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Enrichment of Bread with Whey Treated with High Hydrostatic Pressure

Ekmeğin Yüksek Hidrostatik Basınçla İşlenmiş Peynir Altı Suyuyla Zenginleştirilmesi

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ABSTRACT

There are some deficiencies in the nutritional profile of bread due to the use of refined flour in modern production. Therefore, various additives are employed to enhance the nutritional profile of bread. Whey is a valuable source of functional proteins, lipids, vitamins, and minerals. However, bread volume and water absorption decrease when whey is added directly to the bread dough. Therefore, studies are being carried out to investigate pretreatments that can improve the technological properties of whey. This study aimed to develop a bread product fortified with whey treated with high hydrostatic pressure (HHP) and evaluate its quality. Properties of bread enriched with whey treated with HHP (300 MPa, 3 min, 20°C) (HHPWB) were examined using crumb images, experimental (moisture, ash, and unsalted ash content, acidity, weight, dough yield, volume, specific volume, and crust/crumb ratio), texture, color, and sensory analyses. The HHPWB formulation resulted in a decrease in gas cells, hardness, and chewiness, as well as an increase in ash content, acidity, weight, volume, and *a** color values. HHPWB received better sensory acceptance for crust, symmetry, and color. The HHP treatment may have the potential to boost the benefits of fortifying bread with whey.

Keywords: High hydrostatic pressure, Bread, Whey, Enrichment

ÖZ

Modern üretimde rafine un kullanılması nedeniyle ekmeğin besin profilinde bazı eksiklikler bulunmaktadır. Bu nedenle, ekmeğin besin profilini geliştirmek için çeşitli katkı maddeleri kullanılmaktadır. Peynir altı suyu fonksiyonel proteinler, lipitler, vitaminler ve mineraller açısından değerli bir kaynaktır. Ancak peynir altı suyu doğrudan ekmek hamuruna eklendiğinde ekmek hacmi ve su emilimi azalmaktadır. Bu nedenle, peynir altı suyunun teknolojik özelliklerini geliştirebilecek ön işlemler ile ilgili araştırmak için çalışmalar yürütülmektedir. Bu çalışma, yüksek hidrostatik basınç (HHP) ile işlenmiş peynir altı suyuyla zenginleştirilmiş bir ekmek ürünü geliştirmeyi ve kalitesini değerlendirmeyi amaçlamıştır. HHP (300 MPa, 3 dakika, 20°C) ile işlenmiş peynir altı suyuyla zenginleştirilmiş ekmeğin (HHPWB) özellikleri, kırıntı görüntüleri, deneysel (nem, kül ve tuzsuz kül içeriği, asitlik, ağırlık, hamur verimi, hacim, özgül hacim ve kabuk/iç oranı), doku, renk ve duyusal analizler kullanılarak incelenmiştir. HHPWB formülasyonu gaz hücrelerinde, sertlikte ve çiğnenebilirlikte azalmanın yanı sıra kül içeriği, asitlik, ağırlık, hacim ve *a** renk değerlerinde artışa neden olmuştur. HHPWB kabuk, simetri ve renk açısından daha iyi duyusal kabul görmüştür. HHP uygulaması ekmeğin peynir altı suyuyla zenginleştirilmesinin faydalarını artırma potansiyeline sahip olabilir.

Anahtar Kelimeler: Yüksek hidrostatik basınç, Ekmek, Peyniraltı suyu, Zenginleştirme

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Introduction

Bread, which can be produced in various forms, is one of the most basic traditional foods consumed by people all over the world and can meet a large part of their daily nutritional needs (Lockyer & Spiro, 2020). Although there are varieties of bread made with different grain flours (rye, corn, and barley), wheat flour is the most preferred basic raw material due to its structure, which allows it to form a dough when in contact with water in traditional bread making (Kourkouta et al., 2017). Bread, which is produced by fermenting and baking dough prepared with wheat flour, water, salt, and yeast. However, rafinated wheat flour used in bread production may cause malnutrition in people whose diet mainly consists of bread, due to the low lysine content in wheat protein. In low-income societies where malnutrition is common due to being bread as main food source, research on enriching bread with vitamins, minerals, flavonoids, anthocyanins, fatty acids, carotenoids, folic acid, protein, and/or amino acids is very important (Betoret & Rosell, 2020). In addition, issues such as the production of low-calorie and improved-quality bread that can aid in the treatment of diseases such as obesity in high-income societies have started to receive more attention. For this reason, researchers are focusing on studying the addition of functionality to bread, especially by using additives with proven health benefits (Martins et al., 2017; Meral & Erim Köse, 2019; Lachowicz et al., 2021).

In the food industry, cheese processing plants produce whey in large quantities as waste during cheese making or the coagulation of the milk casein step. Whey causes serious environmental pollution due to its high chemical oxygen demand (COD: 50-80 g/L), biochemical oxygen demand (BOD: 40-60 g/L), and organic content (lactose, proteins, lipids, vitamins) (Das et al., 2016; Zandona et al., 2021). In addition, difficulties in separating whey components pose a significant challenge for treatment plants. It is vital to manage, process, and reuse whey properly. For this purpose, advanced technologies are used to manage high organic and inorganic nutrients in whey, and alternative methods are being explored to maximize benefits and further processing (Yadav et al., 2015). Whey is a byproduct rich in functional proteins and peptides, lipids, vitamins, minerals and lactose. Whey proteins are crucial because they contain essential amino acids such as leucine, isoleucine, and valine. The positive effects of whey proteins on boosting immunity, lowering the risk of heart disease, and reducing cancer incidence have been reported (Pillai et al., 2024; Thampy et al., 2024). Due to these properties, whey was included in bread in various studies (Madenci & Bilgiçli, 2014; Zhou et al., 2018; Tsanasidou et al., 2021; Ingrassia et al., 2022). Lactose in whey increases the Maillard reaction (Dıblan et al., 2024; Zhang et al., 2024). However, it can reduce the volume of the bread by creating high osmotic pressure, slowing down yeast activity. When whey is added directly to the bread dough, it increases protein, mineral, thiamine, and riboflavin contents, but reduces water absorption. In addition, whey protein caused to ruptures of gluten network in dough (Van Riemsdijk et al., 2011). The study aimed to reduce or eliminate adverse conditions in whey by exploring the effects of various technological applications.

There has been increasing attention in high hydrostatic pressure (HHP) due to its ability to increase the extraction efficiency of functional elements and enhance the health efficacy of foods (Huang et al., 2020). HHP is a non-thermal technology that meets consumer requirements by extending the shelf life and enhancing the safety of foods. It is endorsed as reliable by the U.S. Food and Drug Administration (FDA) (Wang et al., 2016). HHP can be applied to inactivate of pathogenic microorganisms that, deactivate enzymes, increase the shelf life of foods, and induce desired conformational and chemical modifications in the food matrix (Aganovic et al., 2021). Previous studies have demonstrated that HHP treatment can increase the surface hydrophobicity, enhance solubility, and improve foaming features of whey proteins (Lim et al., 2008a; Ambrosi et al., 2016). However, no study has been found on the contribution of HHP treated whey to bread quality. Therefore, this study investigated the effects of HHP treated whey on certain quality parameters of bread.

Methods

Materials

Wheat flour and whey were provided from Ankara Public Bread and Flour Factory Inc. (Ankara, Türkiye) and Atatürk Forest Farm Milk Factory (Ankara, Türkiye), respectively. Wheat flours (Type 550, Type 650, and Type 85) were mixed in equal proportions, and the mixed flour was utilized in bread making. Good quality refined salt and baker's yeast (Saccharomyces cerevisiae) were provided from Ankara Public Bread and Flour Factory Inc. (Ankara, Türkiye).

Material Analysis

Moisture content, wet gluten, dry gluten, Zeleny sedimentation, falling number, ash content, acidity, sieve analysis, farinograph, and extensograph properties of flour were analyzed following the methods outlined by Elgün et al. (1998). Dry matter, ash, oil, acidity, and pH values of whey were analyzed using the methods specified by Kurt et al. (1996).

High Hydrostatic Pressure Treatment of Whey

High hydrostatic pressure treatment was conducted at Middle East Technical University. In previous studies, the features of the device used were detailed (Erkan et al., 2011; Önür et al., 2018). Deionized water was used as the medium for isostatic pressure transduction. HHP treatment conditions for whey were justified (R = 0.999). The whey samples were exposed to HHP treatment for 3 minutes at 300 MPa and 20±1°C. Pressurization times did not contain the times for pressure rise and release. The sterile falcon tubes containing whey, wrapped with stretch film, were placed inside the cylindrical vessel of the HHP equipment. The chamber was then closed, and the samples were left for 2 minutes for temperature equilibration. After the HHP treatment, the samples were immediately removed from the chamber and stored at 4°C (Çiçek, 2011).

Bread Baking Procedure

The dough was prepared by combining 45 g of refined salt, 203 g of bread yeast, 3 kg of flour, and 1800 mL of water in a stainless-steel mixing bowl. Water absorption capacity of the flour (59.5%) was determined using a farinograph, as per standard methods. Whey (treated with high hydrostatic pressure or untreated) was added at a ratio of 25% of the water absorption capacity of the flour, with the exact amount of whey added being 450 mL (Dinçoğlu & Ardıç, 2012; Iuga et al., 2020). The ingredients were mixed using a spiral kneader, initially at slow speed for 4 min and then at fast speed for 18 minutes to form the dough. The dough was then weighed and divided into three equal portions, each of which was allowed to rest for 10 min at room temperature. After this, the dough portions were shaped and allowed to rest for an additional 10 min. The dough was transferred to a fermentation room and left to ferment for 75 min at 25±1°C. The oven was preheated to an inlet temperature of 190°C and an outlet temperature of 242°C, and the dough was baked for 28 min, following the AACC 10-10B guidelines with slight modifications. After baking, the bread was removed from the oven, weighed, and allowed to cool to room temperature. Finally, texture analysis was performed on the cooled bread 24 hours after baking.

Bread Quality

Stereo microscope images of bread samples

Bread samples were sliced (3 mm thick) after 24, 48, and 120 hours and photographed under a stereo microscope (Nikon SMZ 1500, Japan, 40X magnification).

Experimental analysis

The moisture, ash, and unsalted ash content, acidity, weight, dough yield, volume, specific volume, and crust/crumb ratio of bread samples were analyzed using the methods specified by Nwosu et al. (2014).

Texture analysis

Texture profile analyse was carried by a texture analyzer (Lloyd TA Plus, UK). The diameter of the cylinder probe was 3.5 cm. The bread was cut into 1.25 cm thick slices using a saw blade after 24, 48, and 72 hours. Two slices were taken from the loaf, stacked on top of each other, and measured to be a total of 2.5 cm thick (Basman et al., 2002; Çetiner et al., 2017). Hardness values were obtained by compressing the bread at a rate of 25% with a stroke of 1 mm/s. The overall average value of three measurements was reported.

Color analysis

Values of brightness (L^*), redness (a^*), and yellowness (b^*) of bread samples were determined using the CIE $L^*a^*b^*$ system with a Minolta Spectrophotometer CM-3600d. The color of bread samples was determined by averaging three L^*, a^*, and b^* readings. In this context, L^* indicates brightness (ranging from 0=black to 100=white), $+a^*$ indicates redness, $-a^*$ indicates greenness, $+b^*$ indicates yellowness, and $-b^*$ indicates blueness. A white calibration plate was used to standardize the equipment before conducting color measurements (Adamczyk et al., 2021). Color measurements were taken at four points on the surface of the bread.

Sensory analysis

Sensory features of bread samples were scored by 10 panelists, consisting of six females and four males aged 23-35. The bread samples were labeled with letters, and the order of sample presentation was entirely randomized before serving them to the panelists. All bread samples were served simultaneously on the same day. The sensory quality characteristics of bread samples (structure of the bread inside, crust, symmetry of shape, color, taste, and smell) were scored on a 1–5 scale, where 1 indicated “dislike extremely” and 5 indicated “like extremely” (Bilgiçli & İbanoğlu, 2015).

Statistical Analysis

All measurements were examined using SPSS 15.0 software (SPSS Inc., Chicago, IL, USA). The least significant difference was calculated at the p <.05 level. Significant differences amongs means were determined using Duncan's multiple range test. All analyses were conducted with at least 3 replications. The values are given as ± standard error.

Results

The physical and chemical parameters of the flour and whey used in the study are provided in Table 1.

The images of the internal structure of the bread samples at 24, 48, and 120 hours are presented in Figure 1.

Table 1.
Physical and chemical parameters of the flour and whey

Parameters for flour	Values (Unit)
Moisture	12.90 (%)
Dry matter	87.10 (%)
Above sieve (the sieve pore size: 224 µm)	0.05 (%)
Under sieve (the sieve pore size: 224 µm)	99.96 (%)
Ash	0.56 (%)
Acidity	0.03 (%)
Wet gluten	31.97 (%)
Dry gluten	11.19 (%)
Sedimentation	26 (cm^3)
Falling number	869 (s)
Parameters for whey	**Values (Unit)**
Dry matter	5.73 (%)
Ash	0.38 (%)
Acidity	0.17 (%)
pH (at 28.5℃)	4.93
Fat	0.30 (%)

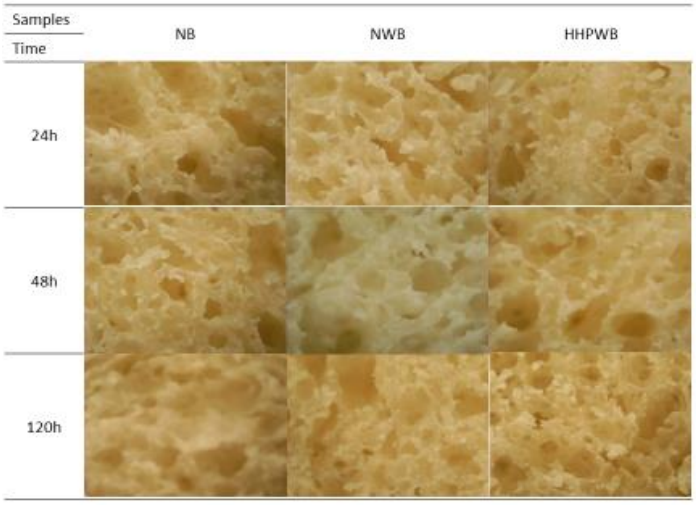

Figure 1.
The images of the internal structure of the bread samples (NB: Normal bread, NWB: Normal whey added bread, HHPWB: HHP treated whey added bread)

The results of the experimental analysis of the bread samples are presented in Table 2.

Table 2.
Experimental Values of the Bread Samples

Experimental analysis	Bread Samples		
	NB	NWB	HHPWB
Moisture (%)	37.63±0.03[a]	37.62±0.02[a]	38.79±0.01[b]
Ash (%)	2.28±0.01[a]	2.28±0.01[a]	2.21±0.01[b]
Unsalted Ash (%)	0.55±0.00[a]	0.53±0.00[a]	0.53±0.01[a]
Acidity	2.85±0.07[a]	3.71±0.05[b]	3.82±0.03[b]
Weight (g)	143.50±1.53[a]	148.50±1.53[b]	148.20±0.18[b]
Dough Yield (%)	166.60±0.32[a]	169.40±1.83[a]	171.30±1.46[a]
Volume (cm^3)	355±0.03[a]	377.50±3.53[b]	365±0.00[c]
Specific volume (cm^3/g)	2.47±0.03[a]	2.54±0.05[a]	2.46±0.00[a]
Crust/crumb ratio	0.76±0.00[a]	0.71±0.00[a]	0.63±0.00[a]

NB: Normal bread, NWB: Normal whey added bread, HHPWB: HHP treated whey added bread; [a, b]: Means with different lowercase letters in the same column are statistically different at $p<.05$

The results of the texture analysis of the bread samples are presented in Table 3.

Table 3.
Texture Values of the Bread Samples

Texture Parameters	Bread Samples		
	NB	NWB	HHPWB
Hardness (N)	13.34[a]	10.16[b]	9.88[b]
Gumminess	0.54[a]	0.54[a]	0.54[a]
Elasticity (mm)	5.40[a]	5.44[a]	5.70[b]
Chewability (Nmm)	38.31[a]	29.64[b]	30.67[b]

NB: Normal bread, NWB: Normal whey added bread, HHPWB: HHP treated whey added bread; [a, b]: Means with different lowercase letters in the same column are statistically different at $p<.05$

The results of the color analysis of the bread samples are presented in Table 4.

Table 4.
Color Values of the Bread Samples

Color Values	Bread Samples		
	NB	NWB	HHPWB
L^*	67.46±5.66[a]	65.09±6.39[b]	65.10±4.96[b]
a^*	7.69±6.37[a]	8.77±6.89[b]	8.80±6.93[b]
b^*	28.35±1.20[a]	27.68±0.78[a]	28.11±0.63[a]

NB: Normal bread, NWB: Normal whey added bread, HHPWB: HHP treated whey added bread; [a, b]: Means with different lowercase letters in the same column are statistically different at $p<.05$

The results of the sensory analysis of the bread samples are presented in Table 5.

Table 5.
Sensory values of the bread samples

Sensory Parameters	Bread Samples		
	NB	NWB	HHPWB
Bread Crumb	3.70±0.95[a]	4.40±0.70[a]	3.50±0.97[a]
Bread Crust	3.20±0.92[a]	4.10±0.88[b]	4.40±0.70[b]
Symmetry	3.10±0.57[a]	4.10±0.57[b]	4.20±0.42[b]
Taste	3.40±1.07[a]	3.80±0.79[a]	4.00±1.15[a]
Odour	3.60±1.17[a]	3.70±1.06[a]	4.10±0.99[a]
Color	2.90±0.99[a]	4.00±1.05[b]	3.90±0.99[b]

NB: Normal bread, NWB: Normal whey added bread, HHPWB: HHP treated whey added bread; [a, b]: Means with different lowercase letters in the same column are statistically different at $p<.05$

Discussion

The parameters, such as moisture content, dry matter, ash content, acidity, wet gluten, and dry gluten of the mixed flour, were found to be suitable for bread making according to the Turkish Food Codex Wheat Flour Communique (Communique Number: 2013/9) (Table 1). The low volume of the normal bread observed in this study may be attributed to the very low amylase activity in the flour, as indicated by the falling number of 869 s. This reduced amylase activity limits the availability of fermentable sugars for the yeast, which can result in insufficient fermentation and lower bread volume.

The whey was characterized by the following parameters: dry matter, ash, acidity, pH, and fat values were 5.73%, 0.38%, 0.17%, 4.93, and 0.30%, respectively (Table 1). It has been reported that the dry matter content of whey from six dairy plants ranged from 5% to 7% (Alsaed et al., 2013). In another study, it has been demonstrated that large variations were observed in the ash content of acid whey (0.57-1.88) and sweet whey (0.37-0.58) (Gernigon et al., 2010). The characterization parameters of whey mostly depend on the processing techniques used in cheese factories.

The addition of HHP-treated and untreated whey to the bread dough did not led to a significant change in bread properties in terms of unsalted ash, dough yield, specific volume, and crust/crumb ratio according to the control group (normal bread: NB). It has been reported that whey affects the specific volume of bread depending on the presence of hydrocolloids in the dough formulation. Whey, which increases the specific volume of bread in the presence of hydrocolloids such as hydroxypropylmethylcellulose (HPMC), yeast β-glucan, and whey protein isolate (WPI), decreases the specific volume of bread in the absence of hydrocolloids (Kittisuban et al., 2014). The decrease in the specific volume can be explained by the low water absorption of proteins. In this case, a more intense breadcrumb feature can be encountered (Kittisuban et al., 2014). A significant decrease in bread acidity, as well as a notable increase in bread weight and volume, were observed with the addition of whey. The addition of HHP-treated whey to bread dough resulted in significant differences in moisture, ash content, and bread volume compared to bread with untreated HHP whey and normal bread. Gluten proteins have a greater capacity to form hydrogen bonds with water molecules compared to whey proteins. Lower water absorption and water binding capacity of whey proteins may be responsible for bread with low moisture content. It has been reported that bread prepared with 20% whey protein concentrate (WPC) had lower moisture content compared to normal bread (Ferreyra et al., 2021). Because high hydrostatic pressure can be applied at low temperatures, it provides an advantage in modifying food products while preserving their quality (Carullo et al., 2021). The incorporation of untreated WPC (5%) into wheat flour decreased water absorption by 66% compared to the control group (100% classical wheat flour with 70% water absorption). Conversely, the inclusion of HHP-treated WPC (5%) at 85 Kpsi for 30 minutes resulted in an increase in water absorption to 70% (Kadharmestan et al., 1998). Pressure treatment up to 300 MPa can cause reversible protein denaturation at low protein concentrations, while pressures above 300 MPa can cause irreversible denaturation of proteins. High pressure causes conformational and structural changes in proteins by deprotonating charged groups, disrupting salt bridges, and hydrophobic interactions. Here, HHP treatment improved the hydrogen bonding of proteins in whey with water molecules (Table 2).

Acidity increased significantly in breads with whey added, both in the HHP-treated and untreated samples. This increase in acidity can be attributed to the presence of whey proteins, which contribute additional amino acids to the bread formulation. In the case of HHP-treated whey, structural changes in the proteins may enhance the availability of amino acids, potentially influencing the acidity further. The alteration of the whey proteins, especially through protonation of their amine groups in the acidic environment, could increase the release of free protons (H^+), contributing to the overall rise in acidity in the bread (Table 2) (Falade et al., 2021; Yang et al., 2019).

