardized fuzzy logic-based water quality index has been developed for national application.

The Gökırmak River, a major tributary of the Kızılırmak River, was selected as the case study for this research due to its ecological and socio-economic significance. Flowing through agricultural areas that are heavily used for rice cultivation, the river is subject to multiple pollution pressures, including nutrient enrichment, domestic discharges, and agricultural runoff (Dengiz et al., 2015). Despite its importance for regional agriculture and biodiversity, few studies have comprehensively evaluated its water quality using advanced computational approaches. This makes the Gökırmak River an appropriate and representative site for testing the applicability of fuzzy logic in Türkiye.

Against this background, the present study aims to evaluate the water quality of the Gökırmak River using a fuzzy logic-based classification system and to compare its performance with the conventional national classification method. The study contributes to the literature by (i) applying fuzzy logic to a river of high agricultural and ecological importance in Türkiye, (ii) providing a methodological framework for integrating multiple physicochemical parameters into a decision support system, and (iii) highlighting the potential for fuzzy logic to complement existing national water quality standards. By addressing these aspects, the research fills a gap in the application of artificial intelligence methods in water quality management in Türkiye and offers insights for future development of a standardized fuzzy logic-based water quality index.

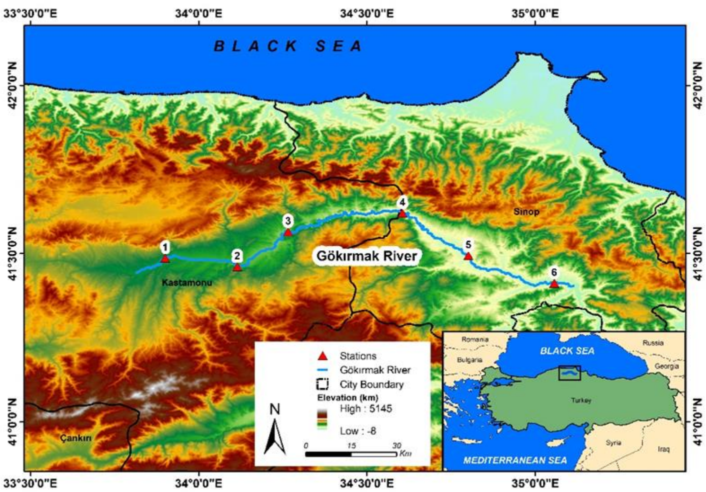
Methods

Study area

The Gökırmak River, depicted in Figure 1, originates from Ilgaz Mountain in Kastamonu province and serves as a significant tributary of the Kızılırmak River, the longest river fully inside Türkiye's borders. It extends 221 kilometers through Kastamonu, Taşköprü, Hanönü, Boyabat, and Durağan until converging with the Kızılırmak. The basin encompasses an area of roughly 7000 km² (Yildirim et al., 2013). The river basin region exhibits a semiarid climate and is predominantly agricultural, particularly for rice (Dengiz et al., 2015). The river is highly influenced by agricultural runoff, domestic discharges, and seasonal hydrological variability, making it a suitable case for water quality assessment. The geological structure of the basin includes sedimentary rocks and alluvial deposits, which contribute to variations in water chemistry. Average annual precipitation is evenly distributed across seasons, while maximum evaporation occurs in July (Tanatmış, 2004).

Figure 1.

Map showing the sampling stations along the Gökırmak River



Method

Water samples were collected monthly from six stations along the Gökırmak River between January 2020 and December 2021 (Figure 1). Stations were selected to represent upstream reference sites, agricultural zones, and downstream sections influenced by settlements. At each station, three replicate samples were taken at surface level (0–50 cm depth) to account for spatial variability. The geographic coordinates of the stations were recorded using a handheld GPS device. Field parameters (temperature, dissolved oxygen, pH, electrical conductivity) were measured in situ using a multiparameter probe (Hach Lange HQ40D). Nutrient and organic pollution parameters (nitrate, nitrite, ammonium, phosphate, biochemical oxygen demand [BOD], and chemical oxygen demand [COD]) were analyzed spectrophotometrically using standard commercial kits in accordance with APHA (2017) protocols.

Ten physicochemical parameters were selected based on their regulatory significance in Türkiye's Surface Water Quality Regulation (YSY, 2012) and their widespread use in international water quality assessment studies. These parameters represent key categories of water quality: (i) general physical conditions (temperature, electrical conductivity), (ii) acid-base balance (pH), (iii) oxygen regime (dissolved oxygen, BOD, COD), and (iv) nutrient enrichment (nitrate, nitrite, ammonium, phosphate). Together, they provide a comprehensive assessment of river water quality and its ecological implications.

The classical classification of water quality was conducted using the "Quality Criteria of Intra-Continental Surface Water Resources According to Their Classes" defined in the Surface Water Regulation (YSY, 2012). The thresholds for each parameter are presented in Table 1.

Table 1.

Water Quality Classes of Intra-Continental Surface Water Resources as per the Surface Water Regulation (YSY, 2012)

Water Quality Parameters	Water Quality Classes			
	I	II	III	IV
Temperature (°C)	≤ 25	≤ 25	≤ 30	> 30
pH	6.5-8.5	6.5-8.5	6.0-9.0	outside 6.0-9.0
Electrical Conductivity (µS/cm)	< 400	400-1000	1001-3000	> 3000
Dissolved Oxygen (mg O_2/L)	> 8	6-8	3-6	< 3
Chemical Oxygen Demand (COD) (mg/L)	< 25	25-50	50-70	> 70
Biochemical Oxygen Demand (BOD) (mg/L)	< 4	4-8	8-20	> 20
Ammonium (mg NH_4^+-N/L)	< 0.2	0.2-1	1-2	> 2
Nitrite (mg NO_2^--N/L)	< 0.002	0.002-0.01	0.01-0.05	> 0.05
Nitrate (mg NO_3^--N/L)	< 5	5-10	10-20	> 20
Phosphorus (mg P/L)	< 0.03	0.03-0.16	0.16-0.65	> 0.65

Fuzzy logic generally includes the stages of fuzzification, fuzzy inference and clarification (defuzzification). The fuzzification module transforms the observed real information into a fuzzy form using membership functions determined in accordance with the problem characteristics. The fuzzy inference mechanism assesses the control rules stored in the fuzzy rule base. As a consequence of the fuzzy inference, one or a few fuzzy output sets are obtained, which is later clarified to obtain the control action of the membership functions. Clarification is the process of converting fuzzy outputs into numbers. It is not possible to use the outputs of fuzzy systems directly in applications. In this case, the fuzzy outputs need to be clarified. The clarification process is considered to be the exact opposite of the fuzzification process (Zadeh, 1988) (Figure 2).

Figure 2.

The flowchart of the Fuzzy Logic Inference System developed to assess the water quality classification along the Gökırmak River

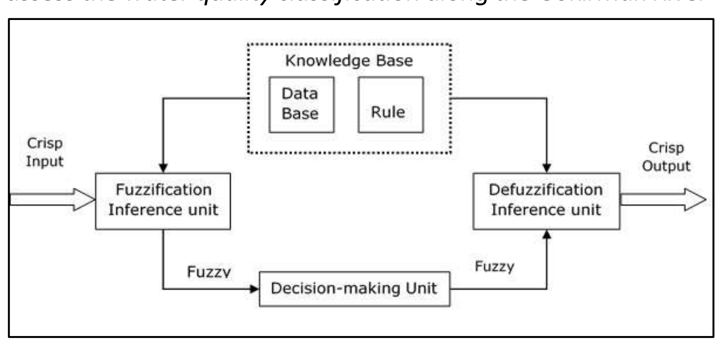
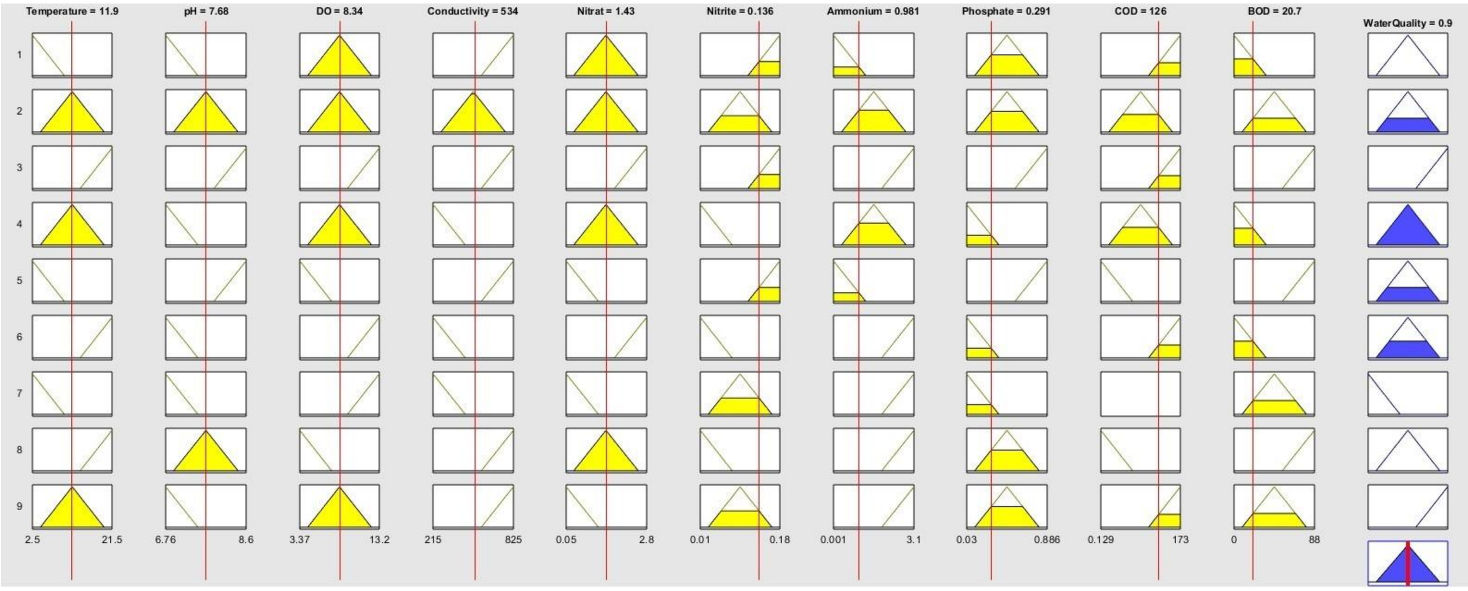


Figure 3.

Triangular membership functions developed to assess the water quality classification along the Gökırmak River



The fuzzy logic model was designed following standard steps of fuzzification, fuzzy inference, and defuzzification (Zadeh, 1988; Ross, 2004). The Mamdani inference system was chosen due to its widespread application in environmental studies and its ability to handle nonlinear and uncertain data with interpretability (Dewanti & Abadi, 2019; Sönmez et al., 2013). Triangular membership functions were applied to represent parameter categories (Classes I–IV), as they provide a simple yet effective structure for modeling gradual transitions between thresholds (Figure 3). The rule base was constructed by translating the classical classification scheme into fuzzy "if–then" rules.

While creating the fuzzy logic model in this study, the classical classification given in Table 1, which separates water quality into four classes, was taken into account. The fuzzy model consists of six steps (Akkaptan, 2012; Ross, 2004; Sivanandam et al., 2007; Sönmez et al., 2013, 2018);

1. Determining the quality classes of physicochemical parameters using the measured values with classical classification and collecting them in four groups.
2. Assigning fuzzy model membership names as the equivalent of classical quality classification.
3. Creating the membership functions of the input and output values in a triangular or trapezoidal structure and determining the limit values.
4. Creating the rule base using the quality classes of the input values.
5. Using the fuzzy logic algorithm with the Mamdani approach and then determining the fuzzy inference outputs of the groups with the membership function degrees of the parameters.
6. Defuzzifying the four different fuzzy inference outputs to determine the quality index ranging from 0 to 1.

It consists of refinement steps to determine the quality index of the four different fuzzy result outputs. All fuzzy logic analyses were performed using MATLAB R2014b with the Fuzzy Logic Toolbox.

Model performance was evaluated by comparing fuzzy logic outputs with expert classifications based on the Surface Water Regulation. Agreement was quantified using an accuracy metric defined as:

$$\text{Accuracy} = \frac{\text{Number of matching classifications}}{\text{Total classifications}} \times 100$$

The fuzzy logic system achieved 90% agreement across all stations and months, indicating that the method provides reliable results in classifying water quality.

Results and Discussion

Water quality classification of 10 physicochemical water parameters, determined at six stations along the Gökırmak River, was carried out using both the classical classification system and the fuzzy logic approach. The classical classification results are summarized in Table 2. According to the Surface Water Regulation (YSY, 2012), parameters such as temperature, pH, dissolved oxygen, and nitrate generally corresponded to Class I, while others (electrical conductivity, BOD, COD, ammonium, and phosphorus) were in Class II and nitrite was in Class III, reflecting moderate pollution pressures in certain sections of the river.

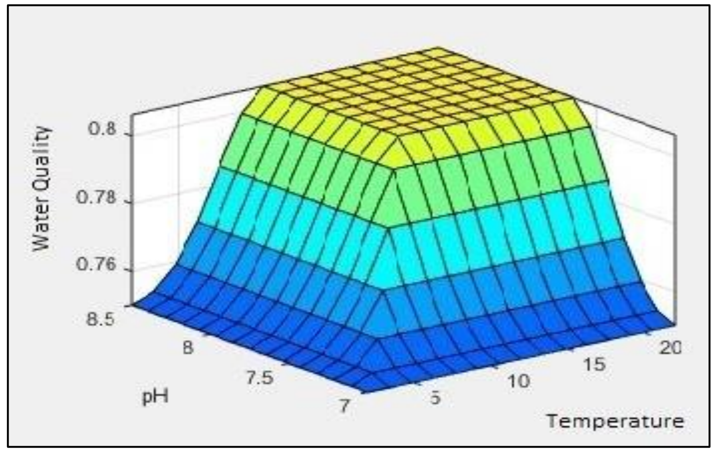
Table 2.
Water quality classes of physicochemical parameters determined in the study according to the classical classification

Parameter	Water Quality			
	I	II	III	IV
Temperature (°C)	X			
pH	X			
Conductivity (µS/cm)		X		
Dissolved Oxygen (mg O_2/L)	X			
COD (mg/L)		X		
BOD (mg/L)		X		
Ammonium (mg NH_4^+-N/L)		X		
Nitrite (mg NO_2^--N/L)			X	
Nitrate (mg NO_3^--N/L)	X			
Phosphorus (mg P/L)		X		

Some physicochemical properties of water included in the water quality standards have been reformatted with measured data, fuzzy logic terms and rule base connections created according to the decision support system structure. In order to create fuzzy sets of inputs and outputs, the classification scale of water quality parameters specified in the Surface Water Regulation was used to define triangular membership functions for each parameter (1st, 2nd, 3rd and 4th Class) (Figure 3). The fuzzy logic-based system provided classifications that showed 90% agreement with expert evaluations based on the national regulation. This high level of consistency demonstrates the capacity of fuzzy logic to serve as a reliable decision-support tool in water quality assessment. The most significant variables affecting water quality were determined to be temperature and pH between samples in the data set. This relationship is displayed in Figure 4. The discrepancies observed in approximately 10% of cases were largely associated with parameter values that were close to class boundaries (e.g., dissolved oxygen around 6 mg/L or COD near 50 mg/L). Unlike the rigid threshold structure of the classical approach, the fuzzy system allows for gradual transitions and reflects uncertainty in borderline cases, thereby offering a more flexible and realistic evaluation of water quality.

Today, many innovative index methods are used to determine water quality in rivers (Said et al., 2004). In the study of case study of Ocampo-Duque et al. (2006) on water quality assessment in rivers, several water quality parameters (dissolved oxygen, biological oxygen demand, organic matter content, microbiological parameters, etc.) were measured in the Ebo River in Spain, then quality classes were evaluated with different water quality indices including the fuzzy inference system. As a result, they reported that the expert opinions and reports specified for this region were in line with the fuzzy inference system.

Figure 4.
3D surface view of the relationships between inputs (temperature and pH) and output (water quality class)



In a study conducted by Sönmez et al. (2013) on water quality assessment in the Karasu River based on heavy metal pollution, it was revealed that the fuzzy logic approach is a suitable tool for evaluating water pollution. Similarly, in a water quality assessment study conducted in the Germeçtepe Dam Lake based on 10 water quality parameters, it was determined that the decision support system created to determine quality classes yields 90% success (Atea et al., 2018).

In a study (Dewanti & Abadi, 2019) aiming to develop a fuzzy logic system to classify the water quality status in the Gajahwong River, 11 parameters, including temperature, pH, dissolved oxygen, BOD, COD, free chlorine, nitrate, nitrite, oil, fat, lead and Escherichia coli were used to classify the water quality status in water samples taken from 3 different stations between 2007 and 2017. These 11 parameters, which were included as inputs to the fuzzy inference system, were exited through the system by being categorized as normal, lightly polluted, moderately polluted and heavily polluted. According to the results obtained, it was observed that the Mamdani Centroid and the Mamdani LOM methods were 90.90% and 96.97% compatible with the decision support system, respectively. Ultimately, they stated that fuzzy logic methods are suitable approaches for developing river water classification models.

Chanapathi and Thatikonda (2019) aimed to develop a Mamdani type fuzzy-based regional water quality index by examining ten different water quality, and used classifications from six countries in various geographical regions to assess the quality of surface water. It was reported that the presented model, despite its various geographical origins, resembles water quality models used in India, Malaysia and the United States and can help self-assess regional water quality on a global scale.

In another work carried out in Morocco on the quality assessment of groundwater, Azzirgue et al. (2022) compared a traditional and a fuzzy-based water quality index. Twelve physicochemical and bacteriological parameters taken from nine different wells for two years were included in the model and compared. According to their results, they concluded that the classical and fuzzy-based quality assessment indices supported each other and that the fuzzy-based model they proposed could be used confidently in water quality assessment.

A fuzzy logic framework was designed in Malaysia to evaluate river water quality by integrating six input variables into a single outcome. This system illustrated how fuzzy logic can streamline complex datasets, making them easier for decision-makers to interpret (Abdullah et al., 2008). In Indonesia, a fuzzy logic-based assessment of the Tanjung Karang watershed helped to measure the impact of agricultural practices on water quality. The capacity of the model to merge heterogeneous datasets proved essential in promoting sustainable farming methods (Gharibi et al., 2012). In Poland, fuzzy logic was applied to assess ecological status by combining biological and chemical indicators, showing its efficiency in reflecting intricate ecosystem interactions (Trach et al., 2022). Similarly, fuzzy logic techniques were employed to monitor the Ganges River, incorporating parameters like biochemical oxygen demand and phosphate levels. The study's results provided critical insights for policymakers aiming to improve river health (Raman et al., 2009).