The specific volume of bread increased when 25% whey was added compared to normal bread, but this increase was not significant (Table 2). Previous studies have shown that adding 5%, 10%, and 15% whey protein to bread resulted in a decrease in specific volume, while adding 20%, 25%, and

30% whey protein led to an increase in specific volume compared to the control group. However, these changes in specific volume were not statistically significant (Zhou et al., 2018). The presence of whey proteins in bread dough in a higher concentration than the gluten content of wheat flour can result in a better specific volume by increasing the gelation of whey proteins with heat and strengthening the expanding cells of the dough. The utilization of HHP-treated whey resulted in the lowest specific volume of bread, although this difference was not statistically significant. HHP treatment results in a reduction in the specific volume of proteins. When water molecules permeate the polypeptide core, they cause the tertiary and quaternary structures to unfold as the spaces become occupied. In this way, conformational and structural changes of proteins occur (Carullo et al., 2021).

A significant decrease was seen in the hardness and chewability properties of HHP-treated and untreated whey-added breads compared to normal breads (Table 3). In previous studies, it was reported that the hardness and chewiness of bread increased when whey was added compared to normal bread. However, some studies have reported that bread made with enhanced whey was softer than normal bread after 30 minutes of baking but tended to become harder over time. Dissolved proteins in whey can play a role by creating a homogeneous structure (Guiné et al., 2020; Hossein, 2009; Ozturk & Mert, 2018). Organic acids and calcium in whey can contribute to a softer texture by influencing the activity of protease and amylase in bread dough. In addition, the high amount of whey added to the bread dough can also contribute to the softness of the bread and increase the fermentation ratio. The elasticity of the bread with whey added and treated with HHP was significantly increased according to the other bread samples. Previous studies have indicated that the HHP treatment affects the foaming, surface hydrophobicity, solubility, gelling, and emulsifying properties of whey, particularly whey proteins (Lee et al., 2006; Lim et al., 2008b). It has been reported that HHP application provides accessibility for antibodies and increases the antigenicity of epitopes embedded in whey proteins. Conformational changes induced by HHP can impact enzyme activity, enhance enzymatic digestion efficiency, alter hydrolysis reaction kinetics, influence flavor binding, and affect overrun and foam stability (Ambrosi et al., 2016; Liu et al., 2005; Lim et al., 2008b).

Color measurements showed that high hydrostatic pressure (HHP)-treated and untreated whey-added breads had a darker but less yellowish color, although there was a decrease in the brightness of normal breads. It can be seen that the *a** value increased in both HHP-treated and untreated whey-added breads, whereas there was no significant change in the *b** values. *L** values were lower in high hydrostatic pressure (HHP)-treated and untreated whey-added breads compared to normal breads (Table 4). It has been demonstrated that bread supplemented with whey protein concentrate (WPC) had a lower *L** value of crumb compared to normal bread. In addition, it has been observed that the *L** value decreased further when the addition of WPC was increased from 5% to 10% (Zhou et al., 2018). In another study, a decrease in *L** values and an increase in *a** values were observed in the crust and crumb color parameters of bread prepared with 20% WPC-added sourdough compared to the control group (Ferreyra et al., 2021). The slightly yellowish hue of bread may be due to vitamin B2 (riboflavin) found in whey (Chudy et al., 2020). The HHP application may have caused the release of riboflavin by affecting the disintegration of micelles in whey. The reduction in micelle size can increase the yellowness of whey color. With the application of pressure in the range of 300 MPa to 676 MPa, it is possible to recombine the dispersed micelles. HHP application can affect non-covalent bonds, such as hydrogen, ionic, and hydrophobic bonds, as well as high molecular weight compounds due to their sensitivity to pressure (Chawla et al., 2011). The darker color can be explained by the active role of the amino acid lysine and lactose in whey in the Maillard reaction. The Maillard reaction is a series of sequential reactions that occur between the α and ε ends of amino acids, including lysine, and the carbonyl group in the reduced carbohydrate monomers at high temperatures (Mzoughi et al., 2024; Xiang et al., 2021). It is important for the desired brown color formation in foods such as bakery products (Wang et al., 2013). The dark color tone and lighter yellow bread tone obtained in this study are consistent with findings from other studies on bread enrichment with whey (Divya & Rao, 2010; Tsanasidou et al., 2021).

With the addition of whey to bread, the sensory scores for bread crust, symmetry, and color were significantly higher compared to normal bread (Table 5). These high scores can be attributed to the role of whey in the Maillard browning reaction. Considering the protein content of whey, it is known to be particularly rich in lysine. The amino acid lysine is highly reactive in the Maillard reaction. In addition, the high lactose content of whey positively affects the Maillard reaction (Komeroski & Oliveira, 2023; Pořízka et al., 2023). In studies on the antioxidant effects of Maillard reaction products, it has been stated that they gain antioxidant properties by scavenging peroxyl radicals in the Maillard reaction, which occurs with the cooperation of lactose and lysine (Feng et al., 2022). The application of high hydrostatic pressure to the whey enhanced the overall sensory perception of bread, with the exception of the crumb structure and color. However, there was no statistical

difference in sensory analysis between normal whey-added bread and HHP-treated whey-added bread. Bread made with HHP-treated whey had the lowest score in crumb properties, but there was no significant difference compared to other bread samples.

The taste and odour of the bread improved with the addition of HHP and untreated whey, but no significant difference was observed. HHP treatment does not affect low molecular weight compounds responsible for nutritional and sensory properties, such as vitamins and aroma compounds (Tirpanci et al., 2022). In the study examining the flavor binding properties of high hydrostatic pressure (HHP) treatment (600 MPa at 50°C) on whey protein concentrate (WPC), it was reported that there were significant increases in the binding sites of WPC for heptanone and octanone (Liu et al., 2005). Hydrophobic, electrostatic, and steric properties of protein molecules affect their functionality. For example, the hydrophobic surfaces of proteins affect their emulsion capacity and stability. With the increase in the hydrophobicity of the proteins, the oil-binding capacity can increase. In this case, the flavor properties of the foods can be positively affected (Liu et al., 2005). B-lactoglobulin (β-Lg), which constitutes over 50% of whey proteins, plays a crucial role in determining the properties of whey, including solubility, gelling, foaming, emulsification, and flavor. It has been reported that the application of high hydrostatic pressure causes openings in the protein structure. This leads to the exposure of embedded hydrophobic groups, thereby increasing the surface hydrophobicity and binding affinities of β-Lg (López-Fandiño, 2006). It has been reported that whey proteins enhance the crust quality of gluten-free breads made with rice flour and corn starch. The bread crust has a high pyrazine content, contributing to its dark color. Additionally, whey proteins increase the volatile compound content through lipid oxidation, thereby influencing the taste of the bread (Pico et al., 2019). Therefore, the concentration and ratio of whey used should be carefully selected to control the development of a rancid taste due to the increase in volatile compounds originating from lipid oxidation. In this study, only one concentration of whey was investigated, as the focus was on evaluating the specific effects of HHP-treated whey on the quality of the bread, particularly physicochemical, texture, sensory, and color. Future studies could explore a range of concentrations to assess how different levels of whey affect lipid oxidation and the associated flavor changes.

Conclusion and Recommendations

This study investigated the impact of HHP-treated whey on the physicochemical, texture, color, and sensory properties of bread. The application of HHP treatment resulted in reduced bread hardness, while increasing the ash content, acidity, weight, and volume of the bread. In addition, there was a decrease in L^* values (lightness) and an increase in a^* values (redness). Sensory evaluation showed improvements in the crust, symmetry, and overall color of the bread compared to the control. The HHP treatment also influenced the ash content and elasticity of the whey in the bread formulation. This study provides valuable insights into the conformational changes in whey proteins induced by HHP, which enhance its potential for enriching bread. HHP treatment has gained significant attention for its ability to induce desired properties by altering the structure of large molecules held together by noncovalent bonds, especially in dairy products. Given the nutritional and technological benefits of dairy products, including whey, their incorporation into bakery products is common. Therefore, further research into the application of HHP-treated whey in other bakery and food products is recommended.

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References

AACC (Approved methods of the American association of cereal chemists) (2000). *American Association of Cereal Chemists*. Approved Methods Committee, 1.

Adamczyk, G., Ivanišová, E., Kaszuba, J., Bobel, I., Khvostenko, K., Chmiel, M., & Falendysh, N. (2021). Quality assessment of wheat bread ıncorporating chia seeds. *Foods, 10*(10), 2376.

Aganovic, K., Hertel, C., Vogel, R. F., Johne, R., Schlüter, O., Schwarzenbolz, U., Jäger, H., Holzhauser, T., Bergmair, J., Roth, A., Sevenich, R., Bandick, N., Kulling, S. E., Knorr, D., Engel, K. H., & Heinz, V. (2021). Aspects of high hydrostatic pressure food processing: Perspectives on technology and food safety. *Comprehensive Reviews in Food Science and Food Safety, 20*(4), 3225-3266.

Alsaed, A. K., Ahmad, R., Aldoomy, H., El-Qader, S. A., Saleh, D., Sakejha, H., & Mustafa, L. (2013). Characterization, concentration and utilization of sweet and acid whey. *Pakistan Journal of Nutrition, 12*(2), 172-177.

Ambrosi, V., Polenta, G., Gonzalez, C., Ferrari, G., & Maresca, P. (2016). High hydrostatic pressure assisted enzymatic hydrolysis of whey proteins. *Innovative Food Science and Emerging Technologies, 38*, 294-301.

Basman, A., Köksel, H., & Ng, P. K. (2002). Effects of increasing levels of transglutaminase on the rheological properties and bread quality characteristics of two wheat flours. *European Food Research and Technology, 215*(5), 419-424.

Betoret, E., & Rosell, C. M. (2020). Enrichment of bread with fruits and vegetables: Trends and strategies to increase functionality. *Cereal Chemistry, 97*(1), 9-19.

Bilgiçli, N., & İbanoğlu, Ş. (2015). Effect of pseudo cereal flours on some physical, chemical and sensory properties of bread. *Journal of Food Science and Technology, 52*(11), 7525-7529.

Carullo, D., Barbosa-Cánovas, G. V., & Ferrari, G. (2021). Changes of structural and techno-functional properties of high hydrostatic pressure (HHP) treated whey protein isolate over refrigerated storage. *LWT- Food Science and Technology, 137*, 110436.

Chawla, R., Patil, G. R., & Singh, A. K. (2011). High hydrostatic pressure technology in dairy processing: A review. *Journal of Food Science and Technology, 48*(3), 260-268.

Chudy, S., Bilska, A., Kowalski, R., & Teichert, J. (2020). Colour of milk and milk products in CIE Lab space. *Medycyna Weterynaryjna, 76*(2), 77-81.

Çetiner, B., Acar, O., Kahraman, K., Sanal, T., & Koksel, H. (2017). An investigation on the effect of heat-moisture treatment on baking quality of wheat by using response surface methodology. *Journal of Cereal Science, 74*, 103-111.

Çiçek, S. (2011). *The effect of addition of whey with high hidrostatic pressure microfluidizer and ultrasoundapplication on some quality parameters, colour, texture of the bread.* (Master's thesis). Atatürk Üniversity, Erzurum.

Das, B., Sarkar, S., Sarkar, A., Bhattacharjee, S., & Bhattacharjee, C. (2016). Recovery of whey proteins and lactose from dairy waste: A step towards green waste management. *Process Safety and Environmental Protection, 101*, 27-33.

Dıblan, S., Salum, P., Ulusal, F., & Erbay, Z. (2024). Impact of conjugation of whey protein concentrate with different carbohydrates: Monitoring structural and technofunctional variations. *International Dairy Journal, 158*, 106036.

Dinçoğlu, A. H., & Ardıç, M. (2012). Peynir altı suyunun beslenmemizdeki önemi ve kullanım olanakları. *Harran Üniversitesi Veteriner Fakültesi Dergisi, 1*(1), 54-60.

Divya, N., & Rao, K. J. (2010). Studies on utilization of indian cottage cheese whey in wheat bread manufacture. *Journal of Food Processing and Preservation, 34*(6), 975-992.

Elgün, A., Ertugay, Z., Certel, M., & Kotancılar, G. (1998). Analytical quality control and laboratory application guide in cereal and cereal products (in Turkish). *Atatürk Uni Ziraat Fak Yay.*

Erkan, N., Üretener, G., Alpas, H., Selçuk, A., Özden, O. & Buzrul, S. (2011). The effect of different high pressure conditions on the quality and shelf life of cold smoked fish. Innovative *Food Science and Emerging Technologies, 12*(2), 104-110.

Falade, E. O., Mu, T. H., & Zhang, M. (2021). Improvement of ultrasound microwave-assisted enzymatic production and high hydrostatic pressure on emulsifying, rheological and interfacial characteristics of sweet potato protein hydrolysates. *Food Hydrocolloids, 117*, 106684.

Feng, J., Berton-Carabin, C. C., Fogliano, V., & Schroën, K. (2022). Maillard reaction products as functional components in oil-in-water emulsions: A review highlighting interfacial and antioxidant properties. *Trends in Food Science & Technology, 121*, 129-141.

Ferreyra, L. S., Verdini, R. A., Soazo, M., & Piccirilli, G. N. (2021).

Impact of whey protein addition on wheat bread fermented with a spontaneous sourdough. *International Journal of Food Science and Technology, 56*(9), 4738-4745.

Gernigon, G., Schuck, P., & Jeantet, R. (2010). Processing of Mozzarella cheese wheys and stretchwaters: A preliminary review. *Dairy Science and Technology, 90*(1), 27-46.

Guiné, R. P. F., Santos, C., Rocha, C., Marques, C., Rodrigues, C., Manita, F., Sousa, F., Félix, M., Silva, S., & Rodrigues, S. (2020). Whey-bread, an improved food product: Evaluation of textural characteristics. *Journal of Culinary Science and Technology, 18*(1), 40-53.

Hossein, J. (2009). Evaluation of physical and sensory properties of Iranian Lavash flat bread supplemented with precipitated whey protein (PWP). *African Journal of Food Science, 3*(2), 28-34.

Huang, H. W., Hsu, C. P., & Wang, C. Y. (2020). Healthy expectations of high hydrostatic pressure treatment in food processing industry. *Journal of Food and Drug Analysis, 28*(1), 1-13.

Ingrassia, R., Torres, P., Bojanich, L., Ratti, J., Baldor, S., Ramunno, C., Dotta, G., Vidal Tesón, A., Forastieri, P., Soazo, M., Spelzini, D., Narambuena, C., & Boeris, V. (2022). Concentration of proteins and fat from whey by coacervation: Evaluation of its incorporation in bread. *Journal of Food Processing and Preservation, 46*(2).

Iuga, M., Boestean, O., Ghendov-Mosanu, A., & Mironeasa, S. (2020). Impact of dairy ingredients on wheat flour dough rheology and bread properties. *Foods, 9*(6), 828.

Kadharmestan, C., Baik, B. K., & Czuchajowska, Z. (1998). Whey protein concentrate treated with heat or high hydrostatic pressure in wheat-based products. *Cereal Chemistry, 75*(5), 762-766.

Kittisuban, P., Ritthiruangdej, P., & Suphantharika, M. (2014). Optimization of hydroxypropylmethylcellulose, yeast β-glucan, and whey protein levels based on physical properties of gluten-free rice bread using response surface methodology. *LWT - Food Science and Technology, 57*(2), 738-748.

Komeroski, M. R., & Oliveira, V. R. D. (2023). Influence of the amount and type of whey protein on the chemical, technological, and sensory quality of pasta and bakery products. *Foods, 12*(14), 2801-2016.

Kourkouta, L., Koukourikos, K., Iliadis, C., Ouzounakis, P., Monios, A., Tsaloglidou, & A. (2017). Bread and health. *Journal of Pharmacy and Pharmacology, 5*(11).

Kurt, A., Cakmakci, S., & Caglar, A. (1996). A guide book of analysis methods of milk and milk products. *In Agricultural Faculty Pub*. No 18.

Lachowicz, S., Świeca, M., & Pejcz, E. (2021). Biological activity, phytochemical parameters, and potential bioaccessibility of wheat bread enriched with powder and microcapsules made from Saskatoon berry. *Food Chemistry, 338*, 128026.

Lee, W., Clark, S., & Swanson, B. G. (2006). Functional properties of high hydrostatic pressure-treated whey protein. *Journal of Food Processing and Preservation, 30*(4), 488-501.

Lim, S. Y., Swanson, B. G., & Clark, S. (2008a). High hydrostatic pressure modification of whey protein concentrate for improved functional properties. *Journal of Dairy Science, 91*(4), 1299-1307.

Lim, S. Y., Swanson, B. G., Ross, C. F., & Clark, S. (2008b). High hydrostatic pressure modification of whey protein concentrate for improved body and texture of lowfat ice cream. *Journal of Dairy Science, 91*(4), 1308-1316.

Liu, X., Powers, J. R., Swanson, B. G., Hill, H. H., & Clark, S. (2005). High hydrostatic pressure affects flavor-binding properties of whey protein concentrate. *Journal of Food Science, 70*(9), 581-585.

Lockyer, S., & Spiro, A. (2020). The role of bread in the UK diet: An update. *Nutrition Bulletin, 45*(2), 133-164.

López-fandiño, R. (2006). Functional improvement of milk whey proteins induced by high hydrostatic pressure. *Critical Reviews in Food Science and Nutrition, 46*(4), 351-363.

Madenci, A. B., & Bilgiçli, N. (2014). Effect of whey protein concentrate and buttermilk powders on rheological properties of dough and bread quality. *Journal of Food Quality, 37*(2), 117-124.

Martins, Z. E., Pinho, O., & Ferreira, I. M. P. L. V. O. (2017). Food industry by-products used as functional ingredients of bakery products. *Trends in Food Science and Technology, 67*, 106-128.

Meral, R., & Erim Köse, Y. (2019). The effect of bread-making process on the antioxidant activity and phenolic profile of enriched breads. *Quality Assurance and Safety of Crops and Foods, 11*(2), 171-181.

Mzoughi, M., Demircan, E., Zouari, A., & Toker, O. S. (2024). *Maillard Reaction for Protein Fortification in Bakery Products*. In Fortified Foods (pp. 263-304). New York, NY:

Springer US.

Nwosu, J. N., Owuamanam, C. I., Omeire, G. C., & Eke, C. C. (2014). Quality parameters of bread produced from substitution of wheat flour with cassava flour using soybean as an improver. *American Journal of Research Communication, 2*(3), 99-118.

Ozturk, O. K., & Mert, B. (2018). The effects of microfluidization on rheological and textural properties of gluten-free corn breads. *Food Research International, 105*, 782-792.

Önür, İ., Misra, N. N., Barba, F. J., Putnik, P., Lorenzo, J. M., Gökmen, V., & Alpas, H. (2018). Effects of ultrasound and high pressure on physicochemical properties and HMF formation in Turkish honey types. *Journal of Food Engineering, 219*, 129-136.

Pico, J., Reguilón, M. P., Bernal, J., & Gómez, M. (2019). Effect of rice, pea, egg white and whey proteins on crust quality of rice flour-corn starch based gluten-free breads. *Journal of Cereal Science, 86*, 92–101.

Pillai, A. T., Morya, S., & Kasankala, L. M. (2024). Emerging Trends in Bioavailability and Pharma-Nutraceutical Potential of Whey Bioactives. *Journal of Nutrition and Metabolism, 1*, 8455666.

Pořízka, J., Slavíková, Z., Bidmonová, K., Vymětalová, M., & Diviš, P. (2023). Physiochemical and sensory properties of bread fortified with wheat bran and whey protein isolates. *Foods, 12*(13), 2635-2049.

Thampy, A., Palani Kumar, M. K., Serva Peddha, M., & Reddy, M. (2024). The effectiveness of whey proteins in prevention and treatment of cancer: a review. *Critical Reviews in Food Science and Nutrition, 64*(8), 2088-2104.

Tirpanci, B., Ozel, B., Oztop, M. H., & Alpas, H. (2022). Stability of acidified milk drinks: Comparison of high hydrostatic pressure (HHP) and thermal treatments. *International Dairy Journal*, 105512.

Tsanasidou, C., Kosma, I., Badeka, A., & Kontominas, M. (2021). Quality parameters of wheat bread with the addition of untreated cheese whey. *Molecules, 26*(24), 7518.

van Riemsdijk, L. E., van der Goot, A. J., & Hamer, R. J. (2011). The use of whey protein particles in gluten-free bread production, the effect of particle stability. *Food Hydrocolloids, 25*(7), 1744-1750.

Wang, C. Y., Huang, H. W., Hsu, C. P., & Yang, B. B. (2016). Recent advances in food processing using high hydrostatic pressure technology. *Critical Reviews in Food Science and Nutrition, 56*(4), 527-540.

Wang, W. Q., Bao, Y. H., & Chen, Y. (2013). Characteristics and antioxidant activity of water-soluble Maillard reaction products from interactions in a whey protein isolate and sugars system. *Food Chemistry, 139*(1–4), 355-361.

Xiang, J., Liu, F., Wang, B., Chen, L., Liu, W., & Tan, S. (2021). A literature review on maillard reaction based on milk proteins and carbohydrates in food and pharmaceutical products: advantages, disadvantages, and avoidance strategies. *Foods, 10*(9), 1998-2015.