Research on Italy's Sele River compared traditional binary assessment tools with fuzzy logic approaches. Results revealed that fuzzy logic delivered a more refined understanding of water quality and enhanced the accuracy of monitoring and sampling strategies (Scannapieco et al., 2012). In Nigeria, fuzzy logic was used to assess the Ikare community's water resources, offering a comparison with the conventional Water Quality Index. Findings showed that fuzzy logic better captured the variability of water parameters, underlining its usefulness in diverse environmental applications (Oladipo et al., 2021). Li et al. (2023) proposed a dual-input fuzzy control model for ammonia nitrogen management, which resulted in more than 95% savings in both water and energy consumption. These results highlight fuzzy logic's potential in sustainable aquaculture management. Likewise, de Oliveira et al. (2014) introduced the Fuzzy Raw Water Quality Index (IQABF) to evaluate raw water treatability. Compared with deterministic indices, IQABF was more restrictive yet consistent, proving effective in handling uncertainty and supporting treatment processes.

The utilization of fuzzy logic has also advanced environmental monitoring by predicting complex parameters such as sea surface temperature and heavy metal contamination. Kale (2020) constructed a fuzzy logic model to forecast sea surface temperature (SST) in the Çanakkale Strait, Türkiye, emphasizing its strong capacity to simulate complex environmental systems with high reliability. Later, Sonmez et al. (2018) explored the challenges of modeling heavy metal pollution in aquatic ecosystems, known for their nonlinear characteristics. Their work reinforced the accuracy and robustness of fuzzy logic, suggesting its broad potential in water quality management.

Taken together, these international studies highlight the adaptability of fuzzy logic to different environmental conditions, reinforcing its role in improving water quality monitoring and management while supporting sustainable resource use (Gharibi et al., 2012).

Sönmez and Taştan (2024) emphasized that fuzzy-based methods present a practical alternative to classical logic in water quality evaluation. Their study concluded that fuzzy approaches allow comparison of different indices and models across water bodies, offering a more rational and dependable option than traditional techniques.

Kale (2024) noted that fuzzy logic models provide an advanced pathway for water quality assessment by offering greater precision and flexibility. They represent a resilient approach capable of addressing the inherent variability and uncertainties in environmental datasets. Their ability to adapt across contexts and integrate with complementary tools makes them valuable for sustainable management. As environmental monitoring gains urgency, continued development of fuzzy logic methodologies will enhance their effectiveness, ensuring more reliable monitoring and management strategies in the future.

The findings are in line with above-mentioned studies that have applied fuzzy logic to river and reservoir systems. These parallels confirm that the fuzzy logic approach used in this study is robust and applicable in diverse hydrological contexts. It also confirms that the fuzzy logic-based approach used in this study is not only consistent with international applications but also contributes to the ongoing discussion on developing standardized and integrated water quality assessment frameworks, particularly for rivers in Türkiye.

The current model has certain limitations. Membership functions were statically defined and may require recalibration for other regions or under different hydrological conditions. Furthermore, the rule base was constructed according to national classification thresholds and expert judgment, which introduces subjectivity. Expanding the dataset with longer-term monitoring and incorporating additional indicators, such as microbiological parameters, would improve the robustness and transferability of the model.

Conclusion and Recommendations

This study evaluated the water quality of the Gökırmak River using a fuzzy logic-based classification system and compared the results with the conventional method defined in Türkiye's Surface Water Regulation. The fuzzy approach, which incorporated ten physicochemical parameters from six stations, achieved 90% agreement with expert assessments. These results confirm that fuzzy logic provides a reliable and flexible alternative to rigid threshold-based classifications, particularly in cases where parameter values are near class boundaries.

The main contribution of this work is the demonstration that fuzzy logic can reduce uncertainties inherent in classical water quality indices and offer a more realistic decision-support framework for environmental management. Unlike traditional methods, the fuzzy system considers gradual transitions and relative importance of parameters, thus improving the robustness of water quality assessments.

Nevertheless, the model has some limitations. Membership functions were statically defined and may require recalibration for different rivers or changing environmental conditions. In addition, the rule base was constructed according to regulatory thresholds and expert judgment, which introduces a degree of subjectivity. Future studies should address these limitations by expanding the dataset to longer time periods, including microbiological and ecological parameters, and testing alternative fuzzy structures such as adaptive neuro-fuzzy inference systems (ANFIS).

From a broader perspective, the findings highlight the potential of fuzzy logic to support the development of a standardized water quality index for rivers in Türkiye. Such an index would contribute to more accurate environmental monitoring, more effective policy-making, and ultimately to the sustainable and rational use of national water resources.

Evaluation of water quality in environmental management provides important information to decision-making mechanisms in terms of producing accurate policies. It provides a scientific basis, especially for the preservation of water resources and their sustainable and rational use. A correct monitoring and evaluation policy is essential to ensure the sustainability of water resources. These monitoring activities should be carried out routinely and inventory records should be made based on healthy and accurate data. It has been demonstrated in this paper that mathematical methods based on artificial intelligence such as fuzzy logic can be used for this purpose, however, they ought to be further developed and disseminated. Redefinition of quality classes by evaluating comprehensive data extending to years and more research are needed.

Peer-review: Externally peer-reviewed.

Ethics Committee Approval: Ethics committee approval was not required for this study.

Author Contributions: Concept - AYS; Design - AYS; Supervision - AYS; Resources - RCÖ; Materials - RCÖ; Data Collection and/or Processing – YT, RCÖ, AEK; Analysis and/or Interpretation – AYS, YT, SK; Literature Search – AYS, SK; Writing Manuscript – AYS, SK, YT; Critical Review – SK, YT.

Conflict of Interest: The authors have no conflicts of interest to declare.

Financial Disclosure: The study was financially supported by the Kastamonu University, Coordination Unit of Scientific Research Projects (Project no: KÜ-BAP01/2020-9).

Hakem Değerlendirmesi: Dış bağımsız.

Etik Komite Onayı: Bu çalışma etik kurul onayı gerektirmemektedir.

Yazar Katkıları: Konsept - AYS; Tasarım - AYS; Denetim - AYS; Kaynaklar - RCÖ; Malzemeler - RCÖ; Veri Toplama ve/veya İşleme – YT, RCÖ, AEK; Analiz ve/veya Yorumlama – AYS, YT, SK; Literatür Araştırması – AYS, SK; Makale Yazımı – AYS, SK, YT; Eleştirel İnceleme – SK, YT.

Çıkar Çatışması: Yazarlar çıkar çatışması olmadığını beyan etmiştir.

Finansal Destek: Çalışma, Kastamonu Üniversitesi Bilimsel Araştırma Projeleri Koordinasyon Birimi (Proje no: KÜ-BAP01/2020-9) tarafından finansal olarak desteklenmiştir.

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ATATÜRK ÜNİVERSİTESİ YAYINLARI
ATATURK UNIVERSITY PUBLICATIONS

Research Article Araştırma Makalesi DOI: 10.17097/agricultureatauni.1738386

The Language of Soil: Soil Analysis with a Machine Learning Approach

Toprağın Dili: Makine Öğrenimi Yaklaşımı ile Toprak Analizi

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ABSTRACT

In Türkiye, rapid population growth combined with unsustainable agricultural practices threatens the sustainable use of fertile soils and poses serious risks for the agricultural sector. To address this challenge, the present study analyzes soil data from the Odunpazarı district of Eskişehir province and proposes a machine learning–based approach. First, Principal Component Analysis (PCA) was applied to reduce data dimensionality, after which the K-Means algorithm classified the soils into three clusters. These clusters revealed significant differences in physical structure, moisture, salinity, and mineral composition, thereby providing a robust basis for further modeling. Building on this foundation, supervised machine learning models were developed and their performances compared. Logistic Regression achieved the highest accuracy (98.9%), followed by Decision Tree (97.8%), Random Forest (97.2%), and K-Nearest Neighbors (91.7%). The findings demonstrate that machine learning algorithms can reliably predict soil group membership and generate valuable insights for regional soil productivity analysis. Overall, the study highlights the effectiveness of data-driven methods in supporting sustainable agricultural planning and offers an integrative model that can guide future applications in precision agriculture.

Keywords: Supervised machine learning, Unsupervised machine learning, Cluster analysis, Sustainable agriculture, Productivity

ÖZ

Türkiye'de artan nüfus ve bilinçsiz tarım uygulamaları, verimli toprakların sürdürülebilir kullanımını tehdit etmekte ve tarım sektöründe ciddi riskler oluşturmaktadır. Bu çalışmada, söz konusu soruna çözüm arayışıyla Eskişehir ili Odunpazarı ilçesine ait toprak analiz verileri incelenmiş ve makine öğrenmesi tabanlı bir yaklaşım geliştirilmiştir. Öncelikle, veri boyutunu azaltmak amacıyla Temel Bileşenler Analizi (PCA) uygulanmış, ardından K-Ortalama (K-Means) algoritmasıyla topraklar üç kümeye ayrılmıştır. Kümeler; fiziksel yapı, nem, tuzluluk ve mineral içerikleri açısından anlamlı farklılıklar göstermiş, böylece sınıflandırma süreci için sağlam bir temel oluşturmuştur. Bu aşamanın ardından kümelenen veriler kullanılarak denetimli makine öğrenmesi modelleri geliştirilmiş ve performansları karşılaştırılmıştır. Lojistik Regresyon modeli %98,9 doğruluk ile en yüksek başarıyı elde ederken, Karar Ağacı %97,8, Rastgele Orman %97,2 ve K-En Yakın Komşu (KNN) %91,7 doğruluk oranına ulaşmıştır. Bulgular, makine öğrenmesi algoritmalarının toprak gruplarını güvenilir biçimde tahmin edebildiğini ve bölgesel toprak verimliliği analizlerinde değerli katkılar sunduğunu ortaya koymaktadır. Sonuç olarak çalışma, akıllı tarım uygulamaları için veri odaklı karar destek sistemlerinin geliştirilmesine yönelik örnek bir model sunmaktadır.

Anahtar Kelimeler: Denetimli makine öğrenmesi, Denetimsiz makine öğrenmesi, Kümeleme analizi, Sürdürülebilir tarım, Verimlilik

This study was supported within the scope of the TÜBİTAK 2209-A Program for Supporting Research Projects of Undergraduate Students. It was also prepared as part of the "Research Project" course conducted under our university's undergraduate curriculum. The poster of the study was presented to faculty members at our university.

Received Date:	09.07.2025
Revision Request Date:	17.08.2025
Last Revision Date:	16.09.2025
Accepted Date:	17.09.2025
Publication Date:	26.09.2025

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Cite this article: Bayram, S., Çayır, E.S., İlhan, E., Arslan, İ. & Gökpınar, E. (2025). The Language of Soil: Soil Analysis with a Machine Learning Approach. *Research in Agricultural Sciences, 56*(3), 243-255.

Introduction

Agriculture is a fundamental activity that provides food and raw materials to people through crop cultivation and animal husbandry. It makes significant contributions to the gross national product of many countries. In addition, it supplies raw materials to sectors such as textiles, the food industry, energy, and biotechnology. However, climate change, the growth of the world population, and the reduction of agricultural resources have caused serious problems in agriculture. Mismanagement practices such as improper land use, overgrazing, faulty crop rotation, and unbalanced fertilizer application are gradually reducing agricultural lands, thereby making agriculture a strategic priority (Demir et al., 2023; Kılavuz & Erdem, 2019). Moreover, fluctuations in the global economy directly affect the performance of enterprises at both national and regional levels. Therefore, countries aiming for economic growth and development should consider the importance of agriculture and base their strategic policies on sound analyses (Esmer & Gezer, 2021).

The inadequacy of traditional farming methods has brought smart farming applications to the forefront. Smart farming does not only aim to increase soil fertility but also seeks to ensure the efficient and sustainable development of agriculture. These approaches minimize environmental damage and enable the effective use of natural resources.

Higher yields can be achieved with less water, fertilizer, and fuel. At the same time, more crops can be cultivated in smaller areas, reducing farmers' costs. Big data analytics enables the analysis of variables such as climate conditions and soil fertility, thereby optimizing processes. At this point, machine learning (ML) methods play an active role in data analysis and prediction (Demir et al., 2023). Thus, innovations ranging from digital technologies to autonomous systems are being implemented in smart agriculture.

The primary goal of agriculture is crop production, and with population growth, the demand for food continues to rise. A review of the literature reveals numerous studies on crop management. For instance, Reddy et al. (2019) developed a crop recommendation system using ML algorithms in the Ramtek region of India. Garanayak et al. (2021) analyzed climate and soil data with ML regression methods to improve soil fertility in the Andhra Pradesh region. Paudel et al. (2022) proposed regional ML models for crop yield prediction at multiple spatial levels. Patel and Patel (2023) aimed to improve crop yield and optimize resource use with ML methods in Gujarat. Bhargavi and Jagannathan (2024) used weather, soil, and location data to predict crop yields in the Maharashtra and Karnataka regions. Burhan and Soydan (2023) predicted production quantities and yields for 2021–2022 using datasets provided by the Turkish Grain Board (TMO) and the Turkish State Meteorological Service (MGM). Prity et al. (2024) developed an ML-based crop recommendation system. Yakut et al. (2023) analyzed more than 7,500 soil data samples from Isparta using ML algorithms to determine which soils are more suitable for which crops.

Crop cultivation depends directly on soil quality and nutrient content, while fertilization, modern irrigation, seed improvement, and erosion prevention play a key role in enhancing fertility. However, continuous cropping depletes nutrients and reduces soil fertility, which is usually determined by nutrient presence or absence (Gruhn et al., 2000). Sustainable soil fertility depends on the soil's ability to supply nutrients to plants. Therefore, assessing soil fertility is a critical aspect of sustainable agriculture (Maathuis, 2009).

The literature shows that crop management studies also consider the physical, biological, and mineral characteristics of the soil. Soil classification based on fertility is used to identify nutrient deficiencies and to develop crop recommendation systems (Taher et al., 2021). Once soil data are obtained, they can be analyzed with ML algorithms for classification, enabling fertilizer and treatment recommendations. For example, Bhargavi and Jyothi (2011) analyzed soil data using data mining techniques. Hayattu et al. (2020) examined soil analysis data from northwestern Nigeria with similar approaches. Yadav et al. (2021) applied various ML algorithms to group and classify soils.

Soil fertility differs across regions, and crops are selected accordingly. Studies in the literature have been conducted by considering the factors affecting soil fertility in different countries. However, studies that comprehensively classify soil properties in Turkey using ML algorithms are very limited. A holistic evaluation of Turkey's soil analysis data and their classification through machine learning methods represents an important research need.

In this study, soil analysis data obtained from the Odunpazarı district of Eskişehir, provided by the Ministry of Agriculture and Forestry of the Republic of Turkey, were used. The physical and chemical components of the soil (e.g., soil depth, water saturation, total salt, lime, sand, clay, calcium, magnesium, boron, sodium, saturation, and other variables) were considered. First, the K-means clustering algorithm was applied to group soils, allowing meaningful differentiation and evaluation of fertility levels. Then, these clusters were used as labels to train supervised machine learning models. The aim was to predict the cluster of a randomly selected soil sample. The findings are expected to guide farmers in soil management practices and contribute to future research. In this context, this study aims to provide benefits such as accurate crop selection for farmers, supporting sustainable agricultural practices, preventing soil degradation, reducing costs through efficient land use, and minimizing environmental impacts.

Methods

In this study, similar soil types were grouped using the K-Means clustering algorithm after data pre-processing. The overall workflow at this stage of the study is presented schematically in Figure 1.

In the first stage, clustering analysis was performed, and soils were categorized according to their characteristics, allowing an evaluation of their soil fertility. In the second stage, a classification step was initiated to predict the group membership of a randomly selected soil sample.

For this purpose, the cluster labels were used to train various machine learning models, including Random Forest, Logistic Regression, Decision Tree, and K-Nearest Neighbour (KNN), and their performances were compared. The process is illustrated in Figure 2.

In addition, the overall two-stage workflow of the study is summarized in Figure 3, highlighting Stage 1 (unsupervised clustering) and Stage 2 (supervised classification).

Data set

The dataset used in this study consists of soil analysis data from the Odunpazarı region of Eskişehir province, obtained from the Ministry of Agriculture and Forestry. The dataset includes the physical and chemical properties of soil samples collected from various locations to evaluate soil fertility. These properties encompass parameters such as water saturation, total salt, lime, sand, clay, silt, calcium, magnesium, boron, sodium, electrical conductivity (EC), pH, sodium adsorption ratio (SAR), and exchangeable sodium percentage (ESP).

Descriptive statistics for the main variables are presented in Table 1. The average water saturation rate is 83.75%, with values ranging from 50.6% to 136.4%, indicating substantial variation in the soils' water holding capacity. The pH is slightly alkaline, averaging 7.74 (range 7.28–8.19). Total salt content is low (average 0.034%), suggesting generally low salinity levels in the region.

The proportions of sand, clay, and silt among the physical components are 30.29%, 45.40%, and 23.66%, respectively. These ratios indicate that the soils are generally clayey-loamy. Regarding chemical properties, the calcium (1.67 meq/L) and magnesium (0.66 meq/L) values provide insight into the mineral content of the soils. Additionally, the average SAR and ESP values (0.24 and 1.60, respectively) suggest that the sodicity level is low.

In general, these descriptive statistics show that the soils of Eskişehir Odunpazarı region have a heterogeneous physical and chemical structure, and this diversity will contribute to the correct grouping of soils in machine learning models.

Figure 1.

Workflow diagram of clustering analysis according to soil properties

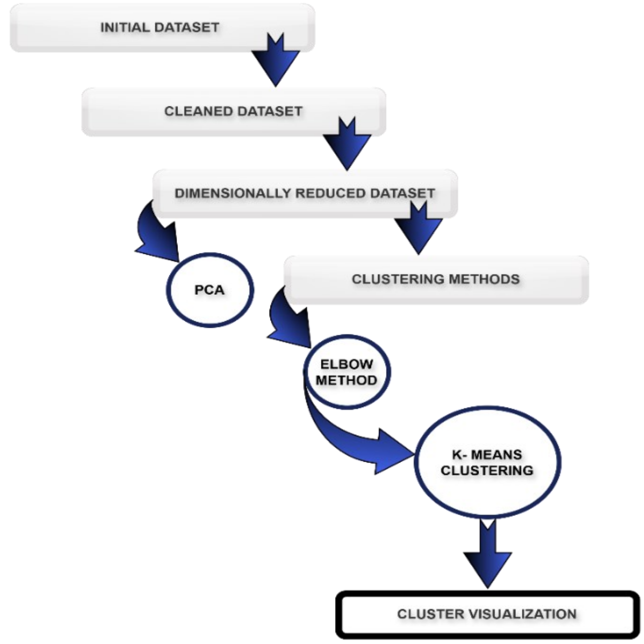


Figure 2.