Yadav, J. S. S., Yan, S., Pilli, S., Kumar, L., Tyagi, R. D., & Surampalli, R. Y. (2015). Cheese whey: A potential resource to transform into bioprotein, functional/nutritional proteins and bioactive peptides. *Biotechnology Advances, 33*(6), 756-774.

Yang, Y., Xia, Y., Wang, G., Tao, L., Yu, J., & Ai, L. (2019). Effects of boiling, ultra-high temperature and high hydrostatic pressure on free amino acids, flavor characteristics and sensory profiles in Chinese rice wine. *Food Chemistry, 275*, 407-416.

Zandona, E., Blažić, M., & Režek Jambrak, A. (2021). Whey utilisation: Sustainable uses and environmental approach. *Food Technology and Biotechnology, 59*(2), 147-161.

Zhang, J., Tu, W., Shen, Y., Wang, H., Yang, J., Ma, M., Man, C., Zhang, W., Zhao, Q., & Jiang, Y. (2024). Changes in whey protein produced by different sterilization processes and lactose content: Effects on glycosylation degree and whey protein structure. *Food Bioscience, 62*, 105040.

Zhou, J., Liu, J., & Tang, X. (2018). Effects of whey and soy protein addition on bread rheological property of wheat flour. *Journal of Texture Studies, 49*(1), 38-46.

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The Frequency and Density of Weeds in Peanut (*Arachis hypogaea* L.) Fields of Adana Province, Türkiye

Adana İli Yer Fıstığı (*Arachis hypogaea* L.) Tarlalarında Yabancı Otların Rastlanma Sıklığı ve Yoğunluğu, Türkiye

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ABSTRACT

Peanut (*Arachis hypogaea* L.) is an important arable crop. However, weeds cause significant yield losses difficulties. This study was conducted to determine the occurrence frequency and density of weed species in peanut fields in Adana province. In the 2021 vegetation period, surveys were conducted in 50 peanut fields in Adana and its districts. As a result of the surveys, 38 weed species belonging to 17 different families were identified. The Poaceae family had the highest number of weed species with 12 species, followed by the Amaranthaceae family with 4 species. Other important families included Euphorbiaceae, Asteraceae, Cyperaceae, Convolvulaceae, Malvaceae, and Solanaceae, each represented by 2 species. The studies showed that most of the weeds in peanut fields were broadleaf and annual species. According to survey results, species such as *Cyperus rotundus* L. (78%), *Sorghum halepense* (L.) Pers (67%), *Xanthium strumarium* L. (52%), *Convolvulus arvensis* L. (49%), and *Portulaca oleracea* L. (46%) were among the most common weeds in the region with the highest occurrence frequencies. In terms of density, *Setaria viridis* (L.) P. Beauv. (1,050 plants/m²) had the highest density. Other dense species included *C. rotundus* (0.715 plants/m²), *Echinochloa colona* L. (0.630 plants/m²), *Echinochloa crus-galli* (L.) P. Beauv. (0.505 plants/m²), and *S. halepense* (0.425 plants/m²). These species are dominant in the weed flora of the region with high occurrence frequencies and density levels.

Keywords: Peanut, Weeds, Adana, Frequency of occurrence, Density

ÖZ

Yerfıstığı (*Arachis hypogaea* L.), ekim alanlarında yabancı otların neden olduğu verim kayıpları nedeniyle önemli bir sorun teşkil etmektedir. Bu çalışma, Adana ilindeki yerfıstığı ekim alanlarında bulunan yabancı ot türlerinin rastlama sıklığı ve yoğunluklarını belirlemek amacıyla gerçekleştirilmiştir. 2021 yılı vejetasyon döneminde, Adana ili ve ilçelerinde toplamda 50 yerfıstığı tarlasında surveyler yapılmıştır. Surveyler sonucunda, 17 farklı familyaya ait 38 yabancı ot türü tespit edilmiştir. Poaceae familyası, 12 türle en fazla yabancı ot barındırırken, Amaranthaceae familyası ise 4 türle ikinci sıradadır. Diğer önemli familyalar arasında Euphorbiaceae, Asteraceae, Cyperaceae, Convolvulaceae, Malvaceae ve Solanaceae yer almakta ve her biri 2 türle temsil edilmektedir. Yapılan incelemeler, yerfıstığı ekim alanlarındaki yabancı otların büyük çoğunluğunun geniş yapraklı ve tek yıllık türlerden oluştuğunu göstermektedir. Survey sonuçlarına göre, *Cyperus rotundus* L. (%78), *Sorghum halepense* (L.) Pers (%67), *Xanthium strumarium* L. (%52), *Convolvulus arvensis* L. (%49) ve *Portulaca oleracea* L. (%46) gibi türler, en yüksek rastlama sıklığına sahip olup bölgedeki en yaygın yabancı otlar arasında yer almaktadır. Yoğunluk açısından, *Setaria viridis* (L.) P. Beauv. (1,050 adet/m²) en yüksek yoğunluğa sahip tür olarak öne çıkmaktadır. Diğer yoğun türler sırasıyla *C. rotundus* (0,715 adet/m²), *Echinochloa colona* L. (0,630 adet/m²), *Echinochloa crus-galli* (L.) P. Beauv (0,505 adet/m²) ve *S. halepense* (0,425 adet/m²) olarak belirlenmiştir. Bu türler, yüksek rastlama sıklığı ve yoğunluk seviyeleriyle bölgedeki yabancı ot florasında baskın durumdadır.

Anahtar Kelimeler: Yer fıstığı, Yabancı otlar, Adana, Rastlama sıklığı, Yoğunluk

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Introduction

Peanut (*Arachis hypogaea* L.) is an annual plant of the legume family that thrives in tropical and subtropical regions characterised by a warm climate. It is found in regions between 40° north and south latitudes (Kadiroğlu, 2018). Peanut is an important oil plant both in Turkey and worldwide (Arslan et al., 2022). This plant, which is a valuable food source for humans and animals, is rich in oil, protein, carbohydrates, vitamins, and minerals (Arıoğlu, 2007). In addition to its use in human consumption and as animal feed, peanut is also significant as an oilseed crop due to its ability to fix nitrogen in the soil (Doğaka, 2020). Peanut seeds contain 42-52% oil and 25-32% protein, and it is particularly used in the production of peanut oil, snack foods, and peanut butter (Chang et al., 2013). Globally, 49% of peanuts are used for oil production, 41% for human consumption, and 10% for animal feed and seed production. In Türkiye, a large portion of the peanut production is consumed as snack foods, while a smaller portion is used in the oil industry (Şahin, 2014). In 2022, a total of 54,238,560.13 tons of peanuts were produced worldwide on 30,536,263 hectares of land. The production came from Asia (58.45%), Africa (32.01%), and America (9.49%). The top three peanut-producing countries in that year were China (18,329,500 tons), India (10,134,990 tons), and Nigeria (4,284,000 tons) (FAO, 2024). In Türkiye, as of 2023, 185,137 tons of peanuts were produced on 460,098 hectares, with Adana province accounting for 48.07% of Türkiye's peanut production, producing 89,011 tons from 208,442 hectares (TÜİK, 2024).

With the increasing global population, the demand for agricultural products is growing. Therefore, enhancing plant production is necessary to meet the nutritional needs of the population. However, various factors negatively affect agricultural productivity, with weeds being one of the most significant (Tepe, 1998; Swinton & Van Deynze, 2017; Gharde et al., 2018). Weeds not only reduce crop yield but also damage the quality of the products (Jabran & Chauhan, 2018). The yield losses caused by weeds vary depending on the type of crop, geographic region, and weed species. Some weed species cause problems in multiple crops, while others affect only specific crops (Güncan, 2025). Weeds compete with crops for resources such as water, light, and nutrients, negatively affecting the physiological processes and growth of the crops, resulting in reduced yield and quality. This leads to economic losses (Anwar et al., 2021; Abdelaal et al., 2022; da Silva et al., 2022; Kumar et al., 2024)

To minimize losses caused by weeds, it is necessary to develop an effective weed management strategy. The foundation of this strategy is to identify weed species and understand their biology (Özer et al., 1998). There are many weed species in peanut cultivation areas in Turkey, and these species cause significant yield and quality losses in peanuts (Uygur, 1997; Arslan & Üremiş 2003; Uludağ et al., 2012; Abacı & Üremiş, 2016; Beycioğlu et al., 2020; Yılmaz et al., 2022). Farmers in the Çukurova region have reported encountering new weed species in peanut fields that are not affected by the currently registered herbicides. This situation necessitates the identification of weeds in peanut fields and a better understanding of their biological/ecological characteristics. Based on the data obtained, it is aimed to develop region-specific weed control methods considering the ecological characteristics of the area (Özaslan & Kendal, 2014). This study aims to determine the occurrence frequencies and densities of weed species found in peanut fields in Adana province, Türkiye.

Methods

Surveys were conducted in the districts of Yüreğir, Karataş, Kozan, Ceyhan, Karaisalı, Yumurtalık, and İmamoğlu in Adana province to identify weed species problematic in peanut production areas. In this study, surveys were conducted in 50 peanut fields during the 2021 vegetation period. The surveyed districts and fields were selected based on the total peanut planting areas (da) in 2020 according to TÜİK data. Table 1 shows the total peanut planting areas (da) in Adana Province and its districts and the number of surveys conducted in these districts.

Table 1.
Peanut planting areas in Adana province and the number of surveys conducted in districts based on 2020 data from TÜİK

Districts	Planting area (da)	Total number of fields surveyed
Yüreğir	46,500	8
Karataş	64,367	9
Kozan	17,300	7
İmamoğlu	12,650	6
Ceyhan	112,400	12
Karaisalı	2,550	3
Yumurtalık	8,250	5

Before the surveys, peanut planting areas were determined, and by going in lines towards these areas, the nearest peanut field, which was randomly selected every 10 km, was entered (Uygur, 1985). In the areas where the study was to be carried out, care was taken to ensure that the land generally consisted of medium-sized parcels. Using Sırma et al., (2001), the plants in the field were counted according to the size of the field (Table 2).

Table 2.
Number of frames thrown according to the size of the field in the surveys

Field Size (da)	Number of Frames Placed
0-5	4
5-10	6
10-20	8
20-50	12
50+	16

In the counts, a 1 m² frame was used to represent the field, starting from 5-10 m inside, away from the edge effect, and the weeds that entered were counted randomly. After the weeds were determined, the % Frequency of Encounter (R.S) of the weeds was calculated according to (Odum, 1983; Uygur, 1985). Frequency of Encounter; It is the ratio showing what percentage of a weed species is encountered in the regions where observations were made. The calculation of these ratios was made with the formula below.

R.S (%) = 100 x N/M

R.S: Frequency of Encounter (%)

N: Number of fields where a species is found

M: Total number of fields where measurements were made

The evaluation was made based on the arithmetic mean to determine the density of weeds. The total number of plants in m^2 of the surveys determined for weed densities (plants/m^2) were divided by the number of surveys made and the density of the species were calculated one by one (Odum, 1971).

Density (plant/m^2) = B/m

B: Total number of individuals in the sample taken

m: Total number of samples

Davis (1965-1988) was used in the identification of plant samples. Scale values developed and adapted by different researchers (Uludağ, 1993) were used to classify the weeds determined in the surveyed planting areas according to their frequency and density values and to emphasize important species. The meanings of the scale values were evaluated according to (Arslan, 2018). The relevant scale values are given in Table 3.

Table 3.
Grading of the density and prevalence of weeds

Frequency			Density		
Ç	≥%50	Very Common	A	≥10 plants/m^2	Very Dense
Y	%25-49	Common	B	5,00 - 9,99 plants/m^2	Dense
O	%13-24	Moderately Common	C	1,00 - 4,99 plants/m^2	Moderately Dense
N	<%12	Rare	D	0,10 - 0,99 plants/m^2	Low Dense
			E	0,01 - 0,09 plants/m^2	Very Low Dense
			F	<0,01 plants/m^2	Rare

Evaluation of data

Sankey diagram was used to visualize the distribution and interactions of weed species according to their families, leaf types and life spans. After transforming and normalizing the data, hierarchical cluster analysis (SRplot) was performed to group weeds according to their similarities in frequency and density. Network graph analysis (PAST software) was applied to determine and visualize the relationships between weeds according to frequency and density. When these two analyses are used together, it is possible to examine and evaluate the relationships of different applications in a much more comprehensive way. In addition, principal component analysis (PAST software) was performed to reduce multivariate data to a lower dimensional space and to determine important variables.

Results and Discussion

As a result of the surveys conducted in peanut cultivation areas of Adana province, a total of 38 weed species belonging to 17 different families were identified. In this study, the number of weed species in each family was determined and these data are presented visually in Figure 1.

The distribution of weed species identified as a result of surveys conducted in peanut cultivation areas by family shows that the Poaceae family has the most species with 12 weed species. This is followed by the Amaranthaceae family with 4 species. Other families include important groups such as Euphorbiaceae, Asteraceae, Cyperaceae, Convolvulaceae, Malvaceae, and Solanaceae, each of which has 2 weed species. The remaining families are represented by only 1 weed species (Figure 1). The identified weed species, their families, whether they are narrow-leaved or broad-leaved, and their life spans are presented in Figure 2 in the form of a Sankey diagram.

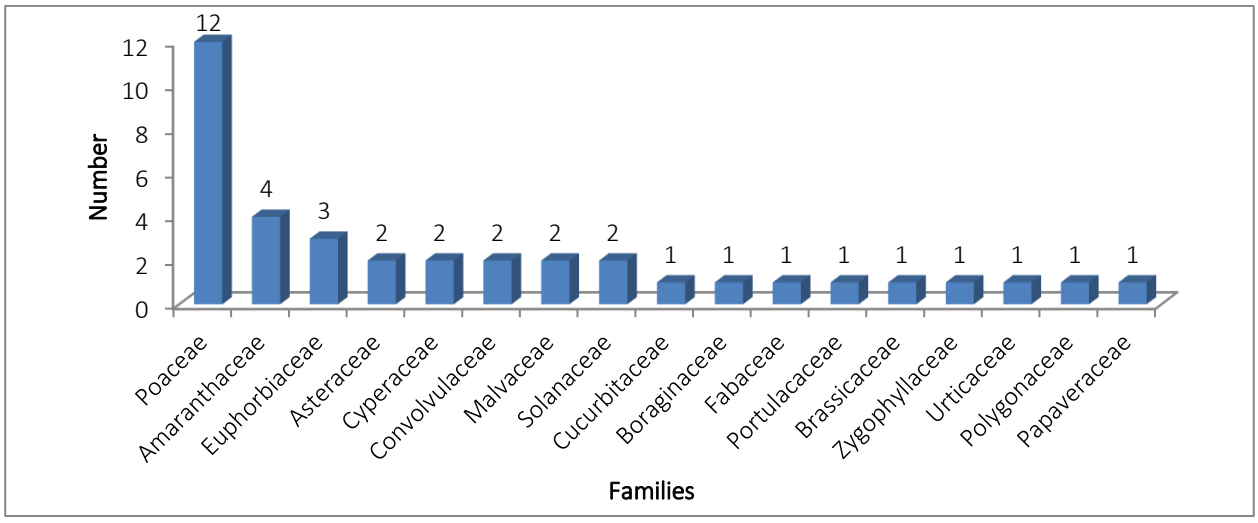

Figure 1.
Number of weed species of the identified weed families

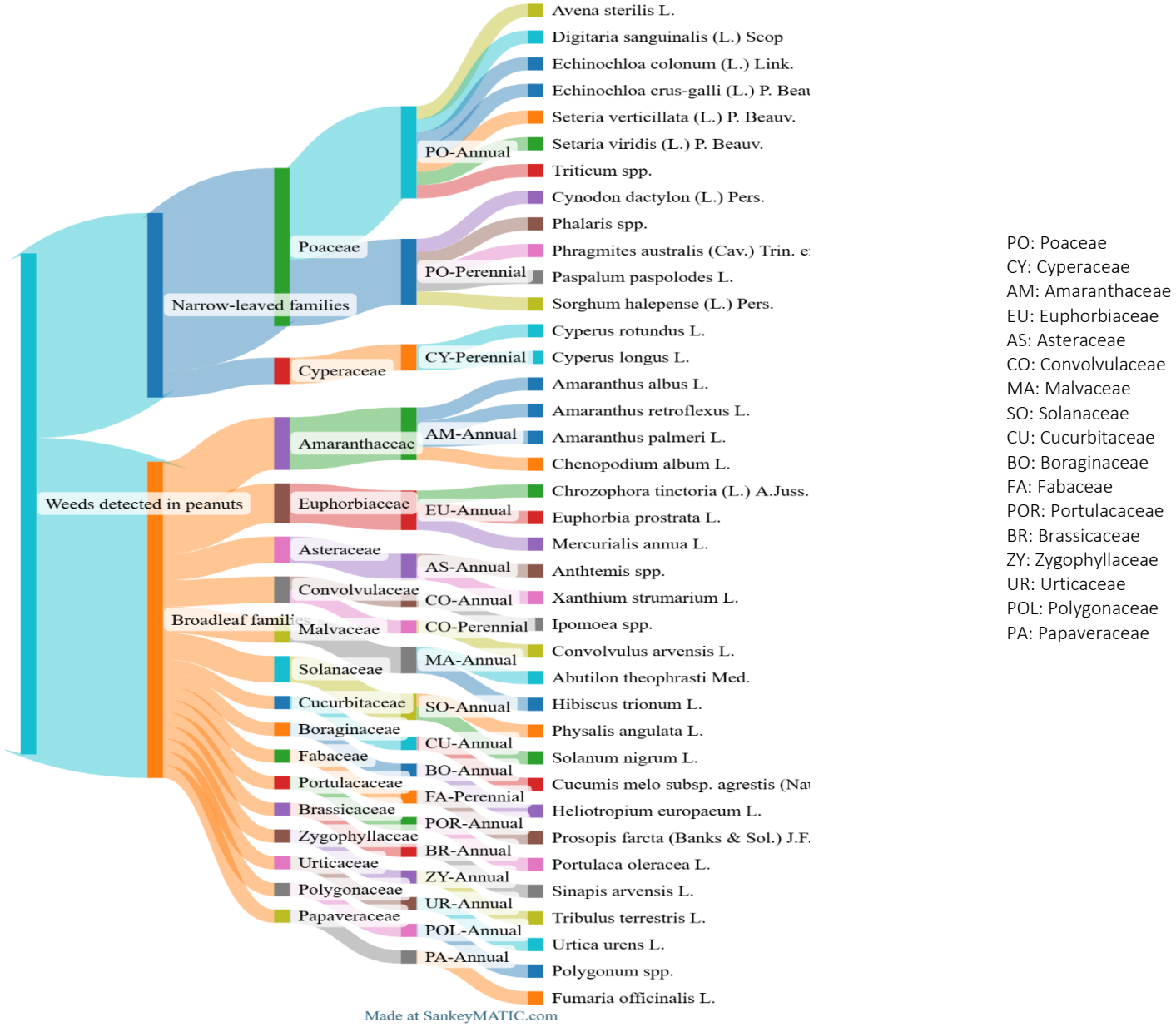

Figure 2.
Sankey diagram of the detected weed species, their families, narrow and broad leaves and their life spans

As a result of the surveys conducted in the peanut cultivation areas of Adana province, a total of 38 weed species belonging to 17 different families were detected. 14 of these species are narrow-leaved and 24 are broad-leaved. Narrow-leaved weeds consist of the Poaceae and Cyperaceae families, 7 of which are annual and 7 are perennial. Among the broad-leaved weeds, 21 species are annual and 3 species are perennial (Figure 2). This distribution shows that the vast majority of weed species in peanut cultivation areas consist of annual broad-leaved, while narrow-leaved weeds have a more balanced mix of annual and perennial species. The percentage frequencies and densities of weed species detected in peanut cultivation areas are given in Table 4.

Table 4.

Percentage frequencies and densities of weed species detected in peanut cultivation areas in Adana.

Scientific Names	Common Names	F (%)	C.	D.(plants/m²)	D.L
Abutilon theophrasti Med.	Velvetleaf	6	O	0.035	F
Amaranthus albus L.	White pigweed	24	O	0.125	D
Amaranthus retroflexus L.	Redroot pigweed	31	O	0.160	D
Amaranthus palmeri L.	Palmer amaranth	16	O	0.095	F
Anthemis spp.	Chamomile	7	O	0.065	F
Avena sterilis L.	Wild oat	8	O	0.130	D
Chenopodium album L.	Lamb's quarters	2	N	0.055	F
Chrozophora tinctoria (L.) A.Juss.	Dyer's croton	3	N	0.040	F
Convolvulus arvensis L.	Field bindweed	49	Ç	0.255	C
Cucumis melo subsp. *agrestis* (Naudin.)	Wild melon	37	Y	0.140	D
Cyperus rotundus L.	Purple nutsedge	78	Ç	0.715	A
Cyperus longus L.	Yellow nutsedge	17	O	0.220	C
Cynodon dactylon (L.) Pers.	Bermuda grass	26	Y	0.325	B
Digitaria sanguinalis (L.) Scop.	Crabgrass	3	N	0.175	D
Echinochloa colonum (L.) Link.	Jungle rice	42	Y	0.630	B
Echinochloa crus-galli (L.) P. Beauv.	Barnyard grass	29	O	0.505	B
Euphorbia prostrata L.	Prostrate spurge	3	N	0.210	C
Fumaria officinalis L.	Fumitory	4	N	0.050	F
Heliotropium europaeum L.	European heliotrope	3	N	0.040	F
Hibiscus trionum L.	Flowering hibiscus	4	N	0.075	F
Ipomoea spp.	Morning glory	21	O	0.090	D
Mercurialis annua L.	Annual mercury	1	N	0.025	F
Prosopis farcta (Banks & Sol.) J.F. Macbride.	Mesquite	7	O	0.175	D
Phalaris spp.	Canary grass	3	N	0.155	D
Phragmites australis (Cav.) Trin. ex Steud.	Common reed	9	O	0.120	D
Physalis angulata L.	Cutleaf groundcherry	4	N	0.045	F
Polygonum spp.	Knotweed	1	N	0.020	F
Portulaca oleracea L.	Purslane	46	Ç	0.235	C
Paspalum paspolodes L.	Nutsedge	5	O	0.040	F
Setaria verticillata (L.) P. Beauv.	Bristly foxtail	16	O	0.385	B
Setaria viridis (L.) P. Beauv.	Green foxtail	14	O	1.050	A
Sinapis arvensis L.	Wild mustard	5	O	0.050	F
Solanum nigrum L.	Black nightshade	4	N	0.060	F
Sorghum halepense (L.) Pers.	Johnsongrass	67	Ç	0.425	B
Tribulus terrestris L.	Puncturevine	4	N	0.060	F
Triticum spp.	Volunteer wheat	17	O	0.275	C
Urtica urens L.	Small nettle	2	N	0.020	F
Xanthium strumarium L.	Common cocklebur	52	Ç	0.260	C

F: Frequency; D: Density; C: Common; D.L: Density level; Ç: F≥%50, Very Common; Y: F= %25-49, Common; O: F=%13-24, Moderately Common; N: F<%12, Rare; A: D≥10 plants/m², Very Dense; B: D= 5.00- 9.99 plants/m², Dense; C: D=1.00-4.99 plants/m², Moderately Dense; D: D= 0.10-0.99 plants/m², Low Dense; E: D= 0.01-0.09 plants/m², Very Low Dense; F: D<0.01 plants/m², Rare.

Among the species identified in the surveys, 16 species had a frequency of occurrence above 10%. The plants with the highest frequency of occurrence were *C. rotundus* (78%), *S. halepense* (67%), *X. strumarium* (52%), *C. arvensis* (49%), and *P. oleracea* (46%). These species are the most common weeds in terms of frequency and generally occur at high density levels. In particular, species like *C. rotundus* and *E. colona* dominate the weed flora in the region. The species with the lowest frequency of occurrence were *M. annua* (1%), *Polygonum spp.* (1%), C*. album* (2%) and *U. urens* (2%). When examining the density (individuals/m²), the species with the highest density in the peanut fields of Adana province was *S. viridis*, with a density value of 1,050 individuals/m². Other species with high density were *C. rotundus* (0.715 individuals/m²), *E. colona* (0.630 individuals/m²), *E. crus-galli* (0.505 individuals/m²), and *S. halepense* (0.425 individuals/m²). Species with lower density values included *A. theophrasti* (0.035 individuals/m²), *C. tinctoria* (0.040 individuals/m²), and *M. annua* (0.025 individuals/m²). In the general evaluation, *C. rotundus* is categorized as "Very Common" with a frequency of occurrence and as "Very Dense" with a density value of 0.715 individuals/m². *S. viridis*, with a density value of 1,050 individuals/m², is also categorized as "Very Dense." Meanwhile, *S. halepense*, with a density value of 0.425 individuals/m², is classified as "Dense." On the other hand, species like *A. albus* and *A. retroflexus* have medium density and are frequently encountered but are not excessively dominant species (Table 4). The weeds identified in peanut fields are an important issue directly affecting production. The species with the highest frequency of occurrence in the Adana study, such as *C. rotundus*, *S. halepense*, *X. strumarium*, *C. arvensis*, and *P. oleracea*, are commonly found in peanut fields. The important weed species observed in peanuts grown in Türkiye, with varying prevalence and density rates, *are S. halepense, X. strumarium, C. arvensis, A. retroflexus* and *P. oleracea* (Uygur, 1997; Arslan & Üremiş 2003; Uludağ et al., 2012; Abacı & Üremiş, 2016; Beycioğlu et al., 2020; Yılmaz et al., 2022). This is similar to findings from studies by Gözüyeşil (2014) and Kadiroğlu (2018), which highlighted common weed species in peanut fields. Furthermore, studies by Grichar (2008) and Burke et al. (2007) also mentioned that weeds like *Amaranthus palmeri* limit peanut growth. As a result, the identified weed species largely align with the existing literature.

Various statistical analyses were conducted to assess and visualize the relationship between weed frequency and density. These analyses included hierarchical clustering analysis, network graph analysis, and Principal Component Analysis (PCA) based on average frequency and density values. The hierarchical clustering analysis was performed in three different ways: by frequency, by density, and by considering both variables together. In the hierarchical clustering analysis based on frequency, the weeds were divided into two main groups. The first group included species with very high frequency, which were widespread in almost all areas, such as *C. rotundus*, *S. halepense*, *C. arvensis*, *X. strumarium*, *P. oleracea*, *C. melo*, and *E. colona*. Within this group, *C. rotundus* and *S. halepense* formed a separate subgroup. The second main group was further split into two subgroups. The first subgroup consisted of species with medium frequency, and the second subgroup included species with low frequency of occurrence. Similarly, the hierarchical clustering analysis based on density revealed two main groups. The species with the highest density, *S. viridis*, formed its own group. In the other main group, species with relatively high density included *S. verticillata*, *S. halepense*, *C. dactylon*, *C. rotundus*, *E. colona*, and *E. crus-galli*. Other species with lower density values were grouped into a separate subgroup.

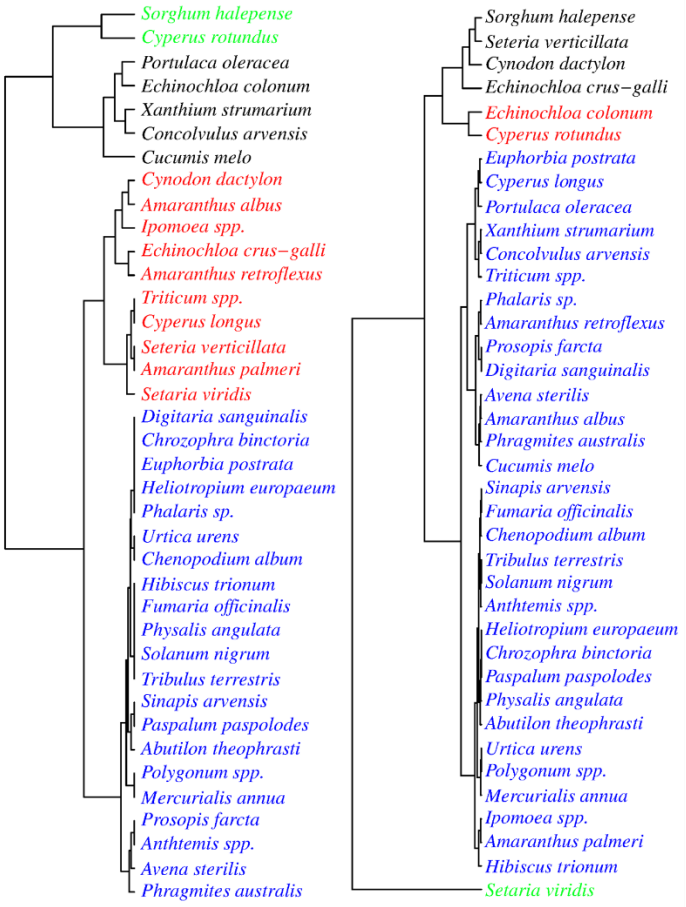

Figure 3.
A; Dendrogram of frequency of occurrence and B; dendrogram of density

In the study, hierarchical clustering analysis was conducted by considering both frequency of occurrence and density values together. As a result, the weed species were divided into two main groups. The first group included *S. viridis*,

which has a density significantly higher than the other species. The other main group was further divided into two subgroups. The first subgroup consisted of seven weed species with both high frequency of occurrence and high density values. Prominent species in this group included *C. rotundus, E. colona, X. strumarium, P. oleracea, C. arvensis, E. crus-galli* and *S. halepense*. These species are dominant in peanut fields due to both their high density and wide occurrence. The second subgroup included rare weed species with low frequency of occurrence and density. These analysis results not only provide an evaluation of the current situation but also highlight which species need more attention (Figure 4).

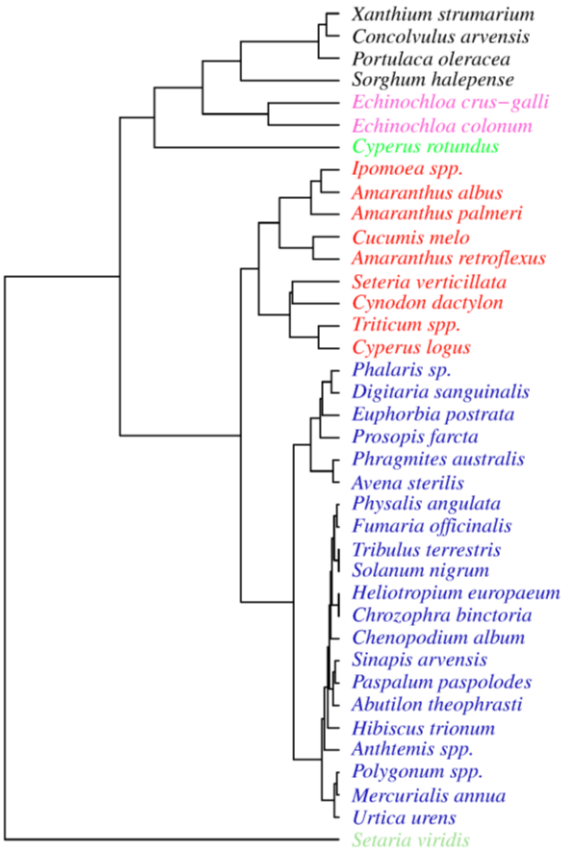

Figure 4.
Dendrogram of frequency and density of occurrence

The network graph analysis performed to determine the relationships between weeds visualized the strength of the connections between species and allowed for a more detailed evaluation of these connections. As a result of the analysis, lines representing the strength of the relationships between species were used. The thickness of the lines indicated the strength of the relationships, while thicker lines indicated strong connections, and thinner or lighter lines indicated weak connections. The results obtained showed that a clear distinction emerged, consistent with the hierarchical clustering analysis. It was determined that weed species with high frequency and density of occurrence in particular were not related to other species. However, a certain degree of relationships were found between other weed species (Figure 5).

In this study, principal component analysis (PCA) was applied to better understand the frequency and density of weed occurrences, to determine the differences between species and to reduce the complexity of the data. PCA is a powerful method that allows multidimensional data to be examined by reducing it to a smaller number of components and stands out as an effective tool especially in evaluating weed profiles in agricultural ecosystems. This analysis determined how species with high frequency and density of occurrence differ from others. Within the scope of the study, the first two components (PC1: 75.45% and PC2: 21.54%) of the data obtained explained 96.99% of the total variance. This rate shows that the parameters related to the distribution and density of weed species can be effectively evaluated with PCA. The high variance explained indicates that the analysis results are reliable. PCA also clearly revealed how dominant species (*S. viridis, C. rotundus, E. colona, X. strumarium, P. oleracea, C. arvensis, E. crus-galli* and *S. halepense*) differed from rare species (Figure 6).

In the study, advanced analyses such as hierarchical clustering, network graph analysis and principal component analysis performed on the average values of the frequency and density of weeds were quite effective in determining the clustering of weed species and their relationships with each other. These analyses were used as a powerful method in reducing the complexity in the data and narrowing down the size of the variables considered. With the applied analyses, the effects and relationships between the parameters such as frequency and density were clearly revealed. In this way, more comprehensive and reliable findings were obtained about the distribution, density and relationships of weed species in our study.

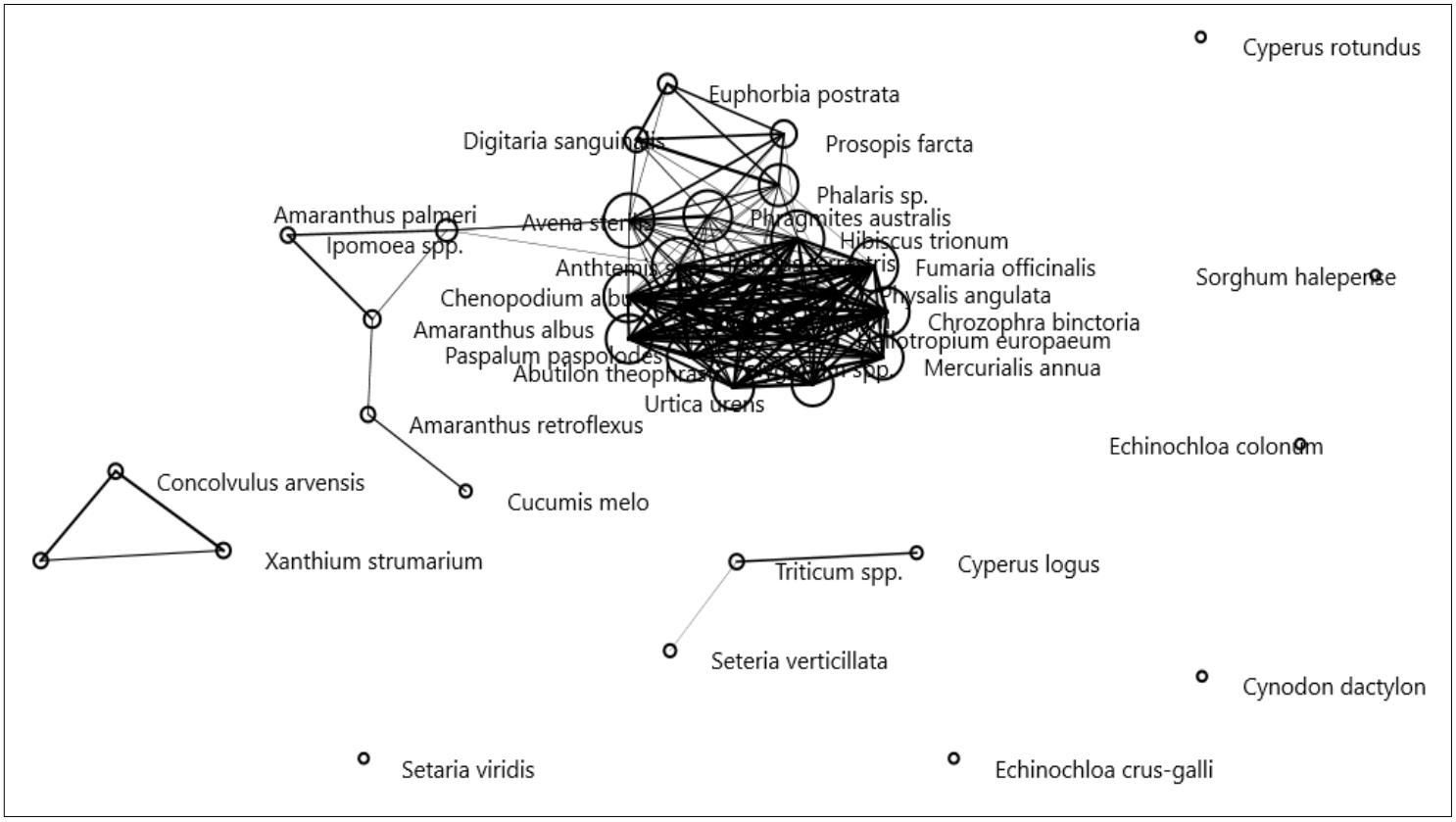

Figure 5.
Network graph analysis of weeds

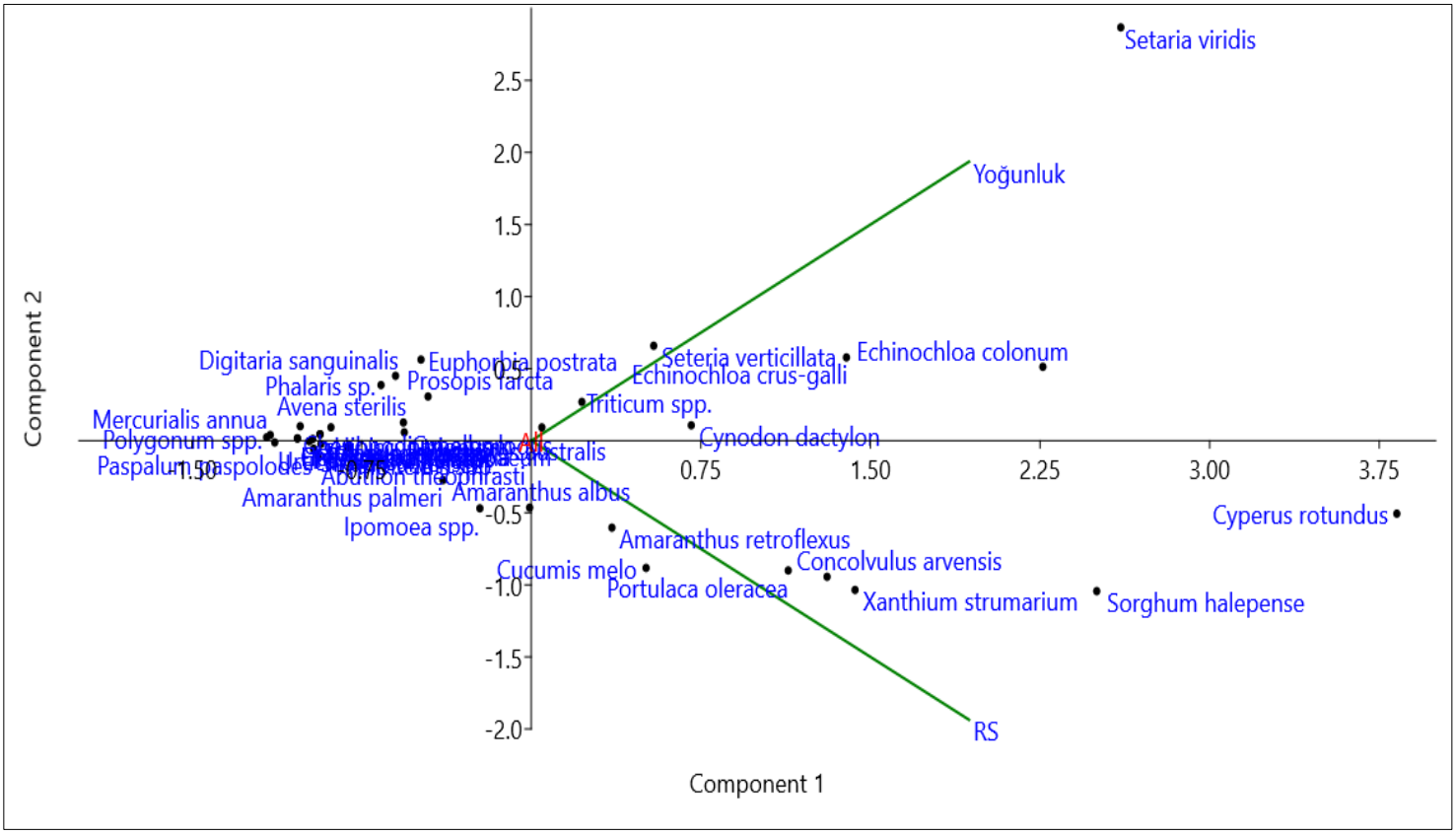

Figure 6.
Principal component analysis of weeds

Conclusion and Recommendations

This study was carried out to determine the frequency and density of weed species found in peanut cultivation areas in Adana province. As a result of the study, a total of 38 weed species belonging to 17 different families were determined, and it was seen that the majority of these species were from the Poaceae and Amaranthaceae families. In addition, the majority of the weeds detected in peanut cultivation areas were annual broad-leaved species. Evaluations based on frequency of occurrence and density data reveal that species such as *C. rotundus*, *S. viridis*, and *S. halepense* are the most common and dense weeds in the region. While *C. rotundus* and *E. colona* are dominant in the weed flora in the region with their very high frequency of occurrence, *S. viridis* draws attention with its high density value. As a result of the study, an integrated weed control method should be applied especially against the weed species detected intensively. The herbicides to be used should be carefully selected to avoid environmental factors and damage to other plant species. In areas where weeds are intensive, rotational farming practices are recommended instead of continuous cultivation of single-type products such as peanuts. These findings provide basic information for the development of effective weed control methods in peanut farming. In order to prevent yield loss, especially in important agricultural products such as peanuts, having information about the types and densities of weeds will help to spread more efficient and sustainable practices in agriculture. In addition, this study can guide local farmers to provide a more efficient production process by using correct and targeted control methods.

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References

Abacı, O., & Üremiş, İ., (2016). Yerfıstığı (*Arachys hypogaea* L.) yetiştiriciliğinde yabancı ot mücadelesinde esas alınacak kritik dönemin belirlenmesi. *Mustafa Kemal Üniversitesi Ziraat Fakültesi Dergisi*, 21(1), 40-47.