Workflow diagram of soil group prediction and model performance evaluation process

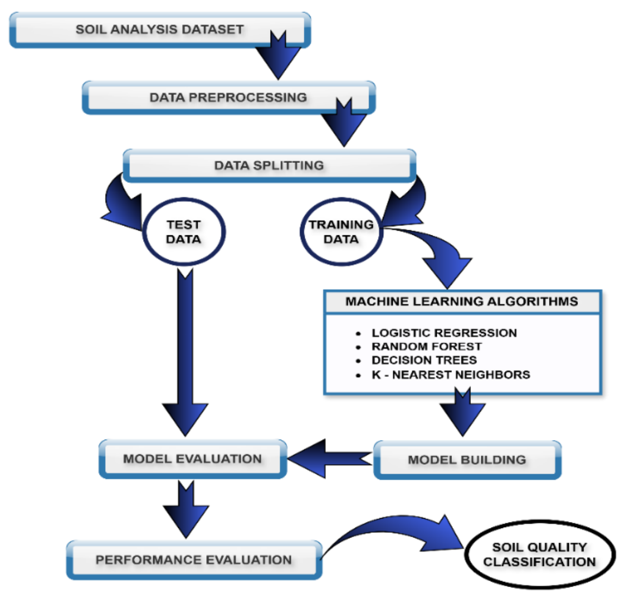


Figure 3.

Overall two-stage workflow of the study

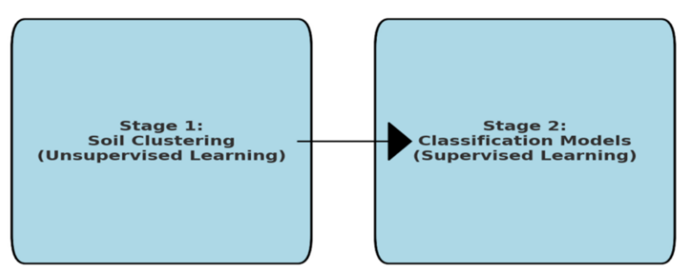


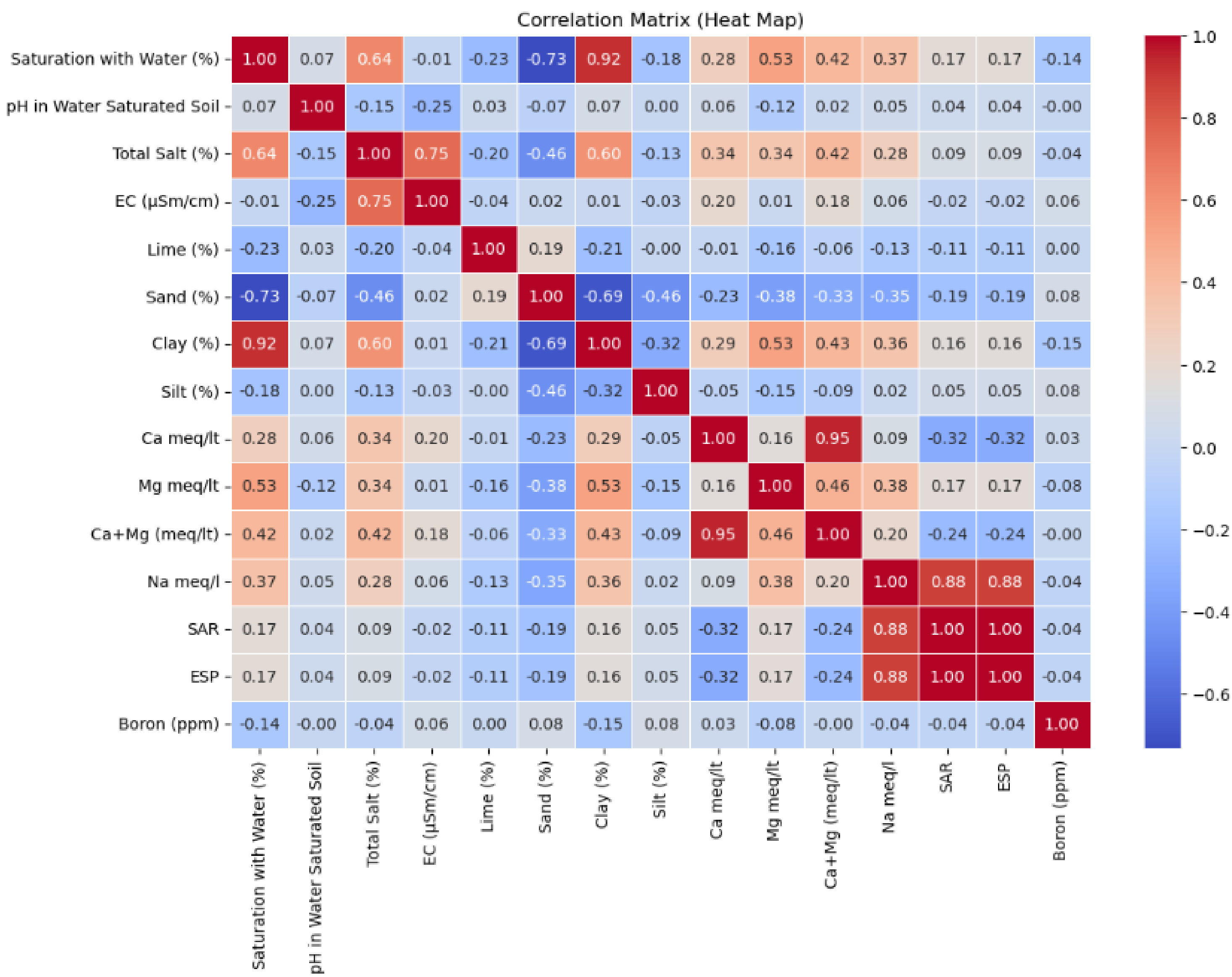
Table 1.

Summary descriptive statistics for numerical variables

	Count	Average	Std. Deviation	Minimum	25%	50%	75%	Maximum
Saturation with Water (%)	905	83.754	18.015	50.600	70.400	81.400	95.700	136.400
pH in Water Saturated Soil	905	7.7431	0.168	7.280	7.630	7.730	7,.860	8.190
Total Salt (%)	905	0.0343	0.011	0.011	0.026	0.034	0.042	0.067
EC (µSm/cm)	905	0.6427	0.153	0.291	0.539	0.641	0.741	1.056
Lime (%)	905	14.442	9.468	0.186	6.460	13.056	21.660	36.267
Sand (%)	905	30.924	7.300	9.010	25.360	32.410	36.580	48.520
Clay (%)	905	45.405	6.854	28.560	39.580	45.160	50.140	63.540
Silt (%)	905	23.669	5.566	7.420	19.650	23.540	27.590	39.970
Ca meq/l	905	1.673	0.812	0.007	1.082	1.566	2.174	4.202
Mg meq/l	905	0.663	0.281	0.009	0.451	0.629	0.835	1.484
Ca+Mg (meq/l)	905	2.335	0.905	0.000	1.677	2.247	2.912	4.897
Na meq/l	905	0.248	0.108	0.005	0.167	0.238	0.311	0.566
SAR	905	0.238	0.103	0.033	0.164	0.223	0.306	0.518
ESP	905	1.606	0.148	1.308	1.498	1.584	1.704	2.008
Boron (ppm)	905	0.230	0.119	0.006	0.144	0.217	0.305	0.558

Figure 4.

Correlation matrix of variables



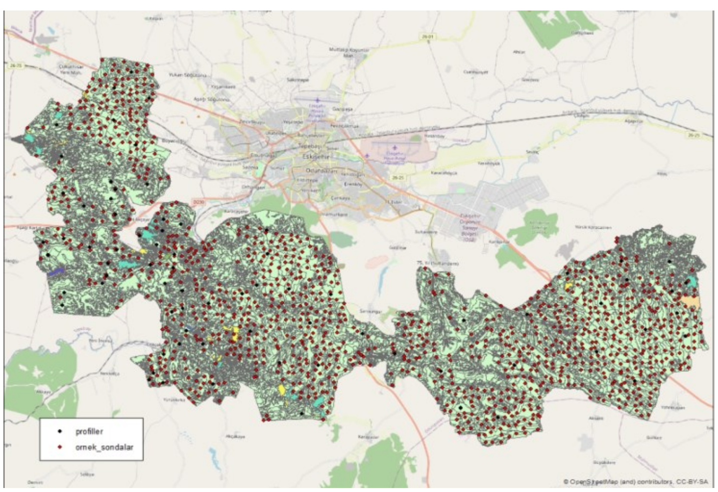
The relationships between soil variables were analyzed using the correlation matrix (heat map) in Figure 4. A very strong positive correlation (.92) was found between water saturation rate and clay (%), indicating that soils retain more water as clay content increases. In contrast, water saturation showed a strong negative correlation (-.73) with sand (%), suggesting lower water retention in sandy soils.

Total salt content was positively correlated with electrical conductivity (EC) (.75), confirming that salt increases ionic conductivity. Calcium (Ca) showed a very high correlation (.95) with Ca+Mg, highlighting the need to evaluate these elements together for mineral balance.

On the other hand, very strong positive relationships were found between sodium (Na) and SAR (Sodium Adsorption Rate) with a coefficient of .88 and between SAR and ESP (Exchangeable Sodium Percentage) with a coefficient of 1.00. This shows that soil sodicity parameters are closely related to each other and provides critical information for salinity management. In general, correlation analysis reveals how the physical and chemical properties of soil components are related to each other, which provides an important basis for variable selection in machine learning models.

Figure 5.

Distribution of raw data



In Figure 5, the distributions of the locations of the soil observations of the Odunpazarı region are visualized with the help of ArcGIS software. Before the analysis, the data was cleaned, missing values were removed, and outliers were checked. In addition, dimensionality reduction was performed using Principal Component Analysis (PCA) and the data set was made suitable for clustering and classification analyses.

Methods used

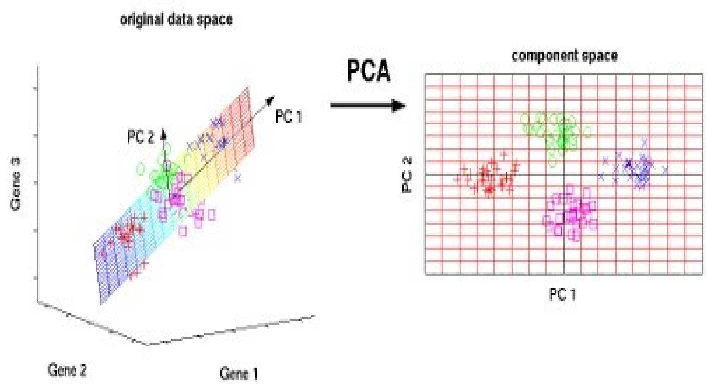
Principal Component Analysis (PCA)

PCA represents multivariate data with fewer variables, reducing dimensionality with minimal information loss. It creates new, uncorrelated variables called principal components, thereby removing dependencies among the original variables (Ersungur et al., 2007).

Principal component analysis aims to determine the best transformation that can express the available data with fewer variables. The variables obtained after the transformation are called principal components of the initial variables. The first principal component is the one with the largest variance value and the other principal components are ranked in order of decreasing variance values. The main advantages of this method are low sensitivity to noise, reduced memory and capacity requirements, and more efficient operation in low-dimensional spaces (Brownlee, 2016; Koldere, 2008).

Figure 6.

PCA model



Principal component analysis performs dimension reduction by representing multidimensional data with fewer components as shown in Figure 6. In addition, as can be seen in the figure, the three-dimensional data in the original data space is reduced to two main components called PC1 and PC2. This transformation preserves most of the total variance in the data set, allowing the data to be expressed in a simpler and more comprehensible component space.

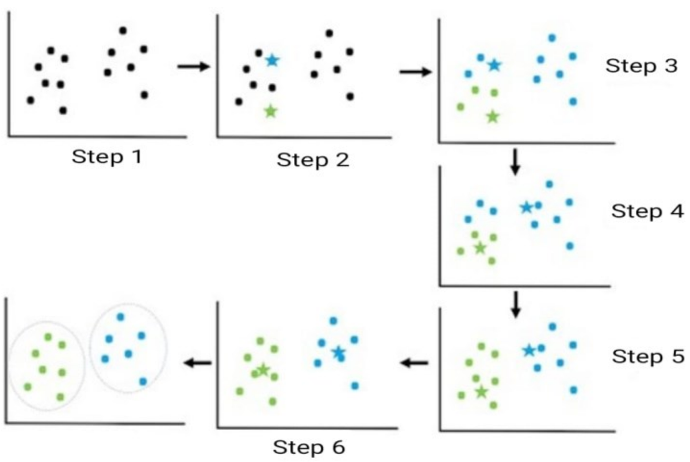
K-means clustering method

K-Means is a fundamental unsupervised learning algorithm for clustering. It groups unlabeled data by assigning similar observations to the same cluster. The algorithm determines k centroids and assigns each data point to the nearest one, iteratively optimizing cluster similarity. The parameter k defines the number of clusters to be formed, and this process continues until the similarity between the data is maximized (Brownlee, 2016; Koldere, 2008).

As can be seen in Figure 7, in Step 1, the data are initially scattered and not clustered. Then two cluster centers are selected as blue and green stars. The data are assigned to clusters according to their proximity to these centers and the centers for each cluster are renewed by averaging the data in that cluster. This process is repeated until the centers remain constant and the clusters become distinct.

Figure 7.

Example of clustering model with k-means algorithm



From this, the Euclidean distance $d(x_i, c_j)$ of the data point x_i to the centre c_j is calculated as follows.

$$d(x_i, c_j) = \sqrt{\sum_{k=1}^{n} (x_{ik} - c_{jk})^2} \quad [1]$$

Where n represents the size of the data point (number of features/parameters).

The new center account,

$$c_j = \frac{1}{N_j} \sum_{x_i \in C_j} x_i \quad [2]$$

c_j, calculates the centre of the jth cluster. N_j, denotes the number of data points in cluster j. and C_j denotes all data points in that cluster.

Classification algorithms

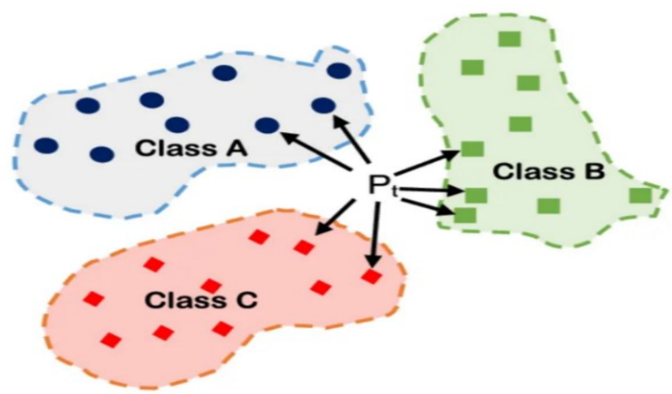
KNN algorithm

The main objective in classification problems is to accurately predict the classes to which the observations belong. The general purpose of the KNN algorithm, which is widely used in this context, is to assign observations to predetermined classes according to their own characteristics, as can be seen in Figure 8. In addition, the classification of a new observation is also provided. The new observation to be classified is classified into the same group with the k closest observations with the help of the learning dataset (Ağlarcı & Karakurt, 2024). This method, which assumes that data with similar characteristics are usually located close to each other, is based on neighbourhood relations when determining the class of new observations. The Euclidean distance is generally preferred for distance measurement. However, alternative distance measures, such as Manhattan and Minkowski, can also be used. The Euclidean distance measures the straight-line distance between two points and is particularly suitable for continuous variables. The Manhattan distance, on the other hand, is based on the sum of the absolute differences between two vectors. Finally, the Minkowski distance provides a generalized form of these two measurements and can be reduced to different distance types depending on the chosen parameter value. Performance metrics such as accuracy, precision, F1 score are used to evaluate the performance of the model.

In this study, three distinct clusters generated using the K-Means algorithm were designated as class labels. The Euclidean distance was employed to quantify the distances between observations, and the KNN algorithm was subsequently trained based on these labels.

Figure 8.

Example of classification model with KNN algorithm



Logistic regression algorithm

Logistic regression is a basic method of probability-based classification with two or more independent variables when the dependent variable is categorical. Logistic regression, unlike linear regression, uses a logistic function that limits the output values between 0 and 1. In this respect, it offers effective decision mechanisms in classification problems. In addition, it is widely preferred due to its simple structure and fast computational capability. Logistic regression can be applied in different types for binary, multiple and sequential classification problems (Hamid et al., 2018).

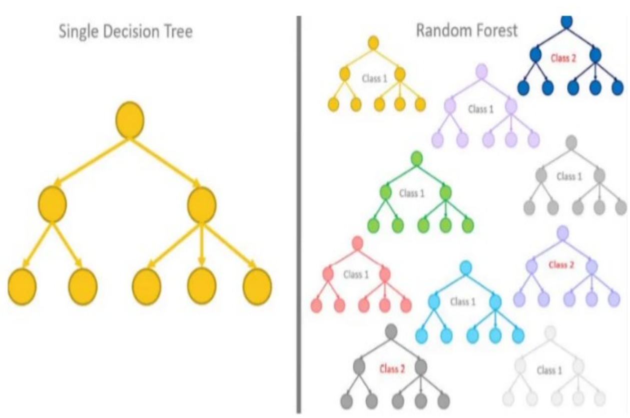
In this study, due to the independent and multi-categorized structure of the clusters, binary logistic regression was not sufficient; instead, multinomial logistic regression model, which is suitable for multi-class problems, was preferred. The model predicted which of the three classes each observation belongs to on a probability basis through the softmax function.

Random forest algorithm

Random Forest is one of the supervised learning methods and is widely used in classification and regression problems. As can be seen in Figure 9, this method is an ensemble model consisting of multiple decision trees. Each tree is trained with a random subset of the training data and different random features are used at each node. The decision made by each tree is considered when making predictions; the majority vote is taken in classification problems, and the average value is taken in regression problems. This structure prevents the model from overlearning and increases its generalization capability. Random Forest provides high success especially in large and complex data sets. In addition, thanks to its feature of determining the importance of variables, it also shows which variables are effective on prediction (Kumral et al., 2022).

Figure 9.