Abdelaal, K., Alsubeie, M. S., Hafez, Y., Emeran, A., Moghanm, F., Okasha, S., & Ibraheem, F. (2022). Physiological and biochemical changes in vegetable and field crops under drought, salinity and weeds stresses: Control strategies and management. *Agriculture*, 12(12), 2084.

Anwar, M. P., Islam, A. M., Yeasmin, S., Rashid, M. H., Juraimi, A. S., Ahmed, S., & Shrestha, A. (2021). Weeds and their responses to management efforts in a changing climate. *Agronomy*, 11(10), 1921.

Arıoğlu, H. (2013). *Yerfıstığı Tarımı*. http://www.halisarioglu.com.

Arslan, H., Ekin, Z,, & Yolbaş, M. (2022). Farklı ekim zamanlarının Siirt koşullarında yerfıstığı (*Arachis hypogaea* L.)'nın verim ve verim unsurları üzerine etkisi. *ISPEC Journal of Agricultural Sciences*, 6(2), 247-259.

Arslan, M., & Üremiş, İ. (2003). *Yerfıstığı tarımında kanyaş* (*Sorghum halepense* (L.) Pers.) *sorunundan kaynaklanan verim kaybı ve en etkin kontrol yönteminin belirlenmesi*. Türkiye 5. Tarla Bitkileri Kongresi (13-17 Ekim 2003, Diyarbakır), Cilt I, 579-583.

Arslan, M., Üremiş, İ., & Uludağ, A. (2006). The critical period of weed control in doublecropped soybean. *Phytoparasitica*, 34(2), 159-166.

Arslan, Z. F. (2018). Şanlıurfa ili mısır tarlalarında bulunan yabancı otların yaygınlık ve yoğunlukları ile mücadele sorunlarına çözüm önerileri. *Türk Tarım-Gıda Bilim ve Teknoloji Dergisi*, 6(10), 1322-1328.

Beycioğlu, T., Kıllı, F., & Kaya, T. (2020). *Türkiye yerfıstığı üretiminin dünya üzerindeki yeri ve yerfıstığı üretiminde karşılaşılan önemli sorunlar*. III. Uluslararası Tarım Kongresi / 3rd International Agricultural Congress, 5-9 Mart, 9-18.

Burke, I.C., Schroeder, M., Thomas, W.E., & Wilcut, J.W. (2007). Palmer amaranth interference and seed production in peanut. *Weed Technology*, 21, 367– 371.

Chang, A. S., Sreedharan, A., & Schneider, K. R. (2013). Peanut and peanut products: A food safety perspective. *Food Control*, 32(1), 296-303.

da Silva, E. M. G., de Aguiar, A. C. M., Mendes, K. F., & da Silva, A. A. (2022). *Weed competition and interference*

in crops. In Applied Weed and Herbicide Science (pp. 55-96). Cham: Springer International Publishing.

Davis, P.H. (1965-1988). *Flora of Turkey and the East Aegean Islands*. Edinburg University Press, Volume; 1-10, Edinburg. UK.

Doğaka, (2020). *Osmaniye İli Yerfıstığı Ezmesi Üretimi*. Ön Fizibilite Raporu, Doğu Akdeniz Kalkınma Ajansı, Hatay, S8.

FAO, (2024). *Food and agriculture data* https://www.fao.org/faostat/en/# data/QCL/visualize

Gharde, Y., Singh, P. K., Dubey, R. P., & Gupta, P. K. (2018). Assessment of yield and economic losses in agriculture due to weeds in India. *Crop Protection*, 107, 12-18.

Gözüyeşil, R. (2014). *Osmaniye ilinde yerfıstığı yetiştiriciliği ile ilgili sorunların saptanması*. (Thesis No: 382521). [Master Thesis, Mustafa Kemal University].

Grichar, W. J. (2008). Herbicide systems for control of horse purslane (*Trianthema portulacastrum* L.), smellmelon (*Cucumis melo* L.), and Palmer amaranth (*Amaranthus palmeri* S. Wats.) in peanut. *Peanut Science*, 35(1), 38-42.

Güncan, A. (2025. *Yabancı Ot Mücadelesi*. Selçuk Üniversitesi Yayınevi, ISBN: 9754481784, Konya, 309s.

Jabran, K., & Chauhan, B.S. (2018). *Overview and significance of non-chemical weed control*. In Non-Chemical Weed Control (pp. 1-8). Academic Press.

Kadiroğlu, A. (2018). *Yerfıstığı Yetiştiriciliği*. Batı Akdeniz Tarımsal Araştırma Enstitüsü Müdürlüğü. 82.

Kholi, R.K., Singh, H.P., & Batish, D. R. (2004). *Allelopathy in Agroecosystems*. New York, USA: Food Products Press.

Kumar, S., Kumari, S., Rana, S. S., Rana, R. S., Anwar, T., Qureshi, H., & Aghayeva, S. (2024). Weed management challenges in modern agriculture: The role of environmental factors and fertilization strategies. *Crop Protection*, 185, 106903.

Odum E.P., (1971). *Fundamentals of Ecology*. W.B. Saunders Company, 574 s.

Odum, E.P. (1983). *Grundlagen der Ökologie* (Band 1,2). Georg Thieme Verlag,Stuttgart.

Özaslan, C., & Kendal, E. (2014). Lice domatesi üretim alanlarındaki yabancı otların belirlenmesi. *Journal of the Institute of Science and Technology*, 4(3), 29-34.

Rajcan, I. & Swanton, C.J. (2001). Understanding maizeeweed competition: Resource competition, light quality and the whole plant. *Field Crops Research*, 71(2), 139-150.

Şahin, (2014). Türkiye'de yerfıstığı (*Arachis hypogaea* L.) yetiştiriciliği ve bir coğrafi işaret olarak Osmaniye yerfıstığı. *Gaziantep Üniversitesi Sosyal Bilimler Dergisi*, 13(3), 619-644.

Sırma, M., Kadıoğlu, İ. & Yanar, Y. (2001). Tokat ili domates ekim alanlarında saptanan önemli yabancı ot türleri rastlanma sıklıkları ve yoğunlukları. *Türkiye Herboloji Dergisi*, 4(1), 39-47.

Swinton, S. M., & Van Deynze, B. (2017). Hoes to herbicides: economics of evolving weed management in the United States. *The European Journal of Development Research*, 29(3), 560-574.

Tepe, I. (1998). *Türkiye'de tarım ve tarım dışı alanlarda sorun olan yabancı otlar ve mücadeleleri*. Yüzüncü Yıl Üniversitesi Yayınları No: 32, ISBN 975-7616-24-9, Van, 237s.

TÜİK, (2024). *Türkiye İstatistik Kurumu. Bitkisel Üretim İstatistikleri*. http:// tuikapp .tuik.gov.tr/bitkiselapp

Uludağ A. (1993). *Diyarbakır yöresinde yetiştirilen buğday-mercimek kültürlerindeki önemli yabancı otların dağılışı ve bunların bazı biyolojik özellikleri üzerinde araştırmalar*. (Thesis No: 28093). [Master Thesis, Cumhuriyet University].

Uludağ, A., Üremiş, İ., Tursun, N., & Bukun, B. (2012). A review on critical period for weed control in Turkey. The 6th International Weed Science Congress (17-22 June 2012, Hangzhou, China), 37s.

Uygur, F. N., (1985). Untersuchungen zu art und Bedeutung der Verunkrautung in der Çukurova unter besonderer Berücksichigung von *Cynodon dactylon* (L.) Pers. und *Sorghum halepense* (L.) Pers. *Verlag Josef Margraf, Aichtal*. PLITS 3(5), 109.

Uygur, S. (1997). *Çukurova bölgesi yabancı ot türleri, bu türlerin konukçuluk ettiği hastalık etmenleri ve dağılımları ile hastalık etmenlerinin biyolojik mücadelede kullanılma olanaklarının araştırılması*. (Thesis No: 65403). [PhD Thesis, Çukurova University].

Yılmaz, M., Şahin, C. B., Yıldız, D., Demir, G., Yıldız, R., & İşler, N. (2022). Dünyada ve Türkiye'de yerfıstığı (Arachis hypogaea) üretiminin genel durumu, önemli sorunları ve çözüm önerileri. *Muş Alparslan University Journal of Agriculture and Nature*, 2(1), 8-17.

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Effect of Plant Growth-Promoting Local Rhizobacteria on Rhizome Development and Plant Growth of *Trachystemon orientalis*

Bitki Büyümesini Teşvik Eden Yerel Rizobakterilerin *Trachystemon orientalis*'in Rizom Gelişimi ve Bitki Büyümesine Etkisi

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ABSTRACT

One of the most important strategies to increase agricultural productivity and sustainability is to use a variety of local plant growth-promoting rhizobacteria (PGPB) and their improved consortium formulations. This study aimed to determine the effect of local PGPB on plant growth and rhizome development of *Trachystemon orientalis*, which has great potential as an alternative food source. Six different combined microbial consortia prepared from 11 different rhizobacteria isolated from tea rhizosphere, based on their multiple beneficial effects, were applied to the rhizomes of *Trachystemon orientalis* planted in 1:1 (v/v) peat: perlite medium. The experiment was set up according to the randomized complete block design with three replications, five rhizomes in each replication, and rhizomes not subjected to any treatment were used as controls. PGPB consortia were detected to be effective on 14 parameters examined related to rhizome development and plant growth. The correlation heatmap revealed a strong relationship between the applications and all the parameters examined. The best result was obtained from the P4 application containing a mixture of *Pseudomonas putida* and *Bacillus* spp. This microbial cocktail can be a good alternative to chemical fertilizers, as it is both beneficial and profitable, especially in seedling cultivation of *Trachystemon orientalis*.

Keywords: Rhizobacter, Quality, Microbial community, Sustainable agriculture, *Bacillus* spp., *Pseudomonas* spp.

ÖZ

Tarımsal verimliliği ve sürdürülebilirliği artırmanın en önemli stratejilerinden biri, çeşitli yerel bitki büyümesini teşvik eden rizobakterileri (PGPB) ve bunların geliştirilmiş konsorsiyum formülasyonlarını kullanmaktır. Bu çalışmada, bitkilerin topraktan daha fazla besin maddesi almasını sağlayan *Trachystemon orientalis*'in bitki büyümesi ve rizom gelişimi üzerine etkisinin belirlenmesi amaçlanmıştır. Çay rizosferinden izole edilen 11 farklı rizobakteriden çok sayıdaki yararlı etkileri göz önüne alınarak hazırlanan altı farklı mikrobiyal konsorsiyum kombinasyonu 1:1 (v/v) torf:perlit ortamına dikilen *Trachystemon orientalis* rizomlarına uygulanmıştır. Deneme tesadüf blokları deneme desenine göre üç tekrarlamalı olarak kurulmuş olup, her tekrarlamada beş rizom yer almış ve herhangi bir uygulama yapılmayan rizomlar kontrol olarak kullanılmıştır. Çalışma sonucunda PGPB konsorsiyumlarının rizom gelişimi ve bitki büyümesi ile ilgili incelenen 14 parametre üzerinde etkili olduğu tespit edilmiştir. Korelasyon ısı haritası, uygulamalar ile incelenen tüm parametreler arasında güçlü bir ilişki olduğunu ortaya koymuştur. En iyi sonuç *Pseudomonas putida* ve *Bacillus* spp. karışımı içeren P4 uygulamasından elde edilmiştir. Mikrobiyal karışım, *Trachystemon orientalis*'in özellikle fide yetiştiriciliğinde faydalı ve karlı olması nedeniyle uygulanabilir olduğu ortaya koyulmuştur.

Anahtar Kelimeler: Rizobakteri, Kalite, Mikrobiyal topluluk, Sürdürülebilir tarım, *Bacillus* spp., *Pseudomonas* spp.

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Introduction

The center of genetic diversity of *Trachystemon orientalis* in the Boraginaceae family of the order Boraginales is in the Mediterranean basin and the Middle East, and its distribution extends to Europe and tropical Africa (Selvi & Bigazzi, 2001). The Trachystemon genus, belonging to the Boraginaceae family, represented by one species, is broadly distributed in the Black Sea region of Türkiye (Akçin et al., 2004). *Trachystemon orientalis* (L.) G. Don, with the diploid chromosome number 56, is a perennial and herbaceous plant with rhizomes, hairy, blue-red flowers, 30-40 cm tall (Akçin et al., 2004; Coppi et al., 2006; Özer & Aksoy, 2019). The venation in the broad and hairy leaves of *Trachystemon orientalis* is reticulate and the veinlets branch out, networking towards the edge of the leaf (Selvi & Bigazzi 2001; Koca et al., 2015). It has been used for medicinal purposes in the mountainous regions along the Türkiye-Georgia border in the Western Lesser Caucasus Region, which is also consumed as wild edible plants (WEPs) by local people in the Black Sea region (Kazancı et al., 2020; Üstün et al., 2018). With its rich phenolic compounds and high antioxidant activity, it has anticarcinogenic, antidiabetic, antioxidant, antifungal, and herbicide properties (Demirel Ozbek et al., 2024). This species, also known by local names such as Hodan, Galdirek, Kaldırık, Kalduruk, Tamara, Zılbıt, and Burğı in Türkiye (Akçin et al., 2004), is of great economic importance for the local people as well as in terms of human nutrition (Üstün et al., 2018). The flowering branches, rhizomes, leaves and stems of the plant are consumed as vegetables in different regions of the Black Sea (Akçin et al., 2004). The rhizome structures are covered with several layers of scaly leaves that protect the apical meristem and help push the soil. The thick, horizontally oriented rhizomes located underground are the main axis of the plant, producing roots downwards and shoots towards the top of the soil. The buds on the rhizome produce adventitious roots to expand the root system of the plants (Guo et al., 2021). *Trachystemon orientalis* is ordinarily found in relatively cool environments such as wetlands and shady areas in deep valleys and mountain slopes (Novák et al., 2019). Since this species has not yet been cultured, it is collected from its natural habitats by ranchers and offered to consumers in local markets (Özer & Aksoy, 2019; Demirel Ozbek et al., 2024). The natural plantations of this perennial species are in regional areas with a unique microbiota adapted to the environment. Its cultivation requires special applications aimed at environmentally friendly production and preservation of the ecological balance.

Plant growth-promoting rhizobacteria promotes plant growth by positively contributing to rhizosphere microbiota change and rhizosphere microbial consortia formation (Zhang et al., 2019). PGPB, free-living microbes on or around roots, promotes plant growth due to their capacity to form stable endospores and can also suppress plant diseases. In addition, they play a role in the carbon, nitrogen, and sulfur cycle and the transformation of nutrients (Lin et al., 2019). However, for naturally occurring PGPB in soil to be effective on plants, it must successfully colonize the rhizome and compete with other resident bacteria (Zhu et al., 2024). Although there is still limited information on PGPB-plant interactions, some of these bacteria are used commercially to promote plant growth in agricultural practices (Glick, 2012).

This study aimed to (i) evaluate the impact of the different plant growth-promoting local rhizobacteria plant growth-promoting rhizobacteria on *Trachystemon orientalis* rhizome development and plant growth, (ii) identify the correlations among plant growth-promoting rhizobacteria composition, rhizome development and plant growth, and (iii) assess the benefits of combining native plant growth-promoting rhizobacteria.

Methods

The research was conducted in a greenhouse covered with polycarbonate and a laboratory during the growing season of 2024 at the Recep Tayyip Erdogan University, Faculty of Agriculture.

Experimental Material

The rhizomes of *Trachystemon orientalis*, a naturally disturbing plant in the Black Sea region of Türkiye, were provided from the Pazar district of Rize province.

Plant growth-promoting rhizobacteria (PGPB) was provided by SoilBiom Biotechnology Research and Development Co. Ltd. PGPB that support plant growth were strains isolated from roots of tea (*Camellia sinensis* L.) grown in Rize province (Yıldız et al., 2024). Plant growth-promoting rhizobacteria (PGPB) used as material in this study were obtained from tea genotypes in the Recep Tayyip Erdoğan University National Tea Gene Pool. Six different combined microbial consortiums prepared according to their multiple beneficial effects from a total of 11 different rhizobacteria isolated belonging to the tea rhizosphere were used in the study. Active components and proportions of PGPB cocktails are presented in Table 1.

Table 1.
The characteristics, active components and proportions of plant growth-promoting rhizobacteria (PGPB) used in the study

Code	Characteristics	Active components	Proportions (CFU/ml)
P1	Siderophores production	*Bacillus toyonensis, Lysinibacillus fusiformis*	1 x 10^7
P2	Phosphate solubilization	*Bacillus proteolyticus, Pseudomonas batumici*	1 x 10^7
P3	Cocktail	*Bacillus cereus, Pseudomonas putida, Bacillus toyonensis, Bacillus safensis*	1 x 10^7
P4	IAA production	*Bacillus toyonensis, Pseudomonas putida*	1 x 10^7
P5	Potassium solubilization	*Pseudomonas lini, Bacillus safensis*	1 x 10^7
P6	N_2 fixer	*Pseudomonas konensis, Bacillus thuringiensis*	1 x 10^7

Experimental Design

The rhizomes, collected from the garden in January, were grown in a 1:1 (v/v) ratio of peat: perlite medium until the rhizomes reached an average length of 10 cm. The plants were uprooted in May 2024; the shoots were removed from the rhizomes. They were transplanted in styrofoam boxes (50x29.7x15 cm) containing peat:perlite (1:1, v/v) mixture. PGPB applications were carried out with six different mixtures, as outlined in Table 1. The application was made once at following the planting. 20 ml of bacterial suspension (containing approximately 1 x 10^7 CFU/ml in sterile water) was inoculated into the rhizosphere for each rhizome. As a control, the rhizomes were treated with an equal volume of sterile distilled water. The trial was laid out as a randomized block design with three replicates and five rhizomes in each replicate.

Plant and Rhizome Growth Index Measurement

Morphological observations were taken at the end of 90 days from the establishment of the experiment. Plant height (PH) was measured with a ruler from the root collar to the tip. Leaf width (LWDT) was determined by measuring the widest part of the leaf that completed its development, and leaf length (LLGN) was determined in cm by measuring the longitude from the tip of the leaf's blade to the stem with a ruler. The number of leaves (LNUM) was recorded by counting all the leaves formed on the plant (number plant^{-1}). Leaf chlorophyll content (SPAD) was estimated using a portable hand-held chlorophyll meter (Minolta SPAD-502 Plus). Leaf color was measured by identifying CIE L, a, and b values with a colorimeter (CR-400, Minolta Corporation, Ltd., Osaka, Japan). Plant fresh weight (PFW) was determined by weighing with a precision scale after the plant material above the soil was harvested. Plant dry weight (PDW) was determined after drying the samples in the oven at 72°C until they reached a constant weight. The root length (PRL) formed on the rhizome was measured with a ruler. The density of hairy roots (RFD) at the branch roots' base was observed morphologically using a rating scale (1=very little, 3=little, 5=medium, 7=dense, 9=very dense). Rhizome development was recorded by calculating the differences between the rhizome's (RLG) lengths measured with a ruler and their diameters (RD) measured with a digital vernier caliper before and after the experiment.

Statistical Analyses

The study's data collected in the study were subjected to variance analysis using the JUMP 13.0 statistics program. Statistically significant differences between the applications were determined using the LSD (Least Significant Difference) multiple comparison test. A correlation heatmap graph was generated using OriginPro Version 2021.

Results

In the study conducted to determine the effects of PGPB on both plant growth and rhizome development of *Trachystemon orientalis*, it was found that the difference in the parameters examined between PGPB inoculated and uninoculated treatments was significant. The effect of PGPB was detected in all growth and development parameters examined. However, it was observed that plant growth responses were variable, and PGPB showed different effects depending on their plant growth-promoting properties (Figure 1).

PGPB inoculations prompted a significant increase in plant height except for the P5 (production of potassium) and P2 (phosphate solubilization) treatments. The N_2 fixer (P6) PGPB produced the tallest plants, 23.53 cm, followed by Cocktail (P3), with 22.27 cm. In contrast, the shortest plants were observed in the P5 treatment, 18.73 cm. Leaf width and leaf lenght were varied considerably among the applications. While the P3 application significantly increased in leaf size, in the P5 application had much smaller leaves than in the other applications. P3 application increased leaf width by 36.42% and leaf length by 30.25% compared to the control. The number of leaves were ranged between 2.70 and 4.53. While the highest leaf formation was observed in the P3 application, the lowest leaf production was detected in the P2 application. The P3 application resulted in a 30.55% increase in leaf number compared to the control group, while the P2 application showed a decrease of 22.19% in leaf number.

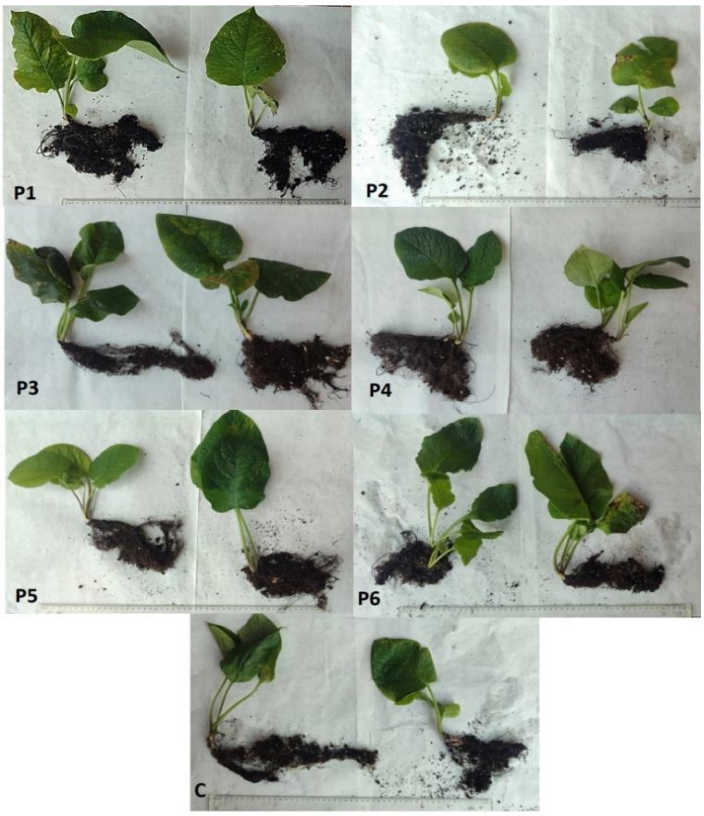

Figure 1.

The effect of PGPB mixtures inoculated and non-inoculated treatments on rhizome development and plant growth of Trachystemon orientalis. P1: Siderophores production, P2: Phosphate solubilization, P3: Cocktail, P4: IAA production, P5: Potassium solubilization, P6: N_2 fixer, C: Control (non-treated)

The chlorophyll content in the leaf blade, referring to SPAD value, was higher in the P3 treatment than in other treatments. CIE L* value was also high in the same application as parallel. It was revealed that the leaves were brighter in the P3 application compared to the others. P1 and P5 applications did not significantly affect on CIE a* value compared to the control, but the other applications caused marked decreases. There was a 25% decrease in the P3 application. A decrease occurred in the CIE b* value in all applications compared to the control and P2. However, the lowest value was measured in the P3 application. In this application, a 55.60% decrease in CIE b* value was detected compared to the control. P3 application contributed significantly to fresh and dry plant weight, and the highest values were obtained from this application. There was an increase of 77.86% for plant fresh weight and 29.73% for plant dry weight. On the other hand, it was determined that there was a significant decrease in the values in other PGPB applications compared to the control, except for P3 and P1 for plant fresh weight and P3 and P4 for plant dry weight. P1, P3, and P5 also contributed positively to the elongation of rhizomes; the longest rhizome was measured in the P3 application. In addition, compared to the pre-trial measurement, the highest elongation was settled in the P4 application. The applications other than P3 caused an increase in rhizome diameter. Compared with the pre-experimental measurement, it was revealed that the P3 application contributed the most to the increase in rhizome diameter (Table 2).

Table 2.

The effects of various mixtures of PGPB on rhizome development and plant growth of Trachystemon orientalis

Code	PH (cm)	LWDT (cm)	LLGN (cm)	LNUM (number plant^{-1})	SPAD	MNTL	MNTa	MNTb	PFW (g plant^{-1})	PDW (g plant^{-1})	PRL (cm)	RFD	RLG (cm)	RD (mm)
P1	21.57± 0.74^{bc}	10.03± 0.31^{b}	12.30± 0.46^{c}	3.20± 0.35^{b}	32.67± 0.40^{d}	55.43± 0.55^{de}	17.93± 0.64^{a}	23.00± 0.44^{b}	36.67± 0.58^{b}	5.46± 0.28^{c}	19.80± 0.53^{b}	4.47± 0.23^{b}	1.17± 0.06^{bc}	0.00± 0.00^{e}
P2	19.43± 0.45^{d}	10.30± 0.26^{b}	13.17± 0.21^{b}	2.70± 0.17^{c}	27.57± 0.55^{f}	55.00± 0.78^{e}	16.60± 0.17^{c}	24.30± 0.44^{ab}	34.40± 1.22^{c}	4.97± 0.06^{c}	16.47± 0.31^{e}	5.66± 0.23^{a}	1.37± 0.08^{b}	0.70± 0.10^{d}
P3	22.27± 0.31^{b}	11.50± 0,36^{a}	15.33± 0.23^{a}	4.53± 0.23^{a}	43.3± 0.32^{a}	67.77± 0.15^{a}	12.90± 0.20^{f}	11.13± 0.31^{e}	67.00± 1.00^{a}	9.73± 1.26^{a}	23.53± 0.42^{a}	5.26± 0.23^{a}	1.37± 0.10^{b}	5.07± 0.15^{a}
P4	21.57± 0.35^{bc}	8.90± 0.20^{c}	11.63± 0.15^{e}	3.53± 0.12^{b}	33.27± 0.71^{d}	61.93± 0.55^{b}	14.40± 0.44^{e}	13.40± 0.70^{d}	31.67± 1.53^{d}	7.21± 0.42^{b}	17.47± 0.23^{d}	4.33± 0.23^{bc}	3.16± 0.15^{a}	3.20± 0.20^{b}
P5	18.73± 0.12^{d}	7.20± 0.20^{d}	9.87± 0.12^{f}	3.33± 0.12^{b}	29.87± 0.67^{e}	58.67± 1.27^{c}	17.40± 0.44^{ab}	18.90± 0.36^{c}	20.00± 1.00^{f}	5.20± 0.61^{c}	19.87± 0.64^{b}	4.73± 0.23^{b}	1.23± 0.15^{b}	1.33± 0.20^{c}
P6	23.53± 1.21^{a}	8.83± 0.40^{c}	12.17± 0.25^{cd}	3.27± 0.23^{b}	37.63± 0.61^{c}	60.97± 0.90^{b}	15.13± 0.25^{d}	15.17± 0.25^{d}	29.67± 1.53^{e}	5.30± 0.36^{c}	16.00± 0.20^{f}	3.27± 0.23^{d}	0.57± 0.06^{d}	1.23± 0.08^{cd}
C	20.63± 0.21^{c}	8.43± 0.23^{c}	11.77± 0.15^{de}	3.47± 0.12^{b}	38.77± 0.15^{b}	56.63± 0.31^{d}	17.23± 0.21^{bc}	25.07± 2.81^{a}	37.67± 0.58^{b}	7.50± 0.53^{b}	19.06± 0.31^{c}	4.93± 0.23^{c}	0.63± 0.06^{cd}	1.37± 0.09^{c}
LSD	1.105	0.516	0.468	0.387	0.846	1.300	0.687	2.014	1.784	0.968	0.366	0.439	0.150	0.168
CV (%)	2.95	3.04	2.14	6.35	1.37	1.23	2.42	6.05	2.73	8.40	1.09	5.46	6.17	5.12

Group means were compared with LSD test (p <.05). P: Plant growth-promoting rhizobacteria P1: Siderophores production, P2: Phosphate solubilization, P3: Cocktail, P4 IAA production, P5: Potassium production, P6: N2 fixer, C: Control (non-treated), PH: Plant height, LWDT: Leaf width, LLGN: Leaf length, LNUM: number of leaves, SPAD: Leaf chlorophyll content, MNTL: Leaf color CIE L value, MNTa: Leaf color CIE a value, MNTb: Leaf color CIE b value, PFW: Plant fresh weight, PDW: Plant dry weight, PRL: Length root formed on the rhizome, RFD: Density of hairy roots, RLG: Differences between the lengths of the rhizomes before and after the experiment, RD: Differences between the diameters of the rhizomes before and after the experiment.

Differences in the development of *Trachystemon orientalis* rhizomes before and after inoculation with various PGPB mixtures are shown with horizontal lines in Figure 2. PGPB, characterized by siderophore production (P1), only contributed to the elongation of rhizome length. Nevertheless, other applications contributed to the increase in length and diameter of rhizome development. P4 and P5 made a balanced contribution to both length and diameter development, while P3 played a greater role in increasing the diameter. The changes in rhizome diameters were 270.07% for the P3 treatment and 133.58% for the P4 treatment, compared to the control group.

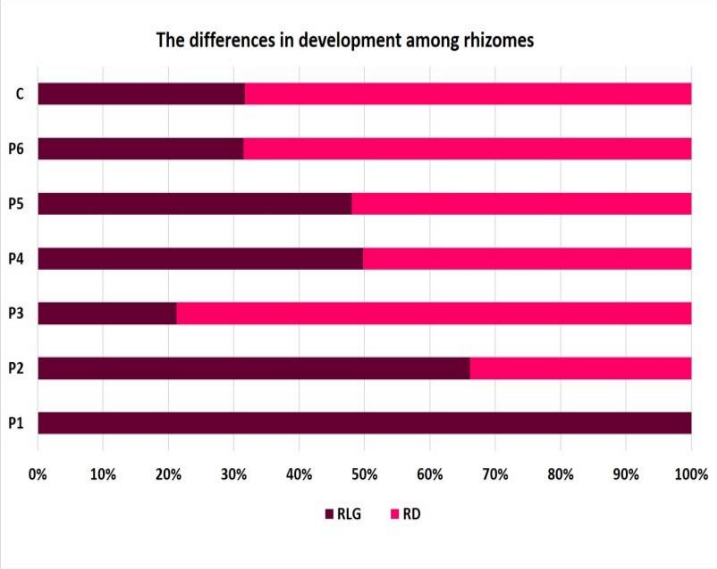

Figure 2.
Differences in the development of Trachystemon orientalis rhizomes before and after inoculation with various PGPB mixtures. P: Plant growth-promoting rhizobacteria P1: Siderophores production, P2: Phosphate solubilization, P3: Cocktail, P4 IAA production, P5: Potassium solubilization, P6: N_2 fixer, C: Control (non-treated). RLG: Differences between the lengths of the rhizomes before and after the experiment, RD: Differences between the diameters of the rhizomes before and after the experiment

The possible relationships between the investigated parameters are displayed with the correlation heatmap graph. Pearson's correlation coefficient was computed to quantify linear associations between variables (p<.0001). Orange and blue colors indicate direct and inverse correlation, respectively. The treatments were strongly associated with all parameters. The plant's fresh weight was positively correlated, with Pearson's correlation coefficients of 0.92 for leaf length and 0.84 for leaf width. In contrast, a negative relationship was found in between plant fresh weight and Leaf color CIE a (r=-0.64) and Leaf color CIE b (r=-0.38) (Figure 3).

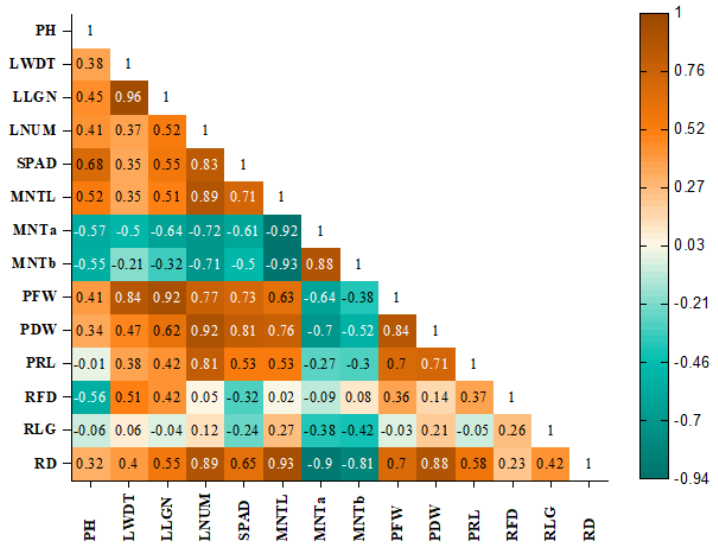

Figure 3.
Correlation heatmap of Trachystemon orientalis rhizome development and plant growth parameters data collected from untreated and treated mixtures of PGPB. PH: Plant height, LWDT: Leaf width, LLGN: Leaf length, LNUM: Number of leaves, SPAD: Leaf chlorophyll content, MNTL: Leaf color CIE L, MNTa: Leaf color CIE a, MNTb: Leaf color CIE b, PFW: Plant fresh weight, PDW: Plant dry weight, PRL: Length root formed on the rhizome, RFD: Density of hairy roots, RLG: Differences between the lengths of the rhizomes before and after the experiment, RD: Differences between the diameters of the rhizomes before and after the experiment.

Discussion

The collection, protection, and sustainability of wild edible vegetables are critical issues on the agenda, and their cultivation as an alternative food source is also key to providing food security (Borelli et al., 2020; Kidane & Kejela, 2021). Sustainable collection programs are needed to ensure supplies of edible wild plants. However, their natural distribution area is threatened by adverse environmental conditions caused by climate change, industrialization, and urbanization (Taghouti et al., 2022). *Trachystemon orientalis* is an important edible wild species used for human nutrition and has potential industrial products for the pharmaceutical and cosmetic industries (Biyik et al., 2023; Chrzanowska et al., 2024). This study provides important findings regarding the PGPB application that may increase the success rate of the *Trachystemon orientalis* cultivation process.

Plant growth-promoting bacteria (PGPB) are generally effective in supporting growth by communicating with the host plant. They play a role in nitrogen fixation, the solubilization of inorganic phosphate and potassium, IAA,

and the production of siderophore molecules (Santoyo et al., 2021; Vocciante et al., 2022). In this study, the relationships of local PGPB with the specified characteristics of the plant were revealed in the environment where no nutrients were added to the growth medium, and there was no competition with other endophytic bacteria. The differences in these relationships on the growth and development of plants were evident.

Research indicates that when a large amount of chemical fertilizer is applied to soil, beneficial bacteria that aid plant growth by supplying nitrogen or phosphorus may not benefit the plants (Glick, 2012). In this study, the effectiveness of plant growth promoting rhizobacteria in a nutrient-free medium was investigated. However, no positive impact on plant development was observed in most traits measured compared to the control group. These results may relate to the structure of the growing medium.

PGPB affects plants' root properties, especially in root length, biomass, and volume, as reported in various studies (Grover et al., 2021). PGPB influenced the root length, the density of hairy roots, and the lenght and diameter of rhizomes formed in the rhizome of *Trachystemon orientalis*. However, the impacts were varied; some consortia had great impacts on root architecture, while others had no impact or the impacts were negative way. The PGPB, Cocktail, mixture of *Bacillus toyonensis* and *Lysinibacillus fusiformis*, and mixture of *Pseudomonas lini* and *Bacillus safensis* contributed positively to the increase of hairy roots. In contrast, the others, except mixture of *Bacillus toyonensis* and *Lysinibacillus fusiformis*, contributed to the increase of rhizome diameter. N2 fixer caused a decrease in root length. Although the N2 fixer bacteria (P6) contributed to the extension of plant height, no positive contribution was detected for other parameters. It may be due to a lack of nitrogen or insufficient nutrients in the growth medium. Similarly, Ghaffari et al. (2018) reported a strong relationship between the activity of Pseudomonas bacteria and the presence and amount of nitrogen in the medium. On the other side, bacteria belonging to the *Bacillus* and *Pseudomonas* genera can perform beneficial interactions in the rhizosphere thanks to their enzymes called adhesins, which facilitate their attachment to plant roots (Santoyo et al., 2021). Therefore, the cocktail, including Bacillus and Pseudomonas, may have contributed more positively to growth and development.

Auxin-producing PGPB may play an important role in improving plant growth by triggering various metabolic processes that directly or indirectly control different aspects of plant growth and development. These processes may provide higher root biomass and reduce stomata size and density (Borah et al., 2023). Compatible with this information, it was observed that the IAA-producing PGPB used in this study actually increased root mass compared to the control and caused a decrease in leaf chlorophyll content.

The discovery of different Pseudomonas strains that support plant growth has brought their use as a safe alternative to chemical fertilizers to the agenda. Pseudomonas strains, in particular, increase the plant's resistance by ensuring the production of defense-related chemicals and stress-protective proteins in the host plant and contribute to the increase in plant height and biomass (Singh et al., 2024). In this study, the mixtures prepared using four different isolates of Pseudomonas (*Pseudomonas batumici*, *Pseudomonas putida*, *Pseudomonas lini*, *Pseudomonas konensis*), the *Pseudomonas putida* isolate had a significant positive effect on plant growth and biomass increase was observed. The positive effect of *P. putida*, a Gram-negative rhizobacteria, on the development of different plant species were also reported in previous studies (Naserzadeh et al., 2018; Arslan & Akkaya, 2020). The presence of different strains of Bacillus together with *Pseudomonas putida* in the most effective mixtures for the growth of *Trachystemon orientalis* indicates that these two families of promoting bacteria may have made an important contribution together. Dimkić et al. (2022) relayed that bacteria belonging to the genera Bacillus and Pseudomonas are known producers of secondary metabolites, enzymes, and other bioactive compounds that can benefit plants. Bacillus promotes plant growth and development and provides biocontrol of plant pathogens. This strain's usage for more sustainable agricultural practices is becoming increasingly widespread (Borriss, 2015). It was evident by Esitken et al. (2010) that the application of Bacillus and Pseudomonas to the roots and leaves of strawberry plants enhances plant growth, yield, and microelement content. They reported that these bacteria could serve as a promising alternative biofertilizer for fruit and vegetable production in sustainable and organic farming systems.

Conclusion and Recommendations

In conclusion, plant growth-promoting rhizobacteria (PGPB) affected the growth and rhizome development parameters of *Trachystemon orientalis*. In the growth medium, where there was no plant nutrient and no competition with other bacteria, the cocktail, including a mixture of Bacillus and Pseudomonas isolates, promoted plant growth. This cocktail has great potential to be used, especially in cultivating seedlings of *Trachystemon orientalis*. However, the effects of PGPB will undoubtedly differ in the soil and the

environments where nutrients are added. Therefore, it cannot be simply claimed that mixtures other than the cocktail are ineffective. The efficiency of these bacterial mixtures should also be tested in the soil with different physical, chemical, and biological characteristics. The effects of PGPB applications should be determined according to each environment and condition.

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References

Akçin, Ö. E., Kandemir, N., & Akçin, Y. (2004). A morphological and anatomical study on a medicinal and edible plant Trachystemon orientalis (L.) G. Don (Boraginaceae) in the Black Sea Region. *Turkish Journal of Botany*, 28(4), 435-442.

Arslan, E., & Akkaya, Ö. (2020). Biotization of Arabidopsis thaliana with Pseudomonas putida and assessment of its positive effect on in vitro growth. *In Vitro Cellular & Developmental Biology-Plant*, *56*(2), 184-192.

Borah, P., Gogoi, N., Asad, S. A., Rabha, A. J., & Farooq, M. (2023). An insight into plant growth-promoting rhizobacteria-mediated mitigation of stresses in plant. *Journal of Plant Growth Regulation*, *42*(5), 3229-3256.

Borelli, T., Hunter, D., Powell, B., Ulian, T., Mattana, E., Termote, C., & Engels, J. (2020). Born to eat wild: An integrated conservation approach to secure wild food plants for food security and nutrition. *Plants*, *9*(10), 1299.

Borriss, R. (2015). Bacillus, A Plant-Beneficial Bacterium. In: Lugtenberg, B. (eds) Principles of Plant-Microbe Interactions. Springer, Cham. https://doi.org/10.1007/978-3-319-08575-3_40

Biyik, B., Sarialtin, S. Y., Gökbulut, A., Çoban, T., & Coşkun, M. (2023). Trachystemon orientalis (L.) G. Don as a valuable source of rosmarinic acid: biological activities and HPLC profiles. *Turkish Journal of Pharmaceutical Sciences*, *20*(3), 141.

Chrzanowska, E., Denisow, B., Ekiert, H., & Pietrzyk, Ł. (2024). Metabolites Obtained from Boraginaceae Plants as Potential Cosmetic Ingredients—A Review. *Molecules*, *29*(21), 5088.

Coppi, A., Selvi, F., & Bigazzi, M. (2006). Chromosome studies in Mediterranean species of Boraginaceae. *Flora Mediterranea*, 16, 253-274.

Demirel Ozbek, Y., Saral, O., & Turker, P. F. (2024). Modern and traditional cooking methods affect the antioxidant activity and phenolic compounds content of Trachystemon Orientalis (L.) G. Don. *Plos one*, *19*(2), e0299037.

Dimkić, I., Janakiev, T., Petrović, M., Degrassi, G., & Fira, D. (2022). Plant-associated *Bacillus* and *Pseudomonas* antimicrobial activities in plant disease suppression via biological control mechanisms-A review. *Physiological and Molecular Plant Pathology*, *117*, 101754.

Esitken, A., Yildiz, H. E., Ercisli, S., Donmez, M. F., Turan, M., & Gunes, A. (2010). Effects of plant growth promoting bacteria (PGPB) on yield, growth and nutrient contents of organically grown strawberry. *Scientia Horticulturae*, *124*(1), 62-66.

Ghaffari, H., Gholizadeh, A., Biabani, A., Fallah, A., & Mohammadian, M. (2018). Plant Growth Promoting Rhizobacteria (PGPR) Application with Different Nitrogen Fertilizer Levels in Rice (Oryza sativa L.). *Pertanika Journal of Tropical Agricultural Science*, *41*(2).

Glick, B. R. (2012). Plant growth-promoting bacteria: mechanisms and applications. *Scientifica*, *2012*(1), 963401.