Example of classification model with random forest algorithm



Decision tree algorithm

Decision trees are among the most widely used supervised learning methods in classification and regression problems. Their main advantage lies in their ease of construction and the interpretability of the results they produce. The structure of decision trees consists of nodes, branches, and leaves. Data are split from the root node into branches and ultimately classified in the leaves. This allows the decision-making process to be followed step by step, facilitates evaluation of the resulting structure, and enables direct application to new data.

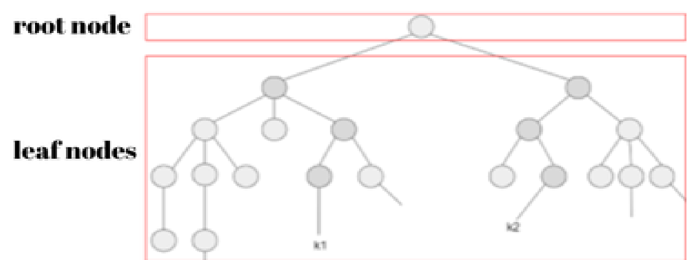
The performance of decision trees depends on several key parameters. Maximum depth determines the maximum number of layers a tree can have, while the minimum number of samples per leaf enhances the model's generalization ability. As splitting criteria, Gini Index or Entropy are commonly used in classification, whereas Mean Squared Error (MSE) is employed in regression. Additionally, limiting the maximum number of features improves efficiency and helps prevent overfitting.

The most important advantage of decision trees is their interpretability. However, very deep trees may become sensitive to noise and prone to overfitting. For this reason, decision trees are often combined with ensemble methods such as Random Forests or Gradient Boosted Trees, which provide higher accuracy and better generalization.

Overall, decision trees stand out as a valuable machine learning method due to their transparent structure and ability to generate explicit decision rules. They are particularly useful in fields such as agriculture, healthcare, and environmental studies, where interpretability is of critical importance. The graphical representation of the model is given in Figure 10.

Figure 10.

Example of classification model with decision tree algorithm



All classification algorithms were implemented using the scikit-learn library in Python. Default parameter settings were employed unless otherwise stated. Specifically, KNN was applied with Euclidean distance and k=5 neighbors, Random Forest with 100 trees (n_estimators=100) and unrestricted depth, and Decision Tree with unlimited depth and Gini impurity as the splitting criterion. Logistic Regression was applied with the 'lbfgs' solver and default regularization parameter (C=1.0). These settings correspond to the standard default values in scikit-learn (version 1.2.2).

Results and Discussion

In this study, by applying PCA, dimensionality reduction was made by reducing many variables in the dataset. In addition, the situation of affecting the performance of the classification models due to the high correlation between the features was eliminated. As a result, six components were determined, explaining a total variance of 80%.

Table 2 shows the component load matrix, which illustrates the relationships between components and variables. Positive values indicate a direct relationship, whereas negative values reflect an inverse relationship. Variables with higher absolute values contribute more significantly to the explanation of the corresponding component. For the components, variables with loading values of 0.30 and above were considered dominant.

Table 2.
Component load matrix

	PC1	PC2	PC3	PC4	PC5	PC6
Saturation with Water (%)	0.415586	-0.061068	0.198644	0.113304	-0.199862	0.033530
pH in Water Saturated Soil	0.002300	0.038581	0.416919	-0.033836	0.282925	0.097506
Total Salt (%)	0.351932	-0.142861	-0.396154	-0.001432	-0.186328	-0.047222
EC (µSm/cm)	0.107791	-0.130041	-0.685855	-0.090043	-0.065777	-0.104965
Lime (%)	-0.137459	-0.032708	0.007639	0.006779	0.338558	-0.592244
Sand (%)	-0.349169	-0.000206	-0.241574	0.405781	0.283475	0.084129
Clay (%)	0.409340	-0.072509	0.188487	0.213763	-0.159239	0.040214
Silt (%)	-0.046109	0.089572	0.084751	-0.795565	-0.175738	-0.159886
Ca meq/l	0.201089	-0.384783	-0.001887	-0.173296	0.456553	-0.045457
Mg meq/l	0.311076	-0.024382	0.072117	0.153362	0.007949	0.060140
Ca+Mg (meq/l)	0.278631	-0.353852	0.022012	-0.106320	0.414892	-0.024034
Na meq/l	0.310514	0.361122	-0.086779	-0.051507	0.333873	-0.037458
SAR	0.182149	0.518991	-0.101796	-0.003153	0.157315	-0.020843
ESP	0.182337	0.518787	-0.102861	-0.003417	0.157258	-0.019659
Boron (ppm)	-0.060200	-0.018620	-0.155223	-0.258950	0.219444	0.763298

Table 3.
Newly assigned names for PCA components

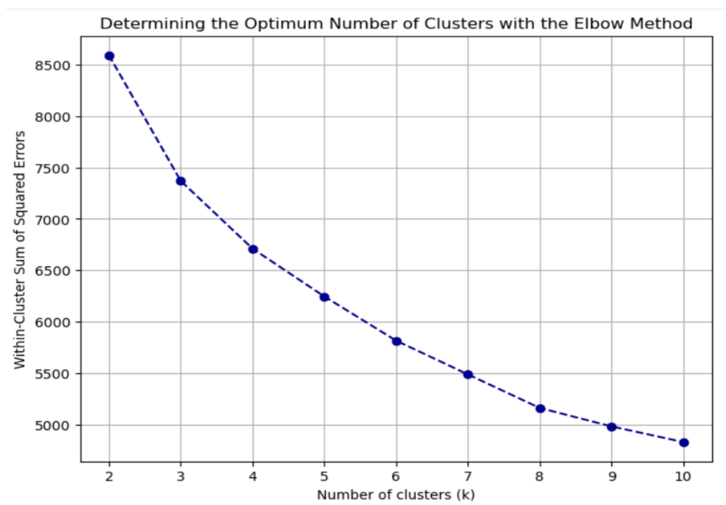
	PCA Components Names Rasyon
PC1	Soil Physical Structure, Moisture and Salinity
PC2	Mineral Content and Ionic Balance
PC3	pH, Salinity and Electrical Conductivity
PC4	Soil Texture
PC5	Chemical and Mineral Content with Ionic Balance
PC6	Micronutrient and Mineral Content

The newly assigned names for the PCA components are presented in Table 3.

When examining the high loading values for each component, it is observed that certain groups of variables stand out. Accordingly, representative names were assigned to the PCA components based on the structural similarities of the dominant variables they contain. For example, in PC1, variables such as 'Saturation with Water (%)', 'Clay (%)', 'Total Salt (%)', and 'Mg meq/l', which are related to physical structure, moisture, and salinity, have high loading values. Therefore, this component was named 'Soil Physical Structure, Moisture and Salinity'. Similarly, in PC2, variables like 'Na meq/l', 'SAR', and 'ESP', which are associated with sodium and ionic balance, are prominent, and thus the component was named 'Mineral Content and Ionic Balance'. For the other components as well, the dominant variables were evaluated collectively, and each component was named with meaningful and descriptive titles that reflect the representative structure in the data.

Before the clustering process, the Elbow Method was applied to determine the most appropriate number of clusters and the optimal number of clusters, i.e. the optimal number of clusters, was determined through this method.

Figure 11.
Optimal number of clusters with Elbow method



As can be seen from Figure 11, the most significant break in the curve gives the optimal number of clusters and this number of clusters is observed as k = 3. Thus, the data set is divided into three clusters.

The K-Means clustering analysis classified the soil samples into three groups. Soils with similar physical and chemical properties were grouped together. Cluster centroids were calculated based on the mean values of the relevant principal components, and the results are presented in Table 4.

Table 4.

Categorization of soil variables based on PCA

	Soil Physical Structure, Moisture and Salinity	Mineral Content and Ionic Balance	pH, Salinity and Conductivity	Soil Texture	Chemical and Mineral Content with Ionic Balance	Micronutrient and Mineral Content
Cluster 0	1.120029	1.893867	-0.188349	-0.065788	0.065901	-0.049974
Cluster 1	1.745496	-1.325928	0.114344	0.006652	-0.108815	0.125175
Cluster 2	-1.930882	-0.266353	0.038773	0.036878	0.03467	-0.056196

These groups, identified through clustering, demonstrated that the soils were significantly differentiated according to fertility levels. These clusters were then used as labels in supervised learning algorithms, supplying data for classification. As shown in the image below, these three clusters are clearly separated.

As shown in Figure 12, Cluster 0 is primarily concentrated in the upper regions, and the soils in this cluster exhibit moderate moisture and salinity levels along with high mineral content. This structure indicates that these areas possess favorable and balanced soil properties for agriculture.

Cluster 1 is concentrated in the right sub-region and consists of soils with high moisture and salinity but low mineral content. This group represents soils that may be considered fertile but require additional fertilizer supplementation.

Cluster 2 is in the left sub-region and is generally characterized by low moisture, low salinity, and average mineral content. This indicates that the soils in this cluster are arid, have low fertility, and offer limited suitability for agricultural production.

Figure 13 displays the locations of agricultural lands in the Odunpazarı district of Eskişehir province, according to the cluster labels obtained by the K-Means algorithm.

Figure 12.

Clustering of soils

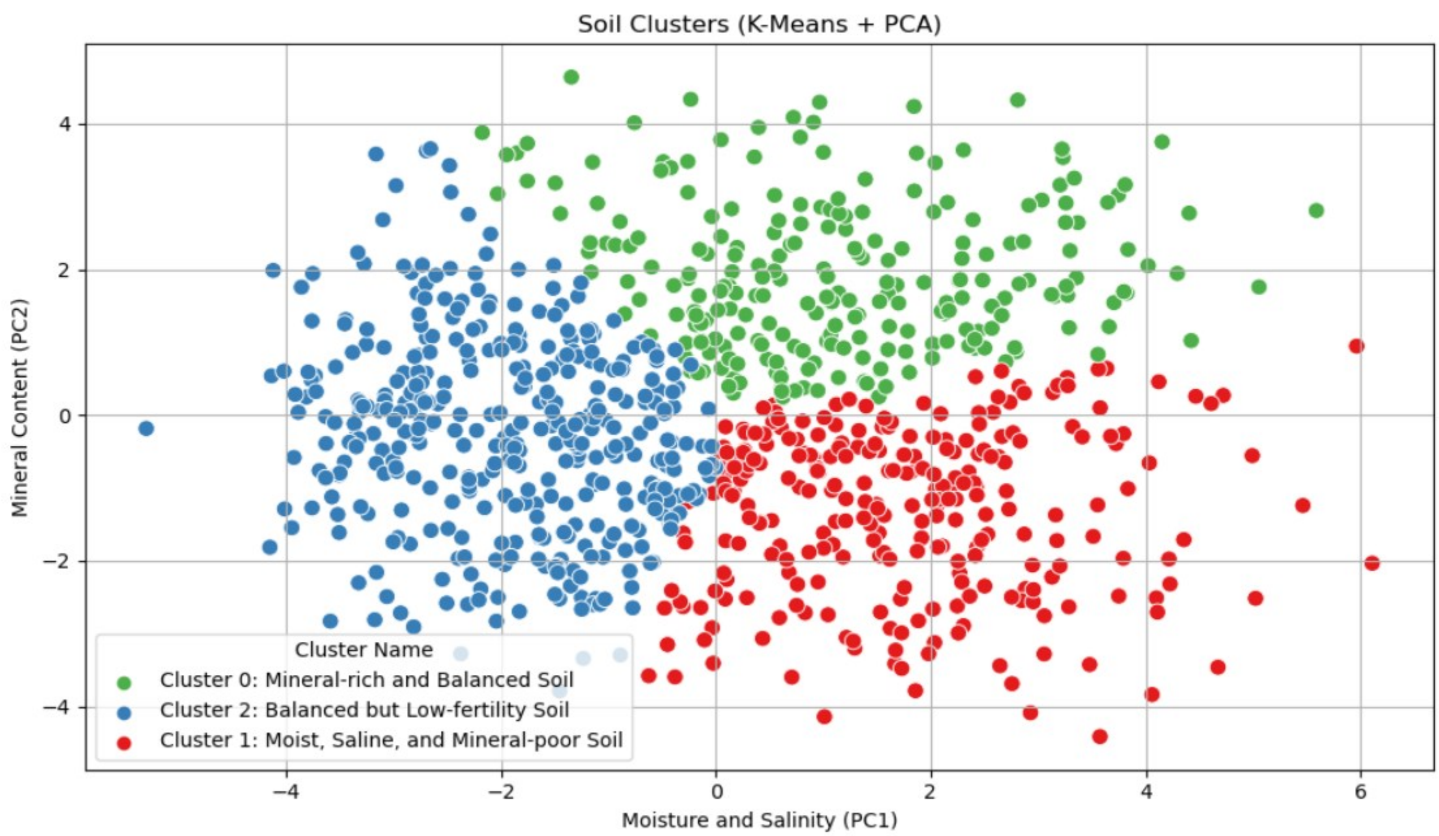
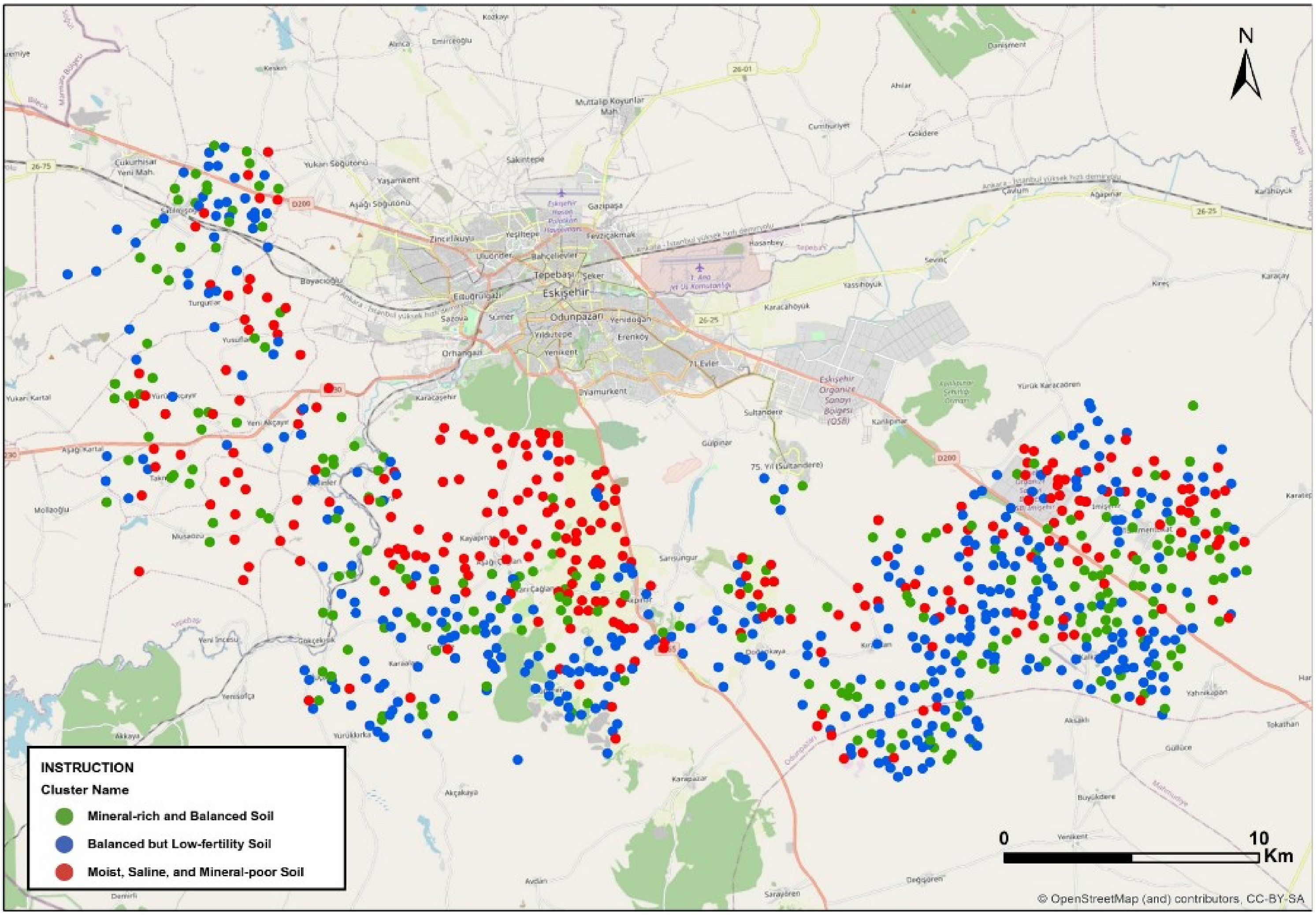


Figure 13.

Location of the fields according to the determined clusters



Mineral-rich and balanced soils (Cluster 0) generally exhibit a scattered distribution on the map, with higher concentrations especially in the western and eastern regions. This cluster is suitable for cereal, vegetable, and fruit cultivation. These soils have low fertilizer requirements and moderate irrigation needs. They are suitable for cereals such as wheat, barley, and corn, as well as vegetables like tomato, pepper, and eggplant, and fruits such as grape, apple, and pear. Moist, saline, and mineral-poor soils (Cluster 1) are generally densely clustered in central regions. These soils have a high-water retention capacity and are therefore particularly suitable for water-resistant crops like rice. With fertilizer support, vegetables such as spinach, lettuce, and beet, as well as salt-tolerant crops like barley and oats, are also suitable for these soils. Balanced but low-fertility soils (Cluster 2) are more distinctly clustered in eastern regions and consist of dry, low-salinity, sandy soils. These areas are more limited in terms of soil fertility and can be considered suitable for dry farming, pasture, or soil rehabilitation. Crops such as chickpea, lentil, bean, alfalfa, vetch, sainfoin, sesame, and safflower are suitable for these soils.

In Phase 2 of the study, these clusters were treated as label variables to establish a suitable framework for the supervised learning process. Additionally, at this stage, PCA was applied again to reduce the dimensionality of the dataset and minimize the impact of correlations between variables, and the first six components explaining 80% of the total variance were included in the analysis.

The resulting dataset was divided into two subsets: 80% for training and 20% for testing. To ensure proportional representation of each class in both subsets, a stratified train/test split was applied. This approach helped to reduce the potential impact of class imbalance on the model. All pre-processing steps were applied exclusively to the training data, while the test data remained independent of these processes. This approach eliminated the risk of data leakage during model evaluation. Four different classification algorithms were employed within the scope of supervised machine learning: Logistic Regression, Decision Tree, Random Forest, and KNN models. Each model was trained on the training data and subsequently evaluated using the test data. The performance of the models has been comparatively analyzed based on metrics such as accuracy, precision, recall, and F1 score. Below is a table containing detailed performance data for each model, including accuracy, precision, recall, and F1 score. This table allows for a clearer understanding of how each model performs across various metrics.