Grover, M., Bodhankar, S., Sharma, A., Sharma, P., Singh, J., & Nain, L. (2021). PGPR mediated alterations in root traits: way toward sustainable crop production. *Frontiers in Sustainable Food Systems*, *4*, 618230.

Guo, L., Plunkert, M., Luo, X., & Liu, Z. (2021). Developmental regulation of stolon and rhizome. *Current Opinion in Plant Biology*, 59, 101970.

Kazancı, C., Oruç, S., & Mosulishvili, M. (2020). Medicinal ethnobotany of wild plants: a cross-cultural comparison around Georgia-Turkey border, the Western Lesser Caucasus. *Journal of Ethnobiology and Ethnomedicine*, 16, 1-20.

Kidane, L., & Kejela, A. (2021). Food security and environment conservation through sustainable use of wild and semi-wild edible plants: a case study in Berek Natural Forest, Oromia special zone, Ethiopia. *Agriculture & Food Security*, *10*(1), 29.

Koca, L., Hasbay, İ., Bostanci, S., Yılmaz, V., & Koca, A. (2015). Some wild edible plants and their dietary fiber contents. *Pakistan Journal of Nutrition*, 14(4).

Lin, Y., Watts, D. B., Kloepper, J. W., Adesemoye, A. O., & Feng, Y. (2019). Effect of plant growth-promoting rhizobacteria at various nitrogen rates on corn growth. *Agricultural Sciences*, 10(12), 1542.

Naserzadeh, Y., Kartoolinejad, D., Mahmoudi, N., Zargar, M., Pakina, E., Heydari, M., ... & Kavhiza, N. J. (2018). Nine strains of Pseudomonas fluorescens and P. putida: Effects on growth indices, seed and yield production of Carthamus tinctorius L. *Research on Crops*, *19*(4), 622-632.

Novák, P., Zukal, D., Kalníková, V., Chytrý, K., & Kavgacı, A. (2019). Ecology and syntaxonomy of Colchic forests in south-western Georgia (Caucasus region). *Phytocoenologia*, 49(3).

Özer, M. Ö., & Aksoy, M. (2019). Mineral composition and nutritional properties of Trachystemon orientalis (L.) G. Don populations in the Central Black Sea Region of Turkey. *Acta Scientiarum Polonorum Hortorum Cultus*, 18(4), 157-167.

Santoyo, G., Urtis-Flores, C. A., Loeza-Lara, P. D., Orozco-Mosqueda, M. D. C., & Glick, B. R. (2021). Rhizosphere colonization determinants by plant growth-promoting rhizobacteria (PGPR). *Biology*, *10*(6), 475.

Singh, P., Singh, R. K., Li, H. B., Guo, D. J., Sharma, A., Verma, K. K., ... & Li, Y. R. (2024). Nitrogen fixation and phytohormone stimulation of sugarcane plant through plant growth promoting diazotrophic Pseudomonas. *Biotechnology and Genetic Engineering Reviews*, *40*(1), 15-35.

Selvi, F., & Bigazzi, M. (2001). Leaf surface and anatomy in Boraginaceae tribe Boragineae with respect to ecology and taxonomy. *Flora*, 196(4), 269-285.

Taghouti, I., Cristobal, R., Brenko, A., Stara, K., Markos, N., Chapelet, B., & Bonet, J. A. (2022). The market evolution of medicinal and aromatic plants: A global supply chain analysis and an application of the delphi method in the Mediterranean area. *Forests*, *13*(5), 808.

Üstün, N. Ş., Pekşen, A., Bulam, S., & Duran, H. (2018). Edible wild herbaceous plants consumed in Giresun province. *Acta Biologica Turcica*, 32(2), 84-89.

Vocciante, M., Grifoni, M., Fusini, D., Petruzzelli, G., & Franchi, E. (2022). The role of plant growth-promoting rhizobacteria (PGPR) in mitigating plant's environmental stresses. *Applied Sciences*, *12*(3), 1231.

Yıldız, A., Başpınar, U. F., Sapaz, D., Peker, O., Keskin, E., Yazıcı, K., Namlı, A., Turgay, O. C. (2024). Importance of Metagenomic Analysis in Determining the Effect of Biofertilizer on Soil Microbiota. National Tea Congress / 21-23 May 2024, Rize, Türkiye. P:32-33.

Zhang, Y., Gao, X., Shen, Z., Zhu, C., Jiao, Z., Li, R., & Shen, Q. (2019). Pre-colonization of PGPR triggers rhizosphere microbiota succession associated with crop yield enhancement. *Plant and Soil*, 439, 553-567.

Zhu, L., Zhang, P., Ma, S., Yu, Q., Wang, H., Liu, Y., ... & Chen, Y. (2024). Enhancing carrot (Daucus carota var. sativa Hoffm.) plant productivity with combined rhizosphere microbial consortium. *Frontiers in Microbiology*, *15*, 1466300.

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Kent Ekolojisi Açısından Diyarbakır Kenti Açık-Yeşil Alanlarında Kullanılan Bitki Materyallerinin Değerlendirilmesi

Evaluation of Plant Materials Used in Open-Green Areas of Diyarbakır City in Terms of Urban Ecology

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ÖZ

Kentsel açık yeşil alanlar, kentlerdeki bahçeler, parklar, yeşil koridorlar, yol peyzajı ve benzeri alanları kapsamaktadır. Bu alanlar rekreasyonel aktiviteler dışında insan psikoloji ve insanlar arası sosyal etkileşimi sağlayan önemli mekânlardır. Sürdürülebilir kent tasarımları için kentsel açık yeşil alanların artırılması önemli bir yere sahiptir. Kentsel yerleşimlerde bitkiler kentsel yaşamın gelişmesinde önemli rol oynarlar. Ancak istenilen amaca ulaşmak için bilimsel ve teknik çerçevede, planlama-tasarım-uygulama-bakım çalışmalarının bir bütün içinde ve özellikle ilgili meslek disiplinleri ve uzman kişiler tarafından gerçekleştirilmesi gereklidir. Çalışmada Diyarbakır kent merkezindeki önemli kent parkları ve resmi kurum bahçeleri, yol ağaçları ve değişik semtlerdeki ev bahçelerinde kullanılan bitki materyalinin tespit edilmesi amaçlanmıştır. Bu kapsamda belirlenen alanlarda bitki sayımları yapılarak, bitkilerin türleri, kullanım alanları, kullanım amaçları, kullanım yoğunlukları ve bitkisel tasarım yönünden değerlendirilmeleri yapılmıştır. Kent açık-yeşil alanlarında, 44 ağaç ve ağaççık (9 türü yaygın) ve 16 çalı (7 türü yaygın) olmak üzere toplam 60 bitki taksonu kullanıldığı belirlenmiştir. Araştırma soncunda belirlenen alanlarda bitkisel materyal kullanımında kente marka değeri kazandıracak bitkisel uygulamaların yetersiz olduğu sonucuna varılmıştır. Sıcak ve kurak iklim şartlarına dayanıklı bitki çeşitliliğinin artırılması yanı sıra biyoçeşitliliğe katkı sağlayacak meyvesi yenen bitki taksonlarının kullanılması gerekliliğine yönelik öneriler yer verilmiştir.

Anahtar Kelimeler: Bitki materyali, Tür çeşitliliği, Açık yeşil alanlar, Diyarbakır

ABSTRACT

Urban green spaces encompass gardens, parks, green corridors, roadside landscapes, and similar areas within cities. Beyond recreational activities, these spaces are important venues for enhancing human psychology and social interaction. Increasing urban green spaces is vital for sustainable urban design. Plants play a significant role in the development of urban life. However, achieving the desired goals requires planning, design, implementation, and maintenance activities to be carried out as a whole within a scientific and technical framework, especially by relevant professional disciplines and experts. This study aims to identify the plant materials used in key urban parks, official institution gardens, roadside trees, and residential gardens in different districts of Diyarbakır city center. In this context, plant inventories were conducted in the specified areas, and the species, usage areas, purposes, densities, and plant design aspects of the plants were evaluated. It was determined that a total of 60 plant taxa, including 44 trees and shrubs (9 of which are widespread) and 16 shrubs (7 of which are widespread), were used in urban open-green spaces. The study concluded that plant applications that would add brand value to the city were insufficient in the identified areas. Recommendations were made for increasing the diversity of plants resistant to hot and dry climate conditions, as well as using fruit-bearing plant taxa that would contribute to biodiversity.

Keywords: Plant material, Species diversity, Open green areas, Diyarbakır

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Giriş

Şehir ağaçları, tarihsel olarak kentleşme ile birlikte şekillenmiş ve zamanla çeşitli sosyal, çevresel ve ekonomik işlevler kazanmıştır. Yeşil alanlar, hava kalitesini artırmaktan sosyal etkileşimleri güçlendirmeye kadar pek çok olumlu etkiye sahiptir. Kentsel yaşamın sürdürülebilirliği ve insanların sağlığı açısından kritik bir unsur haline gelmiştir. Kentsel planlamada yeşil alanların entegrasyonu, modern kentlerin en önemli bileşenlerinden biri olarak öne çıkmaktadır (Dirik, 1997).

Modern kentler ağaçların varlığı ve çeşitliliği ile tanımlanmaktadır. Gelişmiş ülkelerde, kentsel yeşil alanların yönetimi ve korunması, bilimsel ve teknolojik yöntemlerle yapılmaktadır. Kentsel ekosistemlerin sağlığını ve sürdürülebilirliğini artırmak için kritik öneme sahiptir. Böylece, şehirlerin yeşil alanları daha iyi yönetilebilir ve bu alanların sağladığı ekosistem hizmetleri en üst düzeye çıkarılabilir (Ürgenç, 1998).

Kentleşmenin hızla arttığını yapılan çalışmalarda görmekteyiz. 1995-2030 yılları arasında dünya nüfusunun büyük bir kısmı kentlere yerleşeceği ön görülmektedir (McConnachie vd., 2008).

Kentleşme alan kullanımları doğal habitatların kaybı, türlerin yok olmasına ve ekosistem dengelerinin bozulmasına neden oluyor (Sandstrom vd., 2006). Kentleşme süreçlerinin daha çevre dostu ve insan odaklı bir şekilde yönetilmesi, sağlıklı yaşam alanlarının yaratılması için hayati bir gerekliliktir. Bu bağlamda, yeşil alanların korunması ve geliştirilmesi, kentsel çevre kalitesini artırmak için kritik öneme sahiptir (Grahn ve Stigsdotter, 2003).

Kentsel açık yeşil alanların en önemli bileşeni olan bitkiler; hava kirliliği azaltma, iklim değişikliğini önleme, termal konforu sağlama, erozyon kontrolü, estetik görüntü sağlama, yaban hayvanlarına yaşam alanı oluşturma, karbon tutma gibi birçok önemli fayda sağlamaktadır (Yılmaz vd., 2009; Önder ve Akbulut, 2011; Sakıcı vd., 2013; Yılmaz vd., 2017; Düzenli vd., 2018; Gülçin ve Van Den Bosch, 2021).

Kentlerin en önemli faktörlerinden biri bitki örtüsüdür (Oke vd., 2017). Bitki örtüsünün yetersiz olduğu yoğun yerleşim alanların da ısı adası yoğunluğunun fazla olduğu bilenmektedir (Gartland, 2008). Kentsel alanların soğutma çalışmaların da genel olarak bitkilendirme çalışmaları yaygın olarak kullanılan stratejidir. Bitkiler ısı adası etkisini iki şekilde azaltmaktadır. Birincisi buharlaşma yoluyla sıcaklığı aza indirgeme, ikincisi ise beton zeminlerin gölgelenmesiyle sıcaklığın azaltılmasıdır (Saaroni vd., 2018; Yao vd., 2020; He vd., 2021).

Kentleşmenin artmasıyla kentsel ekoloji, birçok alanda yer alarak geleceğin kentlerini ileriye taşımak için önemli bir multidisipliner bilimdir. Kentlerin büyümesi ile süregelen zorlukların ışığında, kentsel sistemlere ait anlayışımızı kolaylaştırıp sürdürülebilir kentler için çözüm odaklı konuları belirlemek amacıyla kentsel ekolojideki konuları çözümlemek gerekecektir (Kowarik, 2023). Biyoçeşitlilik kaybı insanların yarattığı aynı zaman da insanları birebir etkileyen küresel bir sorundur. Dünya nüfusunun çoğunluğu kentlerde yaşadığı için kentlerin biyoçeşitliliğinin insanları hangi yönlerden ve nasıl etkilediği yönünde de çalışmalara çok büyük ihtiyaç vardır (Zari, 2018).

Kentsel biyoçeşitlilik, ekosistemlerin sürdürülebilirliğini ve tüm canlıların refahını sağlamak için temel bir unsurdur. Bu hizmetler, şehirlerde daha sağlıklı ve yaşanabilir bir ortam yaratılmasına yardımcı olur. Kentsel biyoçeşitlilik Kültürel hizmetler, Düzenleyici hizmetler, Ekosistem/Habitat hizmetleri gibi birçok önemli konuda fayda sağlamaktadır (EEA, 2011; Panwar, 2021).

Türkiye'nin farklı kentlerinde açık-yeşil alanlarda kullanılan bitki materyallerine yönelik yapılmış araştırmaları vardır. Çalışmamızda, kent ölçeğinde bitki materyali kullanımının mevcut durumunu değerlendirebilmek, farklı kentlerde benimsenmiş tür tercihlerini, doğal ve ekzotik tür dengesini, aromatik ve tıbbi bitkilerin kullanım oranlarını karşılaştırmalı olarak analiz edebilmek için bu literatür taraması yapışmıştır. Bunlar;

İstanbul Adalarındaki doğal ve ekzotik bitkiler ve peyzaj özellikleri tespit edilmiştir (Yaltırık vd., 1993). İç Anadolu Bölgesi koşullarına uygun bazı herdem yeşil bitki türlerinin adaptasyonu yapılmıştır (Arslan vd., 1996). Düzce kenti açık yeşil alanlarının mevcut bitki potansiyeli belirleniştir (Eroğlu vd., 2005). İstanbul'un özellikle tarihi park, bahçe ve korularında bulunan ekzotik ağaç ve çalı türleri tespit edilmiştir (Yaltırık vd., 1997). Çanakkale kenti açık-yeşil alanlarında kullanılan bitkiler belirlenmiştir (Kelkit, 2002). Erzurum Kent açık-yeşil alanlarında, 44 ağaç ve ağaççık (9 türü yaygın) ve 16'ü çalı (7 türü yaygın) olmak üzere toplam 60 bitki türü kullanıldığı belirlenmiştir (Yılmaz ve Irmak, 2004). Erzincan Kenti Açık-Yeşil alanlarında 23 familyaya ait 46 geniş yapraklı ağaç, 3 familyaya ait 18 iğne yapraklı ağaç, 21 familyaya ait 34 ağaççık çalı, 7 familyaya ait 9 sarılıcı olmak üzere toplam 107 bitki taksonu kullanıldığı belirlenmiştir (Askan ve Yılmaz, 2016). Şanlıurfa ili Haliliye ilçesi açık yeşil alanlarında bitki materyali değerlendirme sonucunda doğal bitki kullanımının az olduğu, yaprak döken ve her dem yeşil bitki türlerinin yeterli olduğu, aromatik bitki çeşitliliği bakımından zengin taksona sahip olduğu tespit edilmiştir (Hatipoğlu ve Ekrem, 2022). Kahramanmaraş kentsel açık ve yeşil alanlarında 173 bitki taksonu tespit edilmiştir. Değerlendirme sonucunda Kahramanmaraş

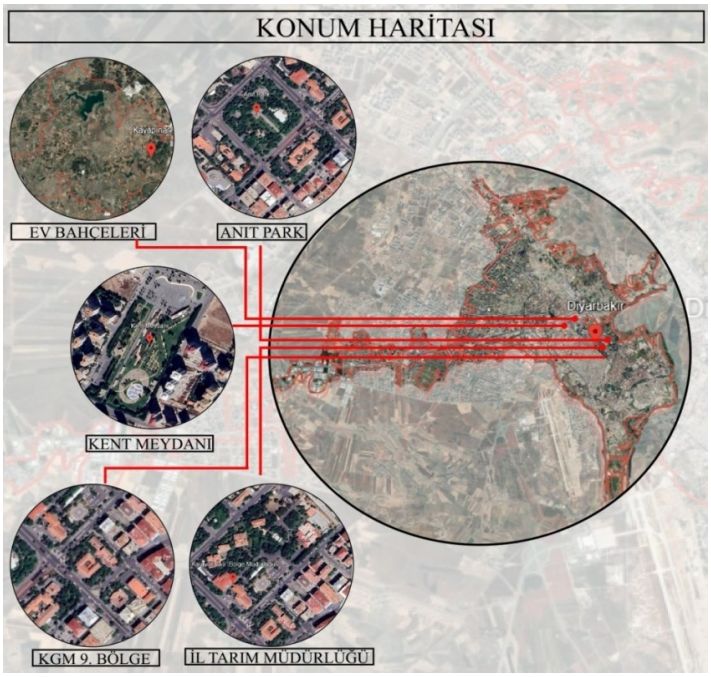
kentinin, zehirli bitki türlerini fazla kullandığı ve doğal türlerin kullanımının az olduğu, tıbbi ve aromatik bitkiler açısından zengin olduğu belirlenmiştir (Ekren ve Çorbacı, 2022). Yapılan bir araştırmada ağaç türü sayısı arttıkça ekosistem direnci artmakta olup, tek bir ağaç türü toplam ağaç türlerinin %10-20'sini geçmemesi (Kendal vd., 2014). Yurtdışında da kentsel ekosistem içinde ağaçların rolü, kullanılan bitki türleri, kentsel ısı adadı oluşumuna olumlu etkileri, estetik değerleri, termal konfora katkıları, ekonomik ve sağlık açısından yararları gibi ana konularda çok sayıda araştırma yapılmıştır;

Kent içinde bulunan bitkiler kent biyoçeşitliliğini destekleyen ve kentlerin iklim değişikliğine direncini yükselten en önemli yapı taşlarından biri olduğu belirlenmiştir. Kentsel ortamlardaki bitkilerin insanların biyosfer ile arasındaki bağı oluşturmaktadır (Liu vd., 2021). Açık yeşil alanlar, kentleşmenin getirdiği nüfus artışına göre sürekli yenilenmesi gereken alanlar olup, uzun ömürlü, sürdürülebilir kentleşme, planlama, geri besleme ve yeniliklere açık olarak planlanıp tasarlanması gerektiği tespit edilmiştir (Friedman ve Lee, 2017). Kentlerde bitkilere dayalı yeşil duvar tasarım tercihlerinin çevresel değerlendirmesinde yeşil duvar sisteminin üretimi kullanımı bu sistemlerin çevresel performansı üzerinde çok yüksek bir etkiye sahip olduğunu göstermiştir (Reyhani vd., 2023). Şehirlerde bitkilerle peyzaj düzenlemesinde ekolojik bilginin kullanılmasında yalnızca estetik açıdan hoş görünmekle kalmaz, aynı zamanda yaygın bakım sorunlarını azalttığı, bitki performansını ve dayanıklılığını iyileştirebildiği belirlenmiştir (Tabassum vd., 2020). Kurak alanlardaki şehirler bitkiler için yapay koruma alanları olarak kullanılıyor ve küresel ısınma, çölleşme yaban hayatını tehdit eder, kalan bitki unsurlarını göç ve yok olma ikilemiyle karşı karşıya bırakır. Yönetilen ve sulanan yeşil alanlarıyla şehirler, birçok bitki için güvenli limanlar olmuştur (Ghahremaninejad vd., 2021).

Gelişmiş ülkelerde kentsel mekanlarda bitki kullanımlarına büyük önem verilmektedir. Bu amaçla Diyarbakır kent merkezindeki değişik açık yeşil alan tiplerinde kullanılan bitki türlerinin tespitini yaparak, kentsel yeşil alan sistemindeki olası rolleri değerlendirilmeye çalışılmıştır. Sıcak iklim bitki türlerini temsil eden kentteki bitki materyalinin ortaya konası diğer çalışmaların yanı sıra, benzer ekolojik ortamlarda bitki kullanımına da kaynak oluşturması amaçlanmıştır.

Yöntemler

Çalışmanın ana materyalini Diyarbakır kent merkezindeki açık ve yeşil alanlarda kullanılan ağaç, ağaççık ve çalılar oluşturmaktadır. Diyarbakır kenti, sönmüş volkanik Karacadağ'dan Dicle'ye uzanan geniş bazalt platosunun doğu kenarında kurulmuştur. Kent, tarihin her döneminde büyük medeniyetlerin, kültürel ve ekonomik hareketlerin merkezi olmuştur (Yiğit, 2002). Güneydoğu Torosları çevresindeki alanlardan farklı kılan asıl iklim özelliği ise yağış miktarının fazlalığı ve yağış rejiminin farklılığıdır. Kentin yıllık sıcaklık ortalaması 22℃, en sıcak ay ortalaması 38.2 ℃ ile Temmuz ayı, en soğuk ay 7℃ ile Ocak ayındadır. Diyarbakır 490 mm yıllık yağışa sahiptir. İlde ortalama nispi nemi en yüksek Aralık ve Ocak aylarında, %77 oranında ölçülmüştür. Yaz aylarında ise en düşük nem temmuz-ağustos aylarında olup, bu aylarda nemin %20'ye düştüğü görülmüştür (Diyarbakır Valiliği, 1990). Diyarbakır ilinde kırsal nüfus %27 (456.660 kişi) ve şehirsel nüfus %73 (1.243.241 kişi)'tür. Kırsal nüfus geniş tarım alanları ve önemli hayvancılık potansiyeline sahip alanlarda yoğunlaşmıştır (TÜİK, 2017). Diyarbakır çalışma alanı konum haritası Şekil 1'de verilmiştir.