Table 5.

Evaluation metrics of models

Model	Accuracy	Precision	Recall	F1 Score
Logistic Regression	0.9889	0.9895	0.9895	0.9895
Decision Tree	0.9779	0.9784	0.9784	0.9784
Random Forest	0.9613	0.9658	0.9593	0.9621
KNN	0.9171	0.9143	0.9143	0.9143

Table 5 compares the performance of four different classification algorithms based on metrics such as accuracy, precision, recall, and F1 score. Logistic Regression has demonstrated the highest overall performance. With an accuracy rate of 98.9%, this model also achieved similarly high values for other metrics such as precision, recall, and F1 score. The results suggest that Logistic Regression is a reliable and balanced model that can make accurate predictions even when classes are imbalanced. The Decision Tree model achieved an accuracy rate of 97.8%, falling behind Logistic Regression in terms of accuracy. However, it still delivered strong results for precision, recall, and F1 score. The Random Forest model, with an accuracy of 96.1%, ranks third in terms of accuracy but has demonstrated a well-balanced performance in terms of precision and recall. The KNN model, in contrast, performs the weakest among the four, with an accuracy rate of 91.7%, placing it at the bottom. Its precision, recall, and F1 score values are also lower compared to the other models.

In conclusion, while Logistic Regression generally yields the best results, Random Forest and Decision Tree also provide strong alternatives. KNN, on the other hand, demonstrates a more limited performance, with lower accuracy compared to the other models.

In the study conducted by Hayattu et al. (2020) in the Northwestern region of Nigeria, soils were categorized into soil fertility classes using the K-Means clustering algorithm. Based on soil parameters such as nitrogen, phosphorus, potassium, organic matter, and pH, three clusters were obtained, corresponding to high, medium, and low soil fertility levels. Similarly, in the present study, soils from the Odunpazarı district were classified into three groups according to their mineral content, moisture, and salinity levels. This shows clear similarities with the Nigerian case. However, while Hayattu et al. (2020) relied solely on clustering methods for soil fertility assessment, the current study additionally applied supervised classification techniques, with Logistic Regression achieving the highest accuracy of 99%. Therefore, although consistent with the international literature, this study further contributes by integrating both clustering and classification approaches, thus providing stronger predictive performance.

In addition, when comparing the classification of soil types using machine learning with other studies, for instance, Taher et al. (2021), 400 soil samples from the Northwestern region of Nigeria were analyzed using 13 soil component attributes to construct different soil fertility classes. According to the experimental results, the highest accuracy was obtained with the KNN algorithm (84%), while Naïve Bayes achieved 69.23%, and both Decision Tree and Random Forest reached 53.85%. In the present study, the Logistic Regression model achieved the highest performance with an accuracy of 98.9%. Unlike the aforementioned studies in the literature, this model yielded higher accuracy values. This discrepancy may be attributed to differences in the type and number of variables used in the dataset, as well as the variation in sample sizes.

This study has certain limitations. First, the dataset used includes only soil analysis results from the Odunpazarı district of Eskişehir. Therefore, the generalizability of the findings is limited, and they should be supported by similar studies conducted in different regions. Moreover, the dataset does not cover other agricultural factors such as climate conditions, irrigation practices, and crop diversity. Future research is recommended to utilize datasets with broader geographical coverage and to compare results obtained through different methods.

Conclusion and Recommendations

This study evaluated the soil fertility of the Odunpazarı district in Eskişehir province, located in Türkiye’s Central Anatolia Region, using soil analysis data and machine learning techniques. After applying PCA for dimensionality reduction, the K-Means algorithm was used to classify the soils into three categories. These clusters showed clear differences in physical structure, moisture, salinity, and mineral content, providing important insights into regional soil fertility.

The clustering results offer practical implications for farmers. Green areas, with high mineral content and balanced moisture, are suitable for cereals, vegetables, and fruits, with relatively low fertilizer requirements. Red areas, characterized by high moisture and salinity but low mineral levels, are suitable for water-tolerant crops such as rice and can also support vegetable production with fertilizer supplementation. Blue areas, which are drier and less fertile, are more appropriate for dry farming, grazing, or soil rehabilitation. This classification supports farmers in making scientifically informed decisions on crop selection and resource management.

For policymakers, the findings emphasize the importance of region-specific strategies. In green areas, crop diversification and improvements in marketing infrastructure can be encouraged. In red areas, fertilizer subsidies, the expansion of drip irrigation systems, and the promotion of organic soil improvement practices should be prioritized. In blue areas, rather than intensive agricultural activities, long-term land rehabilitation projects, erosion control, and pasture management policies should be implemented. This approach would shift agricultural support from a uniform model to region-specific strategies, leading to more efficient resource use, stronger food security, and sustainable soil fertility management at the national level.

These findings make significant contributions to precision agriculture by guiding practices such as fertilization, irrigation, and crop selection. Providing farmers with evidence-based recommendations supports efficient resource use while strengthening environmental sustainability.

Future research can expand these findings in several directions. Larger and multi-regional datasets would enhance the generalizability of results. Multi-season and time-series data could more accurately capture the seasonal variability of soils. The integration of climate data (e.g., rainfall, temperature, drought indices) would improve predictive accuracy and provide insights into the impacts of climate change on soil fertility. Furthermore, the application of deep learning models (CNNs, RNNs, hybrid architectures) could increase classification accuracy and strengthen crop recommendation systems. In addition, the proposed approach could be practically implemented by integrating it with farm decision support tools and mobile applications, allowing farmers to make real-time, data-driven decisions. When combined with real-time soil monitoring systems, operations such as irrigation, fertilization, and crop selection can be managed more quickly and precisely. Transforming these models into user-friendly mobile and web-based decision support systems would further facilitate informed decision-making and accelerate the adoption of smart agriculture practices. Consequently, these findings can serve as a strong reference for future soil fertility research conducted in different regions.

Peer-review: Externally peer-reviewed.

Ethics Committee Approval: This study was conducted solely using environmental/soil data and did not involve any human participants, personal data, or animal experiments. Therefore, ethical committee approval was not required.

Author Contributions: Concept – EG; Design - SB, ESÇ, Eİ, İA; Supervision - EG; Resources - SB, ESÇ, Eİ, İA; Data Collection and/or Processing - SB, ESÇ, Eİ, İA; Analysis and/or Interpretation - SB, ESÇ, Eİ, İA; Literature Search - SB, ESÇ, Eİ, İA; Writing Manuscript - SB, ESÇ, Eİ, İA; Critical Review - EG; Other - SB, ESÇ, Eİ, İA, EG

Conflict of Interest: The authors have no conflicts of interest to declare.

Financial Disclosure: The authors declared that this study has received no financial support.

Hakem Değerlendirmesi: Dış bağımsız.

Etik Komite Onayı: Bu çalışma, yalnızca çevresel/toprak verileriyle yürütülmüş olup herhangi bir insan katılımcı, kişisel veri ya da hayvan deneyi içermemektedir. Bu nedenle etik kurul onayı gerekmemektedir.

Yazar Katkıları: Konsept - EG; Tasarım - SB, ESÇ, Eİ, İA; Denetim - EG; Kaynaklar - SB, ESÇ, Eİ, İA; Malzemeler - SB, ESÇ, Eİ, İA ; Veri Toplama ve/veya İşleme - SB, ESÇ, Eİ, İA; Analiz ve/veya Yorum - SB, ESÇ, Eİ, İA; Literatür Taraması - SB, ESÇ, Eİ, İA; Yazma - SB, ESÇ, Eİ, İA; Eleştirel İnceleme - EG; Diğer – SB, ESÇ, Eİ, İA, EG

Çıkar Çatışması: Yazarlar çıkar çatışması olmadığını beyan etmiştir.

Finansal Destek: Yazarlar, bu çalışma için finansal destek almadığını beyan etmiştir.

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Derleme Makalesi *Review Article* DOI: 10.17097/agricultureatauni.1636831

Gastronomide Fonksiyonel Ürün Kapsamında Kullanılan Pseudotahıllar

Pseudocereals Used as Functional Products in Gastronomy

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ÖZ

Son yıllarda tüketiciler, sağlıklı yaşam tarzlarını benimseme ve besleyici gıdalar tüketme konusunda giderek daha bilinçli hâle gelmiştir. Bu eğilim, geleneksel tarım ürünlerine olan ilgiyi çeşitlendirmiş; alternatif ve fonksiyonel besin kaynaklarına yönelimi artırmıştır. Bu bağlamda, uzun yıllar boyunca ikincil ürün olarak değerlendirilen pseudo tahıllar, 21. yüzyılın başlarından itibaren yeniden keşfedilmiş ve üretim süreçlerinde daha fazla yer bulmaya başlamıştır. Pseudo tahıllar, iyi kaliteli proteinlerle olağanüstü bir besinsel ve fitokimyasal profile sahip tahıllardır. Glutensiz ürün alternatifi olarak öne çıkartılmış olan pseudo tahıllar son çalışmalarda, içerisinde bulunan diyet lifleri, vitaminler, mineraller, fenolikler ve diğer biyoaktif bileşenlerle kanser, diyabet, hipertansiyon ve kardiyovasküler hastalıklar gibi kronik rahatsızlıklarla mücadele etme potansiyeline sahip ürünler olarak öne çıkarılmaktadır. Bu derleme çalışmasında da pseudo tahılların glutensiz ürün geliştirme kapsamında kullanımı dışında amino asit örüntüleri ve diğer biyoaktif bileşenleri ön plana çıkartılarak sağlık üzerine etkileri hakkında detaylı literatür taraması yaparak bu ürünlerin sürdürülebilir gastronomi uygulamalarına kazandırılması amaçlanmaktadır. Elde edilen bilgiler pseudo tahılların toplam protein içeriğinin, elzem amino asit içeriğinin, vitamin, mineral ve diğer biyoaktif bileşen içeriklerinin tahıllardan daha yüksek olduğunu ve filizlendirme işlemleri ile besin öğelerinin biyoyararlılıklarının artırılabildiği ve bu pseudo tahılların tüketiminin kan glikozu, lipit profili ve antioksidan kapasite seviyeleri gibi değerlerde iyileştirmeler yaparak hastalıklara karşı koruyucu olabileceklerini vurgulamaktadır. Pseudo tahılların filizlendirme uygulamalarında depolama ile besin öğeleri içerik değişimleri üzerine yapılmış çalışmalar kısıtlıdır. İleriki çalışmalar bu eksikler üzerine yoğunlaşabilir.

Anahtar Kelimeler: Biyoaktif bileşenler, Beslenme, Elzem amino asitler, Gastronomi, Pseudo tahıllar, Sağlık

ABSTRACT

In recent years, consumers have become increasingly conscious of adopting healthy lifestyles and demanding nutritious food products. This shift in consumer behavior has diversified interest in conventional agricultural products and led to a growing inclination toward alternative and functional food sources. In this context, pseudo-cereals—once regarded as secondary crops for many years—have been rediscovered and have started to gain prominence in agricultural production processes since the early 21st century. Pseudocereals are grains with an exceptional nutritional and phytochemical profile, rich in high-quality proteins. Promoted as gluten-free product alternatives, pseudocereals have been highlighted in recent studies for their potential to combat chronic diseases such as cancer, diabetes, hypertension, and cardiovascular diseases, owing to their dietary fibers, vitamins, minerals, phenolics, and other bioactive compounds. This review aims to evaluate the health effects of pseudocereals, focusing on their protein patterns and other bioactive compounds, alongside their use in gluten-free product development. Additionally, it seeks to assess their role in producing healthy products within sustainable gastronomy applications through a detailed literature review. The findings indicate that pseudocereals have higher total protein content, essential amino acid profiles, vitamins, minerals, and other bioactive components compared to grains. Moreover, sprouting processes enhance the bioavailability of nutrients in pseudocereals. Their consumption has been shown to improve parameters such as blood glucose, lipid profiles, and antioxidant capacity, offering protective effects against diseases. However, studies on changes in nutrient content during storage in sprouting applications of pseudocereals are limited. Future research could focus on addressing these gaps.

Keywords: Bioactive compounds, Nutrition, Essential amino acids, Gastronomy, Pseudocereals, Health

Received Date:	10.02.2025
Revision Request Date:	08.07.2025
Last Revision Date:	03.08.2025
Accepted Date:	07.08.2025
Publication Date:	26.09.2025

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Cite this article: Özer Altundağ, Ö. (2025). Pseudo-Cereals Used as Functional Products in Gastronomy. *Research in Agricultural Sciences, 56*(3), 256-268.

Giriş

Karbonhidratlar, insan beslenmesinde temel enerji kaynağı olarak önemli bir rol üstlenmektedir. Bu bağlamda tahıllar, pek çok toplumda enerji ihtiyacını karşılamak amacıyla yaygın olarak tüketilen başlıca besin grubudur. Ancak son yıllarda, tahıl tüketiminde görülen düzensizlikler ve miktar açısından dengesiz alım, toplum genelinde metabolik bozuklukların görülme sıklığını artırmıştır. Bu tür beslenme dengesizlikleri, diyabet, obezite ve kardiyovasküler hastalıklar gibi metabolik rahatsızlıkların gelişmesinde etkili olabilmektedir. Bu nedenle, bireylerin beslenme alışkanlıklarında daha sağlıklı tercihlere yönelme eğilimi artmış; özellikle daha yüksek kaliteli protein, diyet lifi, doymamış yağ asitleri ve biyoaktif bileşikler içeren "pseudo-tahıllar" (yalancı tahıllar) alternatif birer besin kaynağı olarak öne çıkmaya başlamıştır (Nandan vd., 2024). İnsan oğlunun yemek hazırlamada sıklıkla mısır, buğday ve pirinç gibi tahılları kullanması; bireylerin protein içeriği düşük, gluten içeriği yüksek karbonhidrat türlerinden zengin bir diyete doğru kaymasına ve buna bağlı olarak da bireylerde obezite ve kalp hastalıkları gibi sağlık sorunlarının yaygınlığının artmasına neden olmaktadır (Bekkering ve Tina, 2019). Pseudo tahıllar içerdiği makro ve mikro bileşenler sayesinde son dönemde sürdürülebilir, gluten içermeyen, kaliteli protein kaynakları olarak giderek daha popüler hale gelmektedir (Vidaurre-Ruiz vd., 2023). Yalancı tahıllar olarak da bilinen pseudo-tahıllar, görünüm ve nişasta içeriği bakımından gerçek tahıllara benzerlik gösteren ancak botanik olarak çift çenekli bitkiler sınıfına ait olan besin kaynaklarıdır (Graziano vd., 2022). Bu bitkisel ürünler, yalnızca temel enerji sağlayıcı olarak değil, aynı zamanda sağlığa yönelik çeşitli fonksiyonel özellikleri nedeniyle de giderek daha fazla ilgi görmektedir. Yapılan çalışmalar, pseudo-tahılların hipolipidemik (kan yağlarını düşürücü), anti-inflamatuar, anti-hipertansif, antikanser ve hepatoprotektif (karaciğer koruyucu) etkilere sahip olduğunu göstermektedir. Ayrıca bu besinlerin obezite, diyabet gibi yaygın metabolik hastalıkların önlenmesi ve yönetiminde olumlu katkılar sunduğu da bilimsel olarak ortaya konmuştur. Bu kapsamda, pseudo-tahıllar sadece besleyici değerleriyle değil, aynı zamanda sağlık üzerine olan çok yönlü etkileriyle de fonksiyonel gıda kategorisinde değerlendirilmektedir (Nandan vd., 2024). Pseudo tahılların tohumları, makarna ve fırın ürünleri üretiminde, gluten içermeyen uygun un haline getirilebilmekte ve kullanılmaktadır. En popüler pseudo tahıllar kinoa (*Chenopodium quinoa Willd*), amarant (*AmaranthusL. spp.),* karabuğday (*Fagopyrum esculentum Moench*) ve Tatar karabuğdayı (bir diğer karabuğday türü) (*Fagopyrum tataricum (L.) Gaertn*)'dır (Pirzadah ve Malik, 2020).

Amarant, karabuğday ve kinoa gibi pseudo tahıllar, buğday, pirinç ve mısır gibi geleneksel tahıllara kıyasla daha yüksek protein içeriği, kaliteli bir amino asit örüntüsü, doymamış yağ asitleri içeriği, iyi bir diyet lifi içeriği ve temel mikro besin maddeleri içeriğine sahiptir (Ugural ve Akyol, 2022). Pseudo tahıllar; demir, kalsiyum ve çinko gibi temel minerallerin yanı sıra, fenolik bileşikler, flavonoidler, karotenoidler ve prebiyotikler gibi çeşitli fitokimyasallar açısından buğday ununa kıyasla daha zengin bir içeriğe sahiptir. Bu özellikleri sayesinde, besinsel açıdan yüksek değer taşıyan ve sağlık üzerine olumlu etkiler sunan alternatif un kaynakları olarak değerlendirilmektedir. Ancak, pseudo tahılların doğal olarak gluten içermemesi, gıda endüstrisinde özellikle yapısal bütünlüğü ve elastikiyeti gluten sayesinde sağlanan ürünlerin üretiminde bazı teknolojik zorluklara yol açmakta ve yüksek kaliteli glutensiz ürünlerin geliştirilmesini sınırlayabilmektedir (Poshadri vd., 2023). Bu amaçla bu ürünlerle glutensiz ürün üretiminde nohut unu, soya fasulyesi unu, yer fıstığı unu, yumurta beyazı ve süt tozu gibi besinler kullanılarak, üretilen ürüne istenilen kalite kazandırılmaktadır (Hayıt ve Gül, 2017). Pseudo tahıllar; işlevsel, sosyal, ekolojik ve ekonomik özelliklerinin yanı sıra besinsel açıdan zengin olmaları ve sert iklim koşullarına uyum sağlayabilme yetenekleri sayesinde kullanım açısından dikkat çekmektedir (Shahbaz vd., 2023). Bu çalışmada kısaca dört yalancı tahıl besin öğeleri açısından incelenmiş ve sağlık üzerine etkileri belirtilmiştir.

Pseudo Tahıllar

Dünya nüfusunun 2050 yılında 9,7 milyara ulaşması beklenmektedir. Bu doğrultuda, pseudo tahıllar, artan nüfusun besin ihtiyacını karşılamada ve gıda güvenliğini sağlamada potansiyel bir temel kaynak olarak değerlendirilmektedir. Birleşmiş Milletler Gıda ve Tarım Örgütü (FAO), gıda güvenliğini; tüm bireylerin her zaman, aktif ve sağlıklı bir yaşam sürdürebilmeleri için gerekli olan yeterli, güvenli ve besleyici gıdaya fiziksel ve ekonomik açıdan erişebilme durumu olarak tanımlamaktadır. (Birleşmiş Milletler Gıda ve Tarım Örgütü (FAOSTAT, 2015). Pseudo tahıllar, yalnızca yüksek biyolojik değere sahip protein kaynaklarının sınırlı olduğu ülkelerde besin değeri açısından değil, aynı zamanda gıda üretiminin kısıtlı olduğu durumlarda sosyoekonomik açıdan da önemli potansiyel faydalar sunan alternatif ürünlerdir. Dahası, çevresel bir bakış açısında değerlendirildiğinde, pseudo tahıllar doğal kaynak çeşitliliğini iyileştirebilir ve artırabilir niteliktedir. Olumsuz iklim koşullarında ekolojik uyum sağlama yeteneği ve yüksek besin değeri nedeniyle pseudo tahıllar ekonomik, sosyal, ekolojik, besinsel ve işlevsel bir üründür (Morales vd., 2021).

Kinoa

Kinoa, *Chenopodiaceae* familyasından, *Chenopodium* cinsinden, Şili, Peru, Ekvador ve Bolivya'nın And Dağları bölgelerine özgü bir bitkidir ve yetiştirilmesi binlerce yıl öncesine dayanmaktadır. Kinoa *(Chenopodium quinoa Willd.*), ıspanak ve pancarla aynı olan *Chenopodiaceae* ailesine aittir ve *Chenopodium* cinsi dünya çapında yaklaşık 250 tür olarak tanımlanmıştır (Nandan vd., 2024). Kinoanın Güney Amerika'nın And bölgesinden geldiği ve buradan Peru, Ekvador ve Bolivya'ya dağıldığı; tuza, kuraklığa, soğuğa ve çoraklığa dayanıklı özelliklere sahip olduğu belirtilmektedir (Shahbaz vd., 2023). Birleşmiş Milletler Gıda ve Tarım Örgütü (UNFAO) tarafından halkın temel besin ve diyet gereksinimlerini karşılayan bir bitki olarak tanınan tek besin maddesidir ve ilkel İnka uygarlığı arasında "tahılın anası" olarak da bilinmektedir (Ahmed vd., 2018). Pirinç, buğday ve mısır sırasıyla %56, %49 ve %36 biyolojik değere sahip iken kinoa %73 biyolojik değere sahiptir. Sığır eti yaklaşık %74 biyolojik değere sahiptir. Bu durum da kinoa'nın diyet değerinin bir et ürününün diyet değerine neredeyse eşit olduğu anlamına gelmektedir (Tang vd., 2015). Benzersiz viskozitesi ve donma kararlılığı nedeniyle kinoa nişastası çeşitli gıda ürünlerinin üretiminde kullanılmaktadır (Nandan vd., 2024).

Chia

Chia (*S. hispanica*) yıllık, çiçekli bir bitki olarak bilinir ve nane ailesi *Lamiaceae*'ye aittir. "Chia" kelimesi, yağlı anlamına gelen bir Nahuatl kelimesi olan "chian"dan türemiştir. Bu bitki Güney Amerika'da yeni tanınan bir ürün olup Kuzey Guatemala ve Güney Meksika'ya özgüdür ve çoğunlukla subtropikal ve ılıman bölgelerin dağlık alanlarında yetiştirilmektedir (Shahbaz vd., 2023). Chia tohumları büyük miktarda lif ve omega-3 yağ asitleri, yeterli miktarda protein ve çok sayıda önemli mineral ve antioksidan içermektedir. Chia tohumlarının, sindirim sağlığını desteklediği, kandaki omega-3 yağ asitleri düzeylerini artırdığı ve kardiyovasküler hastalıklar ile diyabet gibi kronik hastalıkların risk faktörlerini azaltmada potansiyel faydalar sunduğu bildirilmektedir. Chia tohumları iyi bir yağ, diyet lifi, mineraller, polifenolik bileşikler ve protein kaynağı olarak kullanılmaktadır (Nandan vd., 2024; Shahbaz vd., 2023).

Chia; musilaj, tam tohumlar, tohum yağı ve un formunda kullanılmaktadır. Chia tohumları tek başına veya salatalar, meyveler ve yoğurtlar gibi diğer gıda maddelerine eklenerek ve ayrıca kek, ekmek, granola barlar ve içeceklerin hazırlanmasında kullanılmaktadır (Shahbaz vd., 2023; Vuksan vd., 2007).

Amarant

Amaranthaceae familyası aynı zamanda "*Amaranth* familyası" olarak da anılır. Amaranthus, uzun ömürlü ve solmayan anlamına gelen bir Yunanca "Anthos" (çiçek) kelimesidir. Bu bitki çok hızlı büyür ve tropikal bölgelerde, daha düşük üretim fiyatı nedeniyle çok ucuz koyu yeşil renkli sebze olarak bilinmektedir. Bu özellikleri nedeniyle bu bitki yaygın olarak fakir halkın sebzesi olarak bilinmektedir. Amarant genellikle dünyanın ılıman, tropikal ve subtropikal bölgelerinde görülmektedir. Diğer yeşil sebzelerin aksine, başka yeşil sebze bulunmadığı yaz aylarında hasat edilmektedir (Shahbaz vd., 2023). Amarant, protein, karbonhidrat, lipit (özellikle omega 6 doymamış yağ asitleri), lif, vitamin, mineral ve polifenoller, tokoferoller, fitosteroller ve skualen dahil olmak üzere birçok biyoaktif madde açısından zengin bir kaynaktır (Nandan vd., 2024). Amarant, flavonoidler, pigmentler, fenolikler, karotenoidler ve C vitamini gibi doğal antioksidan bileşenleri bol miktarda içermektedir. Bu doğal antioksidan bileşenlere sahip ürün, kardiyovasküler hastalıklar, kanser, katarakt, ateroskleroz, retinopati, artrit, amfizem ve nörodejeneratif hastalıklar gibi çeşitli hastalıklara karşı savunma sağladığı belirtilmektedir (Sarker vd., 2020).

Amarantın, gelişmekte olan ülkelerdeki yoksul halk için özellikle protein açısından zengin besinler için ekonomik bir alternatif olabilen bir tahıl ürünü ve sebze olarak kullanılması gerektiği vurgulanmaktadır. Tohumları tahıl olarak tüketilirken yaprakları sebze olarak tüketildiği için benzersiz bir bitki olarak belirtilmektedir. Amarant, gıda endüstrisinde krep, erişte, makarna, bisküvi, şekerleme, kurabiye vb. gibi birçok ürünün yapımında kullanılmaktadır (Shahbaz vd., 2023).

Karabuğday

Karabuğday, genellikle tahıl grubuyla ilişkilendirilen fakat tahıl olmayan, tahıl benzeri tohumlardır ve familyası *Polygonaceae*'dir. Dünya çapında tüketilen ve üretilen iki ana karabuğday türü vardır, bunlar tartar karabuğdayı (yeşil karabuğday, *Fagopyrum tataricum*) ve yaygın karabuğdaydır (*Fagopyrum esculentum*) (Nandan vd., 2024). Karabuğday, yalancı tahıllardan biridir ve dünyanın soğuk bölgelerinde yaygın olarak kullanılmaktadır. Karabuğday çeşitleri çoğunlukla dağlık bölgelerde, özellikle Rusya ve Çin'de bulunmaktadır (Sofi vd., 2023). Adında buğday ifadesi yer almasına rağmen, bitki buğdayla bağlantılı değildir. Buğday yerine karabuğday, kuzukulağı, ravent ve düğüm otu ile ilişkilendirilmektedir. Karabuğday bitkisi, protein, karbonhidrat, diyet lifi, B grubu vitaminler, temel amino asitler ve mineraller bakımından zengin içeriğiyle hem insanlar hem de hayvanlar için değerli bir besin kaynağı olarak öne çıkmaktadır. Ayrıca, sahip olduğu fenolik bileşikler sayesinde etkili bir antioksidan kaynağı olarak değerlendirilmektedir. Bu pseudo tahılda bazı anti-besinsel faktörler bulunsa karabuğday, hayvan ve insan sağlığına yardımcı olmak için değerli besin bileşenleri içermesi sebebiyle insan beslenmesinde ve hayvan yemi üretimde etkili bir ürün olarak değerlendirilebileceği bildirilmektedir (Shahbaz vd., 2023).

Karabuğday tohumları, genellikle kahvaltılık gevreklerin üretiminde kullanılmakta olup; yulaf ezmesi, un ve ekmek gibi fırıncılık ürünleri ile birlikte çay, bal ve filizlenmiş formları gibi zenginleştirilmiş ürünlerde de yaygın olarak değerlendirilmektedir (Hayıt ve Gül, 2017). Karabuğday ve yan ürünlerinin çeşitli sağlık yararları (hipoklesterolemik, hipoglisemik, antikanser ve anti-inflamatuar) fonksiyonel gıda formülasyonu potansiyelini artırdığı ve tarımsal, endüstriyel ve farmasötik kullanımları artarak üretiminin geliştiği belirtilmektedir (Dizlek vd., 2009; Hayıt ve Gül, 2015; Sofi vd., 2023).

Pseudo Tahılların Kimyasal Bileşenleri

Tüm pseudo tahıllar mısır, buğday ve pirinçten daha yüksek protein ve lipit içeriğine ve daha düşük karbonhidrat içeriğine sahiptir. Tahıl tanelerinin aksine pseudo tahıllar, diyet lifi, doymamış yağ asitleri, lignanlar, antioksidanlar, flavonoidler, polifenoller, fitosteroller, mineraller, vitaminler, yüksek sindirilebilirlik ve biyoyararlanımlı dengeli amino asit bileşimine sahip yüksek kaliteli proteinler ve temel mikro besinler dahil olmak üzere biyoaktif bileşikler açısından zengin ürünlerdir (Nandan vd., 2024). Aşağıda pseudo tahılların Beslenme Bilgi Sistemleri (BeBiS 9) programından elde edilen makro ve mikro besin öğeleri verilmiştir (Bebis, 2021).

Pseudo tahılların protein içerikleri (100g üründe) yüksekten düşüğe göre sırasıyla çiya (chia), amarant, kinoa ve karabuğdaydır. Omega 3 içeriği bakımından ise en zengin olan ürün çiyadır (17,8 g/100g). Ayrıca çiyanın 100 g tüketilmesi ile 34,4 gram lif sağlanmakta olup bu değer yetişkin bir bireyin ihtiyaçlarını tam olarak karşılamaktadır (Tablo 1).

Pseudo tahılların elzem amino asit örüntüsü incelendiğinde en yüksek elzem amino asit miktarına kinoanın (6,7g /100g) sahip olduğu, bunu 6,5g/100g ile amarantın takip ettiği görülmektedir. Pseudo tahıllar arasında elzem amino asit toplam miktarı en düşük olan ve elzem amino asitlerinin tamamını içermeyen sadece Chia'dır (Tablo 2).

Tablo 1.
Pseudo tahılların makro besin öğeleri içerikleri (100g) (BeBiS, 2021).

Besin öğeleri	Karabuğday	Amarant	Kinoa	Chia
Enerji (kcal)	343,5	385,0	355,6	486,1
Protein (g)	9,8	14,4	12,2	16,5
Yağ (g)	1,7	6,5	5,9	30,7
Karbonhidrat (g)	71,0	66,2	62,4	42,1
Lif (g)	3,7	9,3	6,9	34,4
Tekli doymamış yağ asidi (g)	0,5	1,5	1,3	2,3
Çoklu doymamış yağ asidi (g)	0,6	2,9	2,6	23,7
C18:3 yağ asidi (omega 3) (g)	0,1	0,1	0,2	17,8

Tablo 2.
Pseudo tahılların amino asit içerikleri (100g) (BeBiS, 2021).

Besin öğeleri	Karabuğday	Amarant	Kinoa	Chia
Lizin (mg)	539,0	747,0	860,0	1,0
Valin (mg)	613,0	679,0	633,0	1,0
Lösin (mg)	613,0	879,0	930,0	1,0
İzolösin (mg)	455,0	582,0	718,0	1,0
Fenilalanin (mg)	381,0	542,0	530,0	1,0
Triptofan (mg)	158,0	181,0	165,0	0,0
Metiyonin (mg)	177,0	226,0	188,0	1,0
Treonin (mg)	437,0	558,0	590,0	1,0
Histidin (mg)	204,0	389,0	368,0	1,0
Arjinin (mg)	901,0	1060,0	1103,0	2,0
Elzem amino asit toplamı (g)	4,9	6,5	6,7	0,009
Elzem olmayan amino asit toplamı (g)	4,9	7,8	5,7	0,0
Bitkisel protein toplamı (g)	9,8	14,4	12,2	16,5

Proteinler

Proteinler dokuların inşası ve bakımı, enzimlerin, hormonların ve antikorların oluşumu, kas gücü ve metabolik süreçlerin düzenlenmesinde rol oynamaktadır. Amino asitler, nitrojene ek olarak vücuda kükürt bileşikleri sağlar. Lipoprotein formunda, trigliseritlerin, kolesterolün, fosfolipitlerin ve yağda çözünen vitaminlerin taşınmasında rol oynarlar (Filho vd., 2017).

Dünyadaki bazı popülasyonlar için, özellikle hayvansal proteini nadiren tüketen kişiler için, diyetlerine yüksek kaliteli protein eklemek bir sorundur; bu kişiler bunları tahıllardan, baklagillerden ve pseudo tahıllardan almalıdır (Filho vd., 2017). Pseudo tahılların, dünyanın protein kaynaklarının az olduğu bölgelerinde ve gıda üretiminin yetersiz kaldığı, sosyoekonomik açıdan düşük ülkelerde besin değeri açısından tahıllara ve diğer gıda ürünlerine bir alternatif olabileceği belirtilmektedir (Ahmad vd., 2022; Cumbane vd., 2022; Morales vd., 2021).

Pseudo tahıllar, tahıllarla karşılaştırıldığında daha yüksek miktarda ve kalitede proteine sahiptir. Çeşitliliğe bağlı olarak, amarant, kinoa ve karabuğdaydaki protein içerikleri sırasıyla %13,10-21,50, %8,01-22,01 ve %5,7-18,9 arasında değişebilmektedir. Tahıl taneleriyle karşılaştırıldığında, amarant, kinoa ve karabuğdaydaki proteinler çoğunlukla globulin ve albüminden, küçük bir oranda prolaminlerden oluşur ve daha yüksek lizin, metiyonin ve sistein içeriğiyle kaliteli bir amino asit dengesine sahiptir. Özellikle, amarant ve kinoa, tahıllarda sınırlı olan lizinin zengin kaynaklarıdır. Ek olarak, pseudo tahıllardaki yüksek arginin ve histidin seviyeleri onları bebek ve çocuklar için uygun besin haline getirmektedir (Nandan vd., 2024).

Kinoa tohumları, proteinlerinin kalitesi ve besin içeriği nedeniyle yeni bir besin kaynağı olarak dikkat çekmektedir. Özellikle lizin açısından zengindir ve bu da onu çoğu tahıl ve sebzeden daha protein açısından zengin bir besin yapmaktadır, özellikle amino asit bileşimi FAO (Gıda Tarım Örgütü) tarafından önerilen ideal protein dengesine yakın ve süte benzerdir. Kinoa tanesindeki protein içeriği %13,8 ile %16,5 arasında değişirken, ortalama %15' dir. Pirinç, mısır, arpa ve buğday gibi geleneksel tahıllarla karşılaştırıldığında daha yüksek seviyelerde toplam protein, metionin ve lizin içermektedir (Filho vd., 2017).

Sarker vd. (2020) tarafından yapılan bir çalışmada, amarant bitkisinin farklı genotiplerinde protein miktarlarının değişkenlik gösterdiği ve bu değerlerin 23,11 g/kg ile 54,98 g/kg arasında değiştiği rapor edilmiştir.

Karabuğday tohumları, dengeli amino asitlere sahip proteinlerin iyi bir kaynağıdır ve albüminler, globulinler, prolaminler ve glutelinler içermektedir. Karabuğday, çeşide, kaynağa ve iklim koşullarına bağlı olarak önemli bir protein (%8,5-%18,8) kaynağıdır. Karabuğday proteinleri glutenden arındırılmış olup, çölyak hastalığı olan kişiler tarafından kabul edilebilir bir ürün olarak değerlendirilmektedir. Karabuğday lösin, fenilalanin, lizin, treonin, izolösin, sistein gibi elzem aminoasitlerden ve asparagin açısından zengin bir kaynaktır (Sofi vd., 2023).

Proteinin besin kalitesi, esansiyel amino asitlerin oranıyla belirlenmektedir. Bu amino asitlerden yalnızca biri sınırlıysa, diğerleri de tam olarak emilemeyecektir, bu da diyet proteininin kaybına neden olacaktır. Dokuz amino asit yetişkin insanlar için elzemdir: fenilalanin, izolösin, lösin, lizin, metiyonin, treonin, triptofan, valin ve histidin (çocukluk çağında esansiyel) (Dünya Sağlık Örgütü (WHO), 2007). Bu amino asitler kinoa'da bulunur (Vega-Gálvez vd., 2010). Dolayısıyla kinoa, Gıda ve Tarım Örgütü (FAO) tarafından belirlenen değerlere yakın değerlerde insan yaşamı için gerekli tüm aminoasitleri sağlayan, kükürtlü aminoasitler ve lizin açısından zengin, kaliteli bir aminoasit dengesine sahip ender bitkisel besinlerden biridir ve özellikle lizin açısından yetersiz olan tahılların protein içeriğinin aksine, yüksek kaliteli bir protein ürünü olarak kabul edilebilmektedir (Filho vd., 2017).

Chia'da iyi protein içeriğine sahip bir diğer pseudo tahıldır. 100 gramında 16,54 gram protein içermektedir. Yetişkinler için elzem aminoasit örüntüsü tahıllara göre daha yüksektir (Alasalvar vd., 2021). Chia tohumları ağırlığının yaklaşık %18-24'ünü oluşturan bitkisel proteinin iyi bir kaynağıdır. Amino asit bileşiminin analizleri arasındaa en büyük içeriklerin arginin, lösin, fenilalanin, valin ve lizin olduğu belirtilmektedir (Kulczyński vd., 2019).