Şekil 1.
Diyarbakır çalışma alanı konum haritası

Bu çalışma inceleme, gözlem, analiz ve değerlendirme aşamalarından oluşmuştur. Örnekleme alanı olarak; kentin değişik semtlerinde bulunan 5 konut bahçesi, önemli 2 resmi kurum bahçesi (Karayolları Tarım İl Müdürlüğü.), farklı semtlerde yaygın olarak kullanılan parkları 3 park (Kent meydanı, Anıt park, Tema parkı) ile kent ana cadde yol ağaçları seçilmiştir. Bu alanlarda bulunan bitkiler sayılarak, teşhisleri, kullanım alanları, yoğunlukları ile bitkisel tasarım yönünden değerlendirilmeleri yapılmıştır. Bitkilerin teşhisinde TÜBİVES (Türkiye Bitkisel Veri Servisi) konuyla ilgili yazılı ve görsel kaynaklar ek olarak alanda yapılan gözlemlerden yararlanılmıştır.

Açık-yeşil alanlarda kullanılan bitkilerin fonksiyonları (G: Grup, S: soliter, Y: Yol Ağacı, K: Koruluk, Ç: Çit, Ü: Üretim, Sa: Sarılıcı) tespit edilmiştir. Bitkilerin kullanım yoğunlukları bitki sayısına göre, nadir: 500 tane, az: 50-200, orta: 200- 500, yaygın: >500 olarak belirlenmiştir (Yılmaz ve Irmak 2004).

Bulgular

Diyarbakır kent merkezinde yoğun olarak kullanılan halka açık yeşil alanlar, şehrin merkezine konumlanan kurum bahçeleri ve yeni yerleşim alanlarının olduğu ev bahçeleri seçilmiştir. Farklı alan kullanımında tespit edilen bitki türleri: kent peyzajının genel karakterini resmi kurum bahçeleri, Anıt Park, Kent meydanı, kentin farklı semtlerinde bulunan ev bahçeleri ve 75 m yolu boyunca yer alan yeşil doku oluşturmaktadır. Diyarbakır kent merkezindeki açık ve yeşil alanlarında kullanılan bitki materyali Tablo 1'de verilmiştir. Araştırma sonucunda kentsel açık-yeşil alanlarda 44 ağaç ve ağaççık ve 16 çalı türü kullanıldığı saptanmıştır.

Bölgede en çok *Morus alba* L. (Beyaz dut), *Platanus orientalis* (Doğu çınarı), *Robinia pseudoacacia* (Beyaz çiçekli yalancı akasya) türlerinin kullanıldığı belirlenmiştir. Bu bitkiler genelde gölgeleme, keskin hatları yumuşatma, maskeleme, tanımlama amaçlı kullanılmıştır.

Yol ve orta refüj ağacı olarak kentte daha çok *Acer saccharum (*Şeker akçaağacı), *Lagerstroemia indica* (Oya ağacı), *Platanus orientalis* (Doğu çınarı), *Robinia pseudoacacia* (Beyaz çiçekli yalancı akasya) ağaçları kullanılmıştır. Yeni yapılaşan alanlarda bitkilerin bakımı ve görünümü sağlıklı iken eski yapılaşmanın olduğu alanlarda bakımların yetersiz olduğu gözlenmiştir. Bununla beraber son zamanlarda orta refüj ve yol bitkilendirilmesinde başarılı sonuçlar alınmakta ve kentin estetik görüntüsünü arttırma yönünde gelişmeler devam etmektedir.

Araştırma yapılan Anıt Park, Kent meydanı parklarında bitki çeşitliliğinin yeterli olmadığı belirlenmiştir. Alanda yapılan araştırma sonucunda 24 ağaç 11 çalı taksonu kullanıldığı tespit edilmiştir. Parklarda en fazla *Morus alba L*. (Beyaz dut), *Platanus orientalis* (Beyaz çiçekli yalancı akasya), *Cercis siliquastrum* (Erguvan), *Catalpa bignonioides* (Katalpa)'ler kullanılmıştır. Çalı türü olarak en fazla kullanılanlar ise *Lonicera etrusca* (Hanımeli), *Spirea japonica* 'Gold Flame' (Pembe çiçekli keçi sakalı), *Euonymus japonica* 'Aurea' (Altuni taflan)'dır (Şekil 2). Son zamanlarda yapılan parklarda çalı formunda farklı bitkilerin kullanılmasıyla görsel kalite olarak gelişme göstermiştir.

Şekil 2.

Diyarbakır kent parkında kullanılan bazı bitki görselleri

1) Catalpa bignonioides (Katalpa), 2) Catalpa bignonioides (Katalpa), 3) Morus alba L. (Beyaz dut), 4) Platanus orientalis (Doğu çınarı), 5) Cedrus libani (Lübnan sediri), 6) Fraxinus excelsior (Adi dişbudak), 7) Tilia tomentosa (Gümüşi ıhlamur), 8) Punica granatum (Nar), 9) Spirea japonica 'Gold Flame'(Pembe çiçekli keçi sakalı), 10) Platycladus orientalis 'Pyramidalis Aurea' (Altuni piramit mazısı), 11) Cotinus coggygria (Duman ağacı), 12) Thuja occidentalis 'Samaragad' (Batı mazısı)

Diyarbakır da kent parklarında kullanılan ağaç türleri;*Thuja occidentalis* 'Samaragad' (Batı mazısı), *Pinus mugo* (Dağ camı), *Malus floribunda* (Süs elması), *Cupressus arizonica* (Arizona servisi), *Prunus cerasifera* (Süs eriği), *Platanus orientalis* (Doğu çınarı), *Populus alba* (Ak kavak), *Prunus armeniaca* (Kayısı), *Crataegus orientalis* (Alıç), *Quercus rubra* (Kırmızı meşe), *Pinus persica* (İran çamı), *Rhus typhina* (Sumak), *Casuarina equisetifolia* (Demir ağacı), *Prunus avium* (Kiraz), *Robinia pseudoacacia* (Beyaz çiçekli akasya), *Tilia tomentosa* (Gümüşi ıhlamur), *Melia azedarach* (Tesbih ağacı), *Punica granatum* (Nar), *Elaeagnus angustifolia* (İğde), *Cedrus libani* (Lübnan sediri), *Catalpa bignoides* (Katalpa), *Acer saccharum* (Şeker akçaağaç), *Morus nigra L.* (Kara dut), *Ailanthus altissima* (Kokar ağaç),

Parklarda çalı türü olarak ise; *Lavandula officinalis* (Lavanta), *Spirea japonica* 'Gold Flame' (Pembe çiçekli keçi sakalı), *Cotinus coggygria* (Duman ağacı), *Rosa hybrida* (Gül), *Berberis thunbergii* (Bodur kadın tuzluğu), *Buddleja davidii* (Kelebek

çalısı), *Cornus, alba "*Sibirica*"* (Kırmızı gövdeli kızılcık), *Cornus alba 'Aurea'* (Sarı gövdeli kızılcık), *Juniperus horizontalis* (Yayılıcı ardıç), *Juniperus chinenesis*. (Çin ardıcı), *Platycladus orientalis* 'Pyramidalis'Aurea' (Altuni piramit mazısı) kullanılmıştır.

Resmi kurum bahçelerinden karayolları 9. Bölge Müdürlüğü ve İl Tarım Müdürlüğü bahçeleri örnekleme alanı olarak seçilmiştir. Bu bahçelerdeki açık-yeşil alanlarda en fazla bitki çeşitliliğini sahip olduğu belirlenmiştir. Bununla beraber bitkisel materyal kullanımı konu uzmanları dışında tasarım ilkelerine uyulmadan sıradan yapıldığı gözlenmiştir. Kentte çok az sayıda görülen *Viburnum opulus* (Kartopu), *Cercis siliquastrum* (Erguvan), *Yucca flamintosa (*Avize ağacı), *Forsythia intermedia* (Altın çanağı) bitkileri kurum bahçelerinde yer almaktadır.

Bu bahçelerde; *Morus alba L.* (Beyaz dut), *Ficus carica* (İncir), *Platanus orientalis* (Doğu çınarı), *Cerciss iliquastrum* (Erguvan), *Robinia pseudoacacia* (Beyaz çiçekli yalancı akasya), *Albizia julibrissin* (Gülibirişim), *Cedrus libani* (Lübnan sediri), *Cupressus arizonica* (Arizona servisi), *Elaeagnus angustifolia* (İğde), P*runus cerasifera* (Süs eriği), *Aesculus hippocastanum* (At kestanesi), *Casurina equisetifolia* (Demir ağacı), *Fraxinus excelsior* (Adi diş budak) yaygın olarak kullanılmıştır. Çalı türlerinden *Buxus sempervirens* (Şimşir), *Hedera helix* (Duvar sarmaşığı), *Rosa hybrida* (Gül), *Euonymus japonica* 'Aurea' (Altuni taflan), *Forsythia intermedia* (Altın çanağı), *Cotinus coggygria* (Duman ağacı), *Spirea japonica* 'Gold Flame' (Pembe çiçekli keçi sakalı), *Lonicera etrusca* (Hanımeli) kullanılmıştır (Şekil 3). Diğer yeşil alanların aksine kurum bahçelerinde az sayıda *Viburnum opulus* (Kartopu), *Cercis siliquastrum* (Erguvan), *Yucca filamentosa (*Avize ağacı) türlerine rastlanmıştır.

Ev bahçelerinde özellikle *Prunus avium* (Kiraz), *Morus alba* L. (Beyaz dut), *Ficus carica* (İncir), *Punica granatum* (Nar) gibi meyve ağaçları kullanımı yoğundur. Kent genelinde kullanılan bitki türü sayısı az olmakla birlikte peyzaj karakteri güçlü bitkiler nadiren kullanılmıştır.

Ev bahçelerinde kullanılan ağaç türleri *Cercis siliquastrum* (Erguvan), *Prunus serrulata* (Süs kirazı), *Platycladus orientalis* 'Pyramidalis'Aurea' (Altuni piramit mazısı), *Ficus carica* (İncir), *Eriobotrya japonica* (Malta eriği/yeni dünya), *Morus alba L.* (beyaz dut), *Nerium oleander* (Zakkum), *Prunus avium* (Kiraz), *Salix babylonica* (Salkım söğüt), *Syringa vulgaris* (Leylak), *Citrus lemon L.* (Limon), *Fraxinus excelsior* (Adi dişbudak)'dır. Çalı türleri olarak *Hedera helix* (Duvar sarmaşığı), *Rosa hybrida* (Gül), *Wisteria sinensis* (Mor salkım), *Lonicera etrusca* (Hanımeli), *Parthenocissus quenquefolia* (Amerikan sarmaşığı), *Photinia x fraseri* 'Red Robin' (Alev çalısı) kullanılmıştır (Şekil 4).

Şekil 3.

Diyarbakır kurum bahçesinde kullanılan bazı bitki görselleri

1) Euonymus japonica 'Aurea' (Altuni taflan), 2) Lonicera etrusca (Hanımeli), 3) Albizia julibrissin (Gülibrişim), 4) Aesculus hippocastanum (At kestanesi), 5) Ficus carica (İncir), 6) Viburnum opulus (Kartopu), 7) Yucca filamentosa (Avize ağacı), 8) Hedera helix (duvar sarmaşığı), 9) Cercis siliquastrum (Erguvan), 10) Rosa hybrida (Gül) , 11) Buxus sempervirens (Şimşir) , 12) Euonymus japonica 'Aurea' (Altuni taflan), 13) Forsthia intermedia (Altın çanağı)

Şekil 4.

Diyarbakır ev bahçelerinde kullanılan bazı bitki görselleri

1) Syringa vulgaris (Leylak), 2) Wisteria sinensis (Mor salkım), 3) Nerium oleander (Zakkum), 4) Parthenocissus quinquefolia (Amerikan sarmaşığı), 5) Lonicera etrusca (Hanımeli)

Tablo 1.

Diyarbakır kenti açık-yeşil alanlarında kullanılan ağaç ve ağaççıklar ile bazı özellikler

Latince Adı	Türkçe Adı	Yaygın Kullanım Alanı	Kullanım Amacı	Kullanım Yoğunluğu
1.Acer saccharum	Şeker akçaağacı	Park, yol	Y, G	Nadir
2.Albizia julibrissin	Gülibrişim	Kurum	S	Az
3.Aesculus hippocastanum	At kestanesi	Kurum	S	Az
4.Ailanthus altissima	Kokar ağaç	Park, kurum	S	Az
5.Buxus sempervirens	Şimşir	Kurum, yol	Ç, Y	Orta
6.Casuarina equisetifolia	Demir ağacı	Park, kurum	S	Orta
7.Catalpa bignonioides	Katalpa	Park, yol	Y, S, G	Yaygın
8.Cedrus libani	Toros sediri	Kurum, park	S	Yaygın
9.Cercis siliquatrum	Erguvan	Kurum, park, ev	S	Orta
10.Citrus lemon	Limon	Ev	S, Ü	Az
11.Cupressus arizonica	Arizona servisi	Park, kurum	K, G, S	Orta
12.Chamaerops filifera	Tüysüz Palmiye	Ev	S	Nadir
13.Crataegus orientalis	Alıç	Park	S, G	Az
14.Elaeagnus angustifolia	İğde	Kurum, park	S	Orta
15.Eriobotrya japonica	Malta eriği (yeni dünya)	Ev	S, Ü	Nadir
16.Ficus carica	İncir	Ev, kurum	S, Ü	Yaygın
17.Fraxinus excelsior	Adi dişbudak	Kurum, park, ev	S	Orta
18.Juniperus horizontalis	Yayılıcı ardıç	Park	G, S	Az
19.Juniperus chinensis	Çin ardıcı	Park	G	Az
20.Lagerstroemia indica	Oya ağacı	Yol, ev	Y, S	Az
21. Populus alba	Ak kavak	Park	S	Az
22.Pinus mugo	Dağ camı	Park	S	Az
23. Pinus persica	İran çamı	Park	S	Orta
24.Punica granatum	Nar	Ev, park	S, Ü	Yaygın
25.Prunus serrulata	Süs kirazı	Ev, park	S	Orta
26.Prunus avium	Kiraz	Ev, park	S, Ü	Orta
27.Prunus armeniaca	Kayısı	Park, ev	S, Ü	Orta
28.Prunus cerasifera	Süs eriği	Park, ev	S	Orta
29.Platanus orientalis	Doğu çınarı	Ev, park, yol, kurum	S, Y	Yaygın
30.Robinia pseudoacacia	Beyaz çiçekli yalancı akasya	Ev, kurum, yol, park	S, Y	Yaygın
31. Rhus typhina	Sumak	Park	S	Az
32.Salix babylonica	Salkım söğüt	Park, ev, kurum	S	Orta
33.Syringa vulgaris	Leylak	Ev	S	Az
34.Malus floribunda	Süs elması	Park, ev	S	Orta
35.Melia azedarach	Tesbih ağacı	Park	S, G, Y	Yaygın
36.Morus alba L.	Beyaz dut	Park, ev, kurum, yol	S, G, Ü, Y	Yaygın
37.Morus nigra L.	Kara dut	Park, ev, kurum, yol	S, G, Ü, Y	Yaygın
38.Nerium oleander	Zakkum	Yol, ev	Y, S, G	Yaygın
39.Thujia occidentalis'Samaragad'	Batı mazısı	Park, kurum	G, Y, S	Orta
40.Platycladus orientalis 'Pyramidalis Aurea'	Altuni piramit mazısı	Park, ev, kurum, yol	Y, S, G	Yaygın
41.Tilia tomentosa.	Gümüşi ıhlamur	Park	S	Az
42.Viburnum opulus	Kartopu	Kurum	S	Nadir
43.Yucca filamintosa	Avize ağacı	Kurum	S	Nadir
44. Quercus rubra	Kırmızı meşe	Park	S, G	Orta

G: Grup; S: Soliter; Y: Yol Ağacı; K: Koruluk; Ç: Çit; Ü: Üretim; Sa: Sarılıcı.

Tablo 2.
Diyarbakır kenti açık-yeşil alanlarında kullanılan çalılar ve bazı özellikleri

Latince Adı	Türkçe Adı	Yaygın Kullanım Alanı	Kullanım Amacı	Kullanım Yoğunluğu
1.Berberisthunbergii	Bodur kadın tuzluğu	Kurum	G	Az
2.Buddleja davidii	Kelebek çalısı	Park	G	Az
3.Cotinus coggygria	Duman ağacı	Kurum, park	S	Az
4.Cornus, alba "Sibirica"	Kırmızı gövdeli kızılcık	Park	G	Az
5.Cornus alba "Aurea"	Sarı gövdeli kızılcık	Park	G	Az
6.Euonymus japonica 'Aurea'	Altuni taflan	Kurum, yol, park	G	Yaygın
7.Forsthia intermedia	Altın çanağı	Kurum	S	Nadir
8.Hedera helix	Duvar sarmaşığı	Kurum, ev	Sa	Yaygın
9.Lavandula officinalis	Lavanta	Kurum, park	G	Yaygın
10.Lonicera etrusca	Hanımeli	Kurum, park, ev	S, G, Sa	Yaygın
11.Parthenocissus quinquefolia	Amerikan sarmaşığı	Ev	Sa	Yaygın
12.Photiniax freaseri 'RedRobin'	Alev çalısı	Ev	S	Az
13.Rosa hybrida	Gül	Kurum, yol, ev, park	S, G	Yaygın
14.Spirea japonica 'Gold Flame'	Pembe çiçekli keçi sakalı	Park, kurum	G	Nadir
15.Vitis vinifera	Asma	Kurum, ev	Sa	Yaygın
16.Wisteria sinensis	Mor salkım	Ev	S	Az

G: Grup; S: Soliter; Y: Yol Ağacı; K: Koruluk; Ç: Çit; Ü: Üretim; Sa: Sarılıcı

Tartışma

Yaşanabilir kentsel mekanlar oluşturmada dinamik bir yapı gösteren, kent estetiği ve ekolojisine katkıda bulunan ağaç ve çalılar modern kentlerin simgesi durumundadır. Nitekim Tyruainen (1997)'e göre ağaçlar sadece kent estetiği değil, aynı zamanda yakınında bulunan taşınmazlarının değerine de oldukça önemli katkılar sağlamaktadır. Kent ekolojisinde bitkisel materyalin önemi üzerinde geniş çaplı araştırmalar yürütülmektedir (Jim ve Liu, 1997).

Kentleşmenin getirdiği alan değişimleri, ekosistemin bozulmasına ve istilacı türlerin sayısının artmasına sebep olmaktadır. Bunların yanında kentleşmeyle beraber su, toprak, hava, ısı adası, gürültü kirliliği, açık yeşil alanların azalması kentsel biyoçeşitlilik üzerinde tehdit oluşturmaktadır. Kentsel biyoçeşitliliği koruma altına almak için, koruluk, çayır, mera, tarım alanları, yeşil kuşaklar, orman ve hobi bahçeleri, parklar, konut bahçeleri, su yüzeyleri gibi alanlar kentsel biyoçeşitliliğe katkı sağlamaktadır (Yılmaz, 2024).

Diyarbakır'da *Prunus serrulata* (Süs kirazı), *Ficus carica* (İncir), *Morus nigra* L. (Kara dut), *Morus alba* L. (Beyaz dut), *Malus floribunda* (Süs elması), *Prunus avium* (Kiraz), *Prunus cerasifera* (Süs eriği),*Punica granatum* (Nar) gibi kuraklığa dayanıklı bitki taksonları tespit edilmiş olup bu bitkiler ev bahçelerinde, kurum bahçelerinde, parklarda ve yol ağaçlandırılmasında görülmüştür.

Giderek artan kentleşmenin var olan olumlu ekosistem bileşenlerini farklılaştırdığı ve kentsel mekanları doğal bitkiler için uyumsuz alanlar haline dönüştüreceği bilinmektedir (Sjöman vd., 2016). Doğal bitkilerin kent iklimine dayanıklı olduğu ve kent biyoçeşitliliğinde pozitif etkisi olduğu görülmüştür. Kentlerin yeni yerleşim alanlarında kent biyoçeşitliliğine hangi bitki türünün katkı sağlayacağı da güncel araştırma konularından olmalıdır (Berthon vd., 2021).

Kentsel açık ve yeşil alanlar, yalnızca fiziksel boşluklar değil; aynı zamanda biyolojik çeşitliliğin barındığı, iklim düzenleyici, estetik, sosyal ve psikolojik katkılar sunan yaşam alanlarıdır. Diyarbakır kent merkezinde yapılan bu araştırmada, 44 ağaç-ağaççık ve 16 çalı türünün kullanıldığı belirlenmiş; bununla birlikte bitki türü çeşitliliğinin özellikle Anıt Park ve Kent Meydanı gibi önemli kamusal alanlarda sınırlı olduğu saptanmıştır. Bu durum, kent genelinde biyoçeşitliliğin potansiyel düzeyinin altında kaldığını göstermektedir.

Kentte özellikle bazı bölgelerde