Karbonhidratlar

Kinoa, büyük ölçüde nişasta ve az miktarda şeker içeren yüksek karbonhidrat içeriğiyle dikkat çeken nişastalı bir ham madde olarak tanımlanabilir. Bununla birlikte, özellikle yüksek kaliteli protein içeriği sayesinde, besin değeri açısından zengin ve tam bir gıda kaynağı olarak kabul edilmektedir (Filho vd., 2017). Nişasta kinoa'nın ana karbonhidrat bileşenidir ve %52 ile %69 arasında bulunur. Toplam diyet lifi tahıllarda bulunan değere yakındır (%7-%9,7). Çözünebilir lif içeriğinin %1,3 ila %6,1 arasında olduğu bildirilmektedir. Kinoa çoğunluğu maltoz olmak üzere yaklaşık %3 basit şeker, ardından D-galaktoz ve D-riboz ve düşük seviyelerde fruktoz ve glikoz içermektedir (Abugoch, 2009).

Kinoa, buğdayda bulunan gluten oluşturan proteinler olan gliadinler ile arpa, çavdar, yulaf ve malt gibi tahıllarda bulunan benzer protein fraksiyonlarını içermemesi nedeniyle, halk arasında "glutensiz" olarak adlandırılan ürünlerin üretimi için uygun bir hammadde olarak değerlendirilmektedir. Bu özelliği, özellikle çölyak hastaları için daha besleyici ve çeşitlilik sunan glutensiz gıda seçeneklerinin geliştirilmesine katkı sağlamaktadır (Filho vd., 2017).

Nişasta, karabuğday tanelerinde %60 ila %70 arasında bulunan ana karbonhidrat kaynağıdır. Amiloz ve amilopektin, karabuğday nişastasında sırasıyla %25 ve %75 oranında bulunur. Karabuğday diğer pseudo tahıllardan daha fazla nişasta içeriğine sahiptir ve karabuğdayın kalori içeriği (343 cal/100 gr) tahıl ve baklagillere benzerdir. Diyet lifi, karabuğdayın ana bileşeni olup, diğer pseudo tahıllardan daha yüksektir ve tahıl tanelerine benzerdir. Karabuğdayın farklı işlenmiş fraksiyonlarında diyet lifi içeriğinin değişkenlik gösterdiği belirtilmektedir; bu oran kabuksuz formda %23,8'e, kabuklu formda ise %10,3'e kadar ulaşabilmektedir. Ayrıca bu konsantrasyonların, karabuğday çeşitleri arasında da farklılık gösterdiği ifade edilmektedir (Sofi vd., 2023).

Chia tohumları yaklaşık 30-34 g/100 g diyet lifi içerir; bunun yaklaşık %85-93'ünü çözünmeyen fraksiyon, yaklaşık %7-15'i ise çözünür diyet lifi formundadır. Diyet lifi içeriği açısından chia tohumları kurutulmuş meyveleri, tahılları veya kuruyemişleri geride bırakmaktadır (Kulczyński vd., 2019).

Yağlar

Kinoa tohumlarındaki lipitler yenilebilir bitkisel yağ olarak yüksek kaliteye sahiptir. Lipit bileşiminde soya fasulyesi yağına benzer yağ asitleri bulunmaktadır. Kinoa, lipid fraksiyonunun kalitesi ve miktarı nedeniyle alternatif bir yağ tohumu ürünü olarak kabul edilmiştir. Kinoa, linoleik ve α-linolenik gibi temel yağ asitleri açısından zengin olup %2,0-%9,5 arasında ortalama %7 yağ içeriğine sahiptir. Bu değer tahıl tanelerinden yüksek, soya fasulyesinden (%19) düşüktür. Kinoada bulunan en önemli doymuş yağ asidi palmitiktir ve bu, mevcut toplam yağ asitlerinin yaklaşık %10'una karşılık gelir. Doymamış yağ asitleri oleik (%19,7 ila %29,5), linoleik (%49,0 ila %56,4) ve linoleniktir (%8,7 ila %11,7) ve bunlar kinoa yağında bulunan toplam yağ asitlerinin %87,2 ila %87,8'ini oluşturur ve bu da soya yağı bileşimine benzerdir (Filho vd., 2017).

Chia tohumları, çoklu doymamış yağ asitlerinin (PUFA) kaynağı olduğu bilinen yağ içeriği nedeniyle diğer pseudo tahıllardan farklı bir özelliğe sahiptir. Chia tohumlarından elde edilen yağ, diğer tanımlanmış doğal kaynaklardan daha fazla alfa-linolenik asit (ALA) ve omega-3 yağ asidi içerdiği için üstün bir yağ kaynağı olduğu belirtilmektedir (Da Silva Marineli vd., 2014).

Karabuğdaydaki lipitler düşüktür ancak çeşitli fizyolojik aktivitelerde iyi bir öneme sahip olduğu beliritilmiştir ve lipit içeriği %1,5 ile %3,7 arasında değişmektedir (Ruan vd., 2020). Karabuğdaydaki lipitler, %81-85 oranında nötr lipitler, %8-11 oranında fosfolipitler ve %3-5 oranında glikolipitler olarak sınıflandırılır. Karabuğday, kalp hastalıkları, kanser, inflamasyon ve diyabet gibi hastalıklara karşı sağlık yararları olan doymamış yağ asitlerinin zengin bir kaynağıdır (%74,5-79,3) (Ruan vd., 2020). Doymamış yağ asitleri karabuğday tohumunun embriyosunda yoğunlaşmıştır ve palmitik, oleik ve linoleik en yaygın yağ asidi türleri olup karabuğday tohumlarında %87,3-88'i temsil etmektedir (Sofi vd., 2023).

Yaygın tahıllarla karşılaştırıldığında kinoa (%4,0-7,6), karabuğday (%0,7-7,4) ve amarant (%3,24-10,9) daha yüksek yağ konsantrasyonlarına sahiptir (Coțovanu vd., 2020). Amarant, kinoa ve karabuğdaydaki toplam doymuş yağ asidi içerikleri düşüktür ve sırasıyla toplam yağların %20,1 ila %30,9'u, %15,5-29,0'ı ve %18,8-19,5'i arasında değişmektedir. Buna karşılık, amarant, kinoa ve karabuğdaydaki doymamış yağ asitleri toplam lipitlerin sırasıyla %61,0-87,3'ünü, %70-89,4'ünü ve %80,1-80,9'unu oluşturmaktadır (Nandan vd., 2024). Ayrıca pseudo tahıllarda filizlendirme uygulamasının yapılmasınının omega 3 yağ asitleri konsantrasyonunun artmasını sağladığı bildirilmektedir (Majzoobi vd., 2023).

Vitaminler

Kinoa yüksek seviyede vitamin ve mineral içermektedir. İçeriğinde B vitamini kompleksini, E ve C vitaminlerini yüksek seviyelerde içermektedir. Kinoa yağında bulunan tokoferol konsantrasyonları 797,2 ppm γ-tokoferol ve 721,4 ppm α-tokoferoldür. Bu seviye mısır yağında bulunan seviyeden biraz daha yüksektir ve bu da maddenin antioksidan potansiyeli nedeniyle kinoa yağının uzun bir raf ömrüne sahip olmasını sağlamaktadır. Ayrıca, E vitamini gibi α-tokoferol içeriği de çok önemlidir çünkü hücre zarı seviyesinde doğal bir antioksidan görevi görerek yağ asitlerini serbest radikallerin verdiği hasara karşı korumaktadır (Abugoch, 2009; Filho vd., 2017). Chia ise bazı vitaminler bakımından, özellikle B_1 vitamini (0,6 mg/100 g), B_2 vitamini (0,2 mg/100 g) ve niasin (8,8 mg/100 g) bakımından oldukça zengin bir pseudo tahıldır (Kulczyński vd., 2019).

Amarant folat ve riboflavin gibi suda çözünen vitaminlerden zengindir. Amaranttan üretilen temel gıdalar incelendiğinde ekmekte 35,5 µg/100 g, kurabiyede 36,3 µg/100 g ve eriştede 38,9 µg/100 g toplam folat içeriği olduğu, buğday kullanıldığında ise ekmeğin sadece 12,0 µg/100 g folat içerdiği bildirilmiştir (Schoenlechner vd., 2010). Amarant ununda riboflavin içeriği 0,29–0,32 mg/100 g aralığında olup buğdaydan yaklaşık 10 kat daha yüksektir (Rollan, Gerez ve Leblanc, 2019).

Kinoa tanesinin vitamin içeriğine yönelik çalışmalar sınırlı olmakla birlikte, 100 gramlık porsiyonunun hem çocukların hem de yetişkinlerin günlük gereksinimlerini karşılayabilecek düzeyde önemli miktarda piridoksin (B_6 vitamini) ve folik asit içerdiği bildirilmektedir. Yapılan bir çalışmada 100 g kinoadaki riboflavin içeriğinin çocukların günlük ihtiyaçlarının %80'ini, yetişkinlerin ise günlük ihtiyaçlarının %40'ını karşıladığı bildirilmiştir (Abugoch, 2009). Niasin içeriği incelendiğinde ise günlük ihtiyaçları karşılamaz iken yine de önemli bir diyet kaynağı olduğu belirtilmektedir. Tiamin (B_1) değerleri yulaf veya arpadaki değerlerden daha düşüktür ancak riboflavin (B_2), piridoksin (B_6) ve folik asit değerleri buğday, yulaf, arpa, çavdar, pirinç ve mısır gibi çoğu tahılda bulunan değerlerden daha yüksektir. Dahası, kinoa daha önce açıklandığı gibi buğdaydan daha yüksek olan iyi bir E vitamini kaynağıdır (Filho vd., 2017).

Karabuğday tanesi B vitamini kompleksleri ile A, C ve E vitaminlerinin zengin bir kaynağıdır. Tiamin, riboflavin, niasin, pantotenik asit ve piridoksin vitaminleri karabuğday tanesinin 100 gramında sırasıyla 0,22, 0,1, 1,8, 1,1 ve 0,17 mg'dır. Karabuğday tanelerindeki doğal antioksidan olan E vitamini (tokoferol) konsantrasyonunun 140,1 µg/g'a kadar çıktığı belirtilmektedir (Sofi vd., 2023). Yapılan bir çalışmada karabuğdayda 5 mg/100 g C vitamini içeriği bildirmiş ve çimlenmeden sonra C vitamini seviyelerinin 25 mg/100 g'a yükseldiği bildirilmiştir (Zhou vd., 2015).

Mineraller

Mineraller, çeşitli metabolik süreçlerde ve makro besinlerin biyosentezinde önemli bir rol oynayan insan sağlığı için gerekli olan temel mikro besinlerdir. Tahıllar demir (Fe), çinko (Zn), bakır (Cu), selenyum (Se) ve magnezyum (Mg) gibi bazı mineraller açısından zengindir; ancak fitik asidin şelatlama etkileri nedeniyle bu minerallerin biyoyararlanımı düşüktür ve bu nedenle yaygın olarak tahılların tüketimi ile gerekli miktarda mineral sağlanamaz. Pseudo tahıllar tahıllara göre daha fazla mineral içeriğine sahiptir ve pseudo tahılların biyoyararlanımı tahıllara göre daha yüksektir. Ayrıca filizlendirme işlemleri hem tahıllarda hem de pseudo tahıllarda minerallerin biyoyararlanımını artırmaktadır. Mineral biyoyararlanımındaki artış, filizlenme süreci sırasında artan fitaz aktivitesinden kaynaklanır ve bu da fitatları parçalayarak minerallerin serbest hale gelmesini sağlamaktadır (Majzoobi vd., 2023).

Kinoa kalsiyum, magnezyum, demir, potasyum, fosfor, manganez, çinko, bakır ve sodyum gibi mineralleri bileşiminde bulundurmaktadır. Kalsiyum ve demir miktarı yaygın olarak kullanılan tahıllardakinden önemli ölçüde daha yüksektir. Kinoa tanesi, biyoyararlanımı yüksek formlarda bulunan kalsiyum, magnezyum ve potasyum mineralleri açısından zengin olup, bu içerikleri sayesinde dengeli bir insan diyeti için yeterli düzeyde mineral desteği sağlamaktadır. Farklı kinoa taneleri farklı oranlarda mineral içeriklerine sahiptir. Bu sebeple yapılan çalışmalarda kalsiyum miktarları 860-1487 mg/kg olarak bildirilmektedir (Filho vd., 2017).

Amarant kalsiyum, magnezyum, demir, potasyum, manganez, çinko ve bakır gibi mineralleri bileşiminde içermektedir. Farklı amarant genotiplerde bu mineraller farklı oranlarda bulunmaktadır. Amarant çeşitlerinin potasyum miktarı 5,86- 10,46 arasında, kalsiyum miktarı 20,82 ila 34,82 arasında ve magnezyum miktarı 24,51- 31,13 arasında değişmektedir (Sarker vd., 2022).

Karabuğdaydaki mikro besinler tahıl tanelerinden daha yüksektir ve konsantrasyonları esas olarak tohum kabuğu, gövde ve aleuron katmanlarıyla sınırlıdır. Fosfor, potasyum, magnezyum ve kalsiyum gibi makro mineraller karabuğdayda yeterli seviyelerde bulunurken, demir, manganez ve çinko gibi mineraller daha düşük konsantrasyonlardadır (Sofi vd., 2023).

Chia tohumları ise birçok minerali sağlamaktadır; fakat fosfor (860–919 mg/100 g), kalsiyum (456–631 mg/100 g), potasyum (407–726 mg/100 g) ve magnezyum (335–449 mg/100 g) en yüksek miktarlarda bulunan mineralerdir (Kulczyński vd., 2019).

Diğer bileşenler (Biyoaktif bileşenler)

Psödotahıllar, diyetteki önemli fitokimyasal kaynaklardır. Fenolik bileşikler genel olarak dört sınıfa ayrılır; fenolik asitler (benzoik veya hidroksisinnamik asit türevleri), flavonoidler (flavonoller, flavonlar, izoflavonlar, flavanonlar ve antosiyanidinler), stilbenler ve lignanlardır.

Karabuğday, kinoa ve amarant gibi pseudo tahılların, yüksek düzeyde polifenoller, antosiyaninler ve flavonoidler içerdikleri bildirilmekte olup, bu bileşenler söz konusu ürünlerin önemli biyoaktif özellikler taşımasına katkı sağlamaktadır. En yüksek fenolik bileşik miktarı kinoa'da (490,2 mg/kg DW), daha sonra biraz daha düşük olarak amarantta (464 mg/kg) bildirilmektedir (Rollan, Gerez ve Leblanc, 2019). Chia tohumları yüksek biyolojik aktivite ile karakterize edilen özellikle ilginç fitokompakt gruplarının zengin bir kaynağıdır. Bunlar özellikle polifenollerdir: gallik, kafeik, klorojenik, sinamik ve ferulik asitler, kuersetin, kaempferol, epikateşin, rutin, apigenin ve p-kumarik asit gibi. Daidzein, glisitein, genistein ve genistin gibi izoflavonların ise az miktarda bulunduğu bildirilmektedir (Kulczyński vd., 2019).

Son zamanlarda, özellikle hücre zarlarının korunması için, dokulardaki serbest radikalleri ve oksidasyon zincir reaksiyonlarını inhibe etmede önemli bir rol oynayabilen, sinirsel işlevlerde kanıtlanmış başarısı olan, kanser, kardiyovasküler hastalık ve osteoporoz gibi oksidatif stresle ilişkili çeşitli dejeneratif hastalık riskini azaltan doğal antioksidanlara büyük ilgi gösterilmiştir (Nsimba vd., 2008). Tahıllar ve pseudo tahıllar arasında karabuğdayın polifenoller açısından en iyi kaynaklardan birisi olduğu, kuersetin, apigenin ve luteolinin başlıca flavonoid glikozitleri olduğu bildirmiştir. Kinoa tohumları da esas olarak kuersetin ve kaempferol glikozitlerinden oluşan zengin bir flavonoid kaynağıdır. Amarant tohumlarında ise kafeik asit, p - hidroksibenzoik asit ve ferulik asit başlıca bulunan fenoliklerdir (Alvarez-Jubete vd., 2010).

Pesudo tahılların biyoaktif bileşikleri ve antioksidan aktivitesinin genellikle filizlenme sırasında artırdığı bildirilmektedir. Karbonhidratlar ve proteinler gibi diğer bileşenlerin filizlenme sırasında kaybı da toplam fenolik bileşikleri artırabilmektedir (Majzoobi vd., 2023). Amarant, kinoa ve karabuğdayın antioksidan aktivitesinin filizlenme sürecinde önemli ölçüde arttığı belirtilmektedir. Kinoa ve karabuğdayın filizlenmesinin ardından toplam fenolik içeriğinin iki katına ve amarantta ise dört katına çıktığı bildirilmektedir. Benzer filizlenme koşulları altında, karabuğday en yüksek toplam fenol içeriğine sahip iken bunu kinoa ve amarantın takip ettiği bildirilmektedir (Dumitru vd. ,2021).

Kinoa α- ve γ-tokoferol gibi yüksek konsantrasyonlarda antioksidanlar içermektedir (Filho vd., 2017). Skualen ve fitosteroller, tokoferollerle birlikte gıdalarda bulunan sabunlaştırılamayan lipit fraksiyonunun temel bileşenleri arasında yer almaktadır. Skualen, kolesterol biyosentezinde bir ara madde olarak görev yapmakta olup, tüm yüksek organizmalar tarafından sentezlenen ve insan sağlığı açısından çeşitli yararlı biyolojik etkilere sahip olduğu bilinen doğal bir triterpendir. Kinoa içinde 33,9 -58,4 mg/100 g arasında skualen bulunur. Bu, tüm steroid ailesinin biyokimyasal öncüsüdür ve etkili antioksidan aktivitesine ek olarak, tokotrienollerin özellikle sağlıklı bir kardiyovasküler sistemin korunmasında ve kanser korumasında olası bir rolde olmak üzere diğer önemli işlevleri vardır (Abugoch, 2009).

Polifenolik bileşikler (flavonoidler ve fenolik asitler) karabuğdaydaki biyoaktif bileşenlerdir ve karabuğdayın nutrasötik potansiyelini artırmaktadır. Karabuğday, rutin, izoorientin, kuersetin, izoviteksin, viteksin ve orientin gibi flavonoidlerin zengin bir kaynağıdır. Tüm pseudo tahıllar arasında rutin bileşeni yalnızca karabuğdayda bulunur ve daha yüksek antioksidan, anti-inflamasyon ve antikanser özelliklere sahiptir (Sofi vd., 2023).

Fitosteroller anti-inflamatuar, antioksidan ve antikarsinojenik etki gibi farklı biyolojik etkilere sahiptirler. Kinoa'da bulunan fitosterolin bazıları sırasıyla 63,7 mg/100 g β-sitosterol, 15,6 mg/100 g kampesterol ve 3,2 mg/100 g stigmasterol olup bunlar bitkilerde en bol bulunan sterollerdir. Bu düzeyler kabak çekirdeği, arpa ve mısırda bulunanlardan daha yüksek, ancak mercimek, nohut ve susam tohumlarındakilerden daha düşüktür. Önerilen doz, doğal kaynaklar dahil olmak üzere günde 0,8-1,0 g fitosterol eşdeğeridir ve bunlar sağlıklı bir kalbi korumaya yardımcı olan düşük yoğunluklu lipoproteinin (LDL) etkisinin azaltılmasında önemli bileşenlerdir (Ryan vd., 2007; Abugoch, 2009).

Emilimi zorlaştırıcı ajanlar

Bitkilerin beslenmede besin kaynağı olarak kullanılmasından kaynaklanan temel sorunlardan biri, ikincil bitki metabolizmasından türetilen bazı bileşiklerin varlığıdır. "Anti-besin faktörü" terimi, çok çeşitli bitkisel gıdalarda bulunan ve tüketildiğinde besin değerlerini azaltan, sindirilebilirliklerini, emilimlerini veya besin kullanımını etkileyen ve yüksek konsantrasyonlarda alındığında sağlık üzerinde zararlı etkilere neden olabilecek bu bileşik sınıfını tanımlamak için kullanılmıştır. Bu nedenle, besin değerlerine müdahale eden bileşikleri belirlemek için geleneksel ve geleneksel olmayan bitki kullanımının anti-besin faktörleri üzerinde çalışmalar yapılması esastır. Farklı sebzelerde çeşitli tipte anti-besinsel faktörler tanımlanmıştır. Kinoa tohumunda tanımlanan anti-besinsel faktörler saponinler, fitik asit, tanenler, nitratlar, oksalatlar ve tripsin inhibitörleridir. Bu maddeler tahılın dış katmanlarında daha yüksek konsantrasyonlarda bulunur. Ancak kinoada bulunabilecek potansiyel anti-besinsel faktörler üzerine yapılan çalışmalar sınırlıdır ve bu bileşenlerin beslenmeye etkili biçimde dahil edilmesi sürecinde besinsel kaliteyi olumsuz yönde etkileyebilecek anti-besinsel ve/veya toksik etkileri hakkında yeterli bilgi bulunmamaktadır. Kinoa tanesi, genellikle tanenin dış katmanlarında (episperm) bulunan ve onu kuşlardan ve böceklerden koruyan saponine sahiptir. Kinoa'da dört ana saponin vardır. Bunlar sırasıyla; oleanolik asit, hederagenin, fitolaksajenik asit ve 30- O -metil-espergulagenat'dır (Filho vd., 2017). Bunlar metanol veya suda çözünür ve kırmızı kan hücrelerinin hemolizine neden olan toksik özelliklere sahiptir. Bu toksisite saponin türüne ve alıcı organizmanın duyarlılığına bağlıdır. Bununla birlikte, soğukkanlı hayvanlar için son derece toksik olmalarına rağmen, memelilerde oral toksisiteleri düşüktür ve proteinin besin kalitesi üzerinde herhangi bir olumsuz etki yaratmaz. Bazı saponinlerin, demir ve çinko gibi minerallerle kompleks oluşturarak bu elementlerin biyoyararlanımını azalttığı bilinmektedir; ancak A, E ve D_3 vitaminleri ile benzer komplekslerin oluştuğuna dair yeterli bilimsel kanıt bulunmamaktadır. Yüksek negatif yükü nedeniyle fitik asit, kalsiyum, demir, magnezyum, çinko ve bakır gibi iki değerlikli mineralleri ve nişasta, protein ve enzimi şelatlayarak bu bileşenlerin biyoyararlanımını tehlikeye atan anti-besinsel eylemin bir bileşeni olarak kabul edilmiştir (Jancurová vd., 2009). Kinoa'daki fitik asit miktarı tahıllardakinden daha yüksek olmasına rağmen, kemiklerden kalsiyumun çekilmesine veya demir emiliminde herhangi bir olumsuz etki belirtilmemiştir. Ayrıca pseudo tahıllarda fitik asit içeriği, ıslatma, çimlendirme ve fermantasyon ile önemli ölçüde azaltılabilmektedir (Filho vd., 2017). Yapılan bir çalışmada, glutensiz unların/malzemelerin değişken fitat konsantrasyonlarına sahip olduğunu belirtilmiştir; pirinç %0,12, darı %0,25, amarant %0,47, teff %0,70, acı bakla %0,77, mısır %0,92, yulaf %1,13, kinoa %1,18 ve soya fasulyesi %1,33 (Arendt vd., 2011).

Tanenler, bitki aleminde yaygın olarak bulunan ve doğal olarak dağılım gösteren polifenoller grubuna dahil bileşiklerdir. Bu bileşikler, proteinler ve nişasta gibi makromoleküllerle kompleks oluşturma yetenekleri nedeniyle istenmeyen biyolojik etkilere yol açabilir ve bu durum, gıdaların besin değerinde azalmaya neden olabilir. Tanenlere atfedilen diğer olumsuz etkiler arasında, enzimatik esmerleşme reaksiyonları yoluyla gıdada istenmeyen renk değişimlerine neden olmaları, büzücü özellikleri nedeniyle tat kalitesini düşürmeleri ve bağırsak mukozasına zarar vererek demir, glikoz ve B_{12} vitamini emilimini olumsuz yönde etkilemeleri yer almaktadır. Tanenler kinoa tohumlarında az miktarda bulunur (%0,53). Proteaz inhibitörleri, doğada yaygın olarak dağılmış, proteolitik enzimlerle çok kararlı kompleksler oluşturan proteinlerdir (Filho vd., 2017). Kinoa tohumlarındaki proteaz inhibitörlerinin konsantrasyonu 50 ppm'den azdır. Kinoa, yaygın olarak tüketilen tahıllarda bulunanlardan çok daha düşük miktarda tripsin inhibitörleri içerir ve bu nedenle büyük endişeler oluşturmazlar (Vega-Gálvez vd., 2010).

Nitratlar (NO_3) tüm bitkilerde bulunur ve normal büyümeleri için gerekli azot kaynağıdır. Bazı bitkiler, emilim metabolik ihtiyaçlarını aştığında bu maddeyi köklerinde ve sürgünlerinde biriktirir. İnsan vücudunda nitratlar A vitamini metabolizmasına ve tiroid bezinin işlevlerine müdahale eder. Bunlar nitritlere indirgenebilir ve emildikten sonra metmiyoglobin oluşumu nedeniyle siyanoz oluşturabilir veya ikincil ve üçüncül aminlerle reaksiyona girerek potansiyel olarak kanserojen N-nitröz bileşiği oluşturabilir (Filho vd., 2017). WHO tarafından önerilen nitrat iyonları ve nitritin kabul edilebilir günlük alımı (ADI) sırasıyla vücut ağırlığı başına 3,7 ve 0,06 mg/kg'dır (WHO, 2002). Kinodaki nitrat seviyeleri (63,26 mg/100g) ıspanak, marul, turp gibi sebzelerde bildirilen değerden iki kat daha düşüktür. Bu durum kinoa'nın diyet ve sağlık açısından hiçbir dezavantajı olmadığını ortaya koymaktadır (Filho vd., 2017).

Oksalat toksik bir maddedir ve büyük bir sağlık riski oluşturur. Genellikle ıspanak, pancar, pazı, domates, fındık ve kakao gibi sebzelerde bulunur. İnsanlar tarafından metabolize edilemez ve idrarla atılır. Diyette yüksek oksalat alımı minerallerin ve eser elementlerin emilimini etkiler, böylece oksalatların gastrointestinal kanaldaki iki değerlikli katyonlarla çözünmeyen kompleksler oluşturma yeteneği nedeniyle böbreklerde kalsiyum oksalat taşlarının oluşumu için bir risk faktörü olan hiperoksalüride önemli bir rol oynar. Kinoa ıspanak ve pancara göre daha düşük oksalik asit seviyelerine sahiptir (380 mg/100 g) (Filho vd., 2017).

Pseudo tahılların toksikolojik yönlerine gelince, bunları tüketmek oldukça güvenlidir. Daha düşük miktarda anti-besinsel faktörlere ve saponinler gibi daha düşük içsel toksine sahiptirler. Bağırsak sistemi üzerinde potansiyel zararlı etkilere sahip olan saponinler yalnızca küçük miktarlarda emilmektedir. Bu durum onun zararlı etkilerini önemsiz hale getirmekedir. Örneğin, amarant tohumları oldukça düşük miktarda saponin içerir (%0,09) ve amarant tohumlarındaki bu düşük saponin konsantrasyonu, diğer tahıllara kıyasla düşük toksisite olarak tanımlanmasını sağlamaktadır (Shahbaz vd., 2023).

Pseudo Tahılların Sağlık Üzerine Etkileri

Günümüzde küresel gıda ekonomisi, düşük işlenmemiş karbonhidrat ve yüksek yağ içeriğine sahip, enerji yoğun diyetlerin artan tüketimiyle şekillenen sürekli değişen beslenme kalıplarının etkisi altındadır. Yaşam tarzı ve diyet tasarımlarındaki bu farklılıklar nedeniyle, ateroskleroz, felç, kalp sorunları, diyabet, hipertansiyon, bazı kanser türleri ve obezite gibi kronik bulaşıcı olmayan hastalıklar (NCD'ler) hem yeni gelişmiş hem de gelişmekte olan ülkelerde giderek önemli hale gelmekte olup zamansız ölüm nedenleri arasında yer almaktadır. Tüm bunlar, bu rahatsızlıklara karşı işlevsel özelliklere sahip yeni gıda kaynaklarına doğru toplumun artan bir eğilimini oluşturmaktadır. Pseudotahılların kronik hastalıkların önlenmesindeki etkisini kontrol etmek için birçok in vivo çalışma yapılmaktadır (Shahbaz vd., 2023).

Fenolik bileşikler; anti-alerjik, anti-inflamatuar, anti-mikrobiyal, antioksidan, anti-trombotik, kardiyoprotektif gibi kronik hastalık riskini azalttığı ve tip 2 diyabette insülin salgılanmasını uyardığı için insanlara sağlık yararları sağlayabilir olarak bildirilmektedir. Diyetle alınan fenolik bileşikler, bağırsak mikrobiyal dengesini (yararlı bakteriler/patojen bakteriler) düzenleyerek sağlıklı bir bağırsağın korunmasına katkıda bulunabilmektedir. Fenolik bileşiklerin biyolojik etkileri esas olarak biyoerişilebilirliğine (sindirim sırasında gıda matrisinin emilebilir bir formda salınması) ve biyoyararlanımına (kan dolaşımına emilim ve aktarım) bağlıdır ve her ikisi de kimyasal yapılarına, matris etkileşimlerine, antioksidan aktivitelerine ve gıda işlenmesine bağlıdır. Ancak, pseudo tahıllardaki bu çalışmalar hala eksiktir (Rollan vd., 2019).

Kinoa, "işlevsel gıda"nın mükemmel bir örneğidir ve çeşitli hastalık riskini azaltmaya yardımcı olabilir. İşlevsel özellikleri, özellikle hücre zarlarının korunmasında insan beslenmesine katkıda bulunan lif, mineraller, vitaminler, yağ asitleri, antioksidanlar ve bitki hormonlarının varlığıyla ilişkili olabilir ve nöronal işlevin iyileştirilmesinde kanıtlanmış sonuçlar vardır. Bu özellikler tahıla insan beslenmesi ve sağlık bakımı için diğer bitkisel gıdalara göre, büyük bir avantaj sağlar (Repo-Carrasco-Valencia ve Serna, 2011; Vega-Gálvez vd., 2010). Kinoa karbonhidratları, faydalı hipoglisemik etkilere sahip oldukları ve serbest yağ asitlerinin azalmasını sağladıkları için nutrasötikler olarak kabul edilebilir. Çölyak hastalığı olan bireylerde yapılan çalışmalar, kinoanın glisemik indeksinin glutensiz makarna ve ekmeklerden biraz daha düşük olduğunu göstermiştir. Ayrıca kinoa, glutensiz makarnaya kıyasla daha düşük serbest yağ asidi seviyeleri ile karakterize edilirken, glutensiz ekmeğe göre anlamlı düzeyde daha düşük trigliserit içeriği göstermektedir (Berti vd., 2004; Filho vd., 2017). Son yıllarda, çoklu doymamış yağ asitleri, kardiyovasküler hastalık, prostaglandin metabolizması, artan insülin duyarlılığı, bağışıklık sistemi ve hücre zarı fonksiyonu üzerindeki olumlu etkiler gibi kendilerine atfedilen sağlık yararları nedeniyle önem kazanmıştır (Abugoch, 2009; Filho vd., 2017).

Günümüzde chia, doğru oranda biyoaktif bileşen içerdiği için dünya çapında fonksiyonel gıda ürünleri üretmek için kullanılmaktadır. Chia'nın kardiyovasküler hastalıklar, obezite, kanser ve diyabet gibi kronik hastalıklarla ilişkili birçok sağlık yararı sağladığı bildirilmektedir. Bu nedenle chia tohumunun kullanımı yıllar geçtikçe artmaktadır (Kulczyński vd., 2019; Shahbaz vd., 2023). Chia'nın temel faydaları arasında yüksek lif, omega 3 ve demir içermesi yer almaktadır. Ayrıca süte kıyasla daha fazla miktarda kalsiyum ve magnezyum içermektedir. Çalışmalar ayrıca diyabet hastalarında chia tohumlarının düzenli alımının kan şekeri seviyelerini kontrol edebileceğini ve stabilize edebileceğini bildirmektedir. Trombositlerin toplanmasını kısıtlayarak felçleri ve kalp krizlerini önleyebilir ve kan basıncını (sistolik) 6 mmHg'ye kadar düşürebilir olarak belirtilmektedir (Vuksan vd., 2007).

Amarant, kinoa, chia ve karabuğday gibi pseudo tahıllar iyi birer antioksidan kaynağı olarak nitelnedirilmektedir. Tahıllara göre daha fazla fenolik bileşik ve antioksidan kapasite göstermektedirler. Yapılan çalışmalar bu besinlerin tüketiminin kan örneklerinde antioksidan seviyelerinde artış sağladığını ve serbest radikalleri süpürücü etki gösterdiğini belirtmektedir (Morales vd., 2021; Shahbaz vd., 2023; Tang vd., 2015; Vuksan vd., 2007;).

Polifenol ve proantosiyanidinlerin (PA) alımının artırılması, kronik hastalıkların ve tıbbi bozuklukların görülme sıklığının azalmasıyla olumlu bir şekilde bağlantılı olarak belirtilmektedir. Karabuğday pseudo tahıllar arasında proantosiyadin içeren tek pseudo tahıldır. Bu özelliği karabuğdayı kronik hastalıkların görülme sıklığı üzerinde olumlu etkiler ortaya koyabileceğini belirtmektedir. Öte yandan, PA açısından zengin gıdalar büzücü/acı olabilir ve bu da duyusal kaliteyi ve ticari potansiyeli olumsuz etkileyebilir olarak belirtilmektedir (Zhu, 2019). Karabuğdaydaki protein, yağ, vitamin ve metal elementlerinin miktarı pirinç, buğday, mısır ve diğer temel gıdalardakinden daha yüksektir. Özellikle serum kolesterolünü azaltabilen ve yaşlanma karşıtı etkilere sahip olabilen; kalp hastalığı, serebrovasküler hastalık ve diyabetin önlenmesinde ve tedavisinde kullanılabilen, vitaminler, diyet lifi ve eser elementler açısından zengin olduğu belirtilmektedir. Karabuğday, insan vücudu için gerekli eser elementlerin önemli bir diyet kaynağı olarak popülaritesi artmış bir üründür (Zhao vd., 2023).

Sonuç ve Öneriler

Pseudo tahıllar, doymamış yağ asitleri, protein, diyet lifi, vitamin, mineral ve karabuğdaydaki fagopiritoller ve flavonoller, kinoadaki saponinler; amaranttaki skualen ve amarant, kinoa ve karabuğdaydaki fitosteroller gibi biyoaktif bileşikler açısından iyi birer kaynaktır. Psödo tahılların bu besleyici besin bileşimi ve düşük alerjenitesi onları tahıllara göre (buğday, mısır ve pirinç) iyi bir alternatif ürün haline getirmektedir. Ayrıca pseudo tahılların anti-besinsel faktör içerikleri diğer besinlerle kıyaslandığında kabul edilebilir düzeydedir ve etkileri de düşüktür. Bu durum pseudo tahılların fonkisyonel besinler olarak kullanımını artırmaktadır. Pseudo tahıllar sürdürülebilir gastronomi kapsamında un formülasyonunda özellikle glutensiz ürün üretiminde kullanıldığı çalışmalarda görülmtektedir. Bu amaç doğrultusunda pseudo tahılların kek, ekmek, erişte, makarna, bar ve içecek gibi ürünlerin üretiminde yer aldığı çalışmalarda bildirilmektedir. Pseudo tahıllar içerikleri besin öğeleri ve biyoaktif bileşenler ile obezite, kalp hastalıkları, hiperlipidemi, kanser gibi birçok hastalığa karşı koruyucu ürün olarak nitelendirilmektedir. Alerjen dostu, tam tahıllı, yüksek lifli ve yüksek proteinli gibi işlevsel sağlık özelliklerine sahip bu pseudo tahıllar, fonksiyonel gıda ürünlerinin üretiminde kullanılmaktadır. Fakat bu faydalara rağmen, tüketicilerin pseudo tahıllar ve formüle edilmiş ürünler hakkındaki farkındalıkları oldukça düşüktür. Bunun nedeni ise, pseudo tahılların yüksek maliyetleri ve dünya çapında sınırlı bulunabilir olmasıdır. Ayrıca, bu pseudo tahılların yetiştirilmesi dünyanın belirli bölgeleriyle sınırlı kalmış durumdadır. Besinsel faydaları ve büyük pazar potansiyelleri göz önüne alındığında, bu pseudo tahılların sürdürülebilir gastronomi uygulamalarında üretimlerinin teşvik edilmesi önem taşımaktadır.

Peer-review: Externally peer-reviewed.
Ethics Committee Approval: This study does not require ethics committee approval.
Conflict of Interest: The author has no conflicts of interest to declare.
Financial Disclosure: The author declared that this study has received no financial support.

Hakem Değerlendirmesi: Dış bağımsız.
Etik Komite Onayı: Bu çalışma için etik kurul onayına gerek yoktur.
Çıkar Çatışması: Yazar çıkar çatışması olmadığını beyan etmiştir.
Finansal Destek: Yazar bu çalışmanın herhangi bir finansal destek almadığını beyan etmiştir.

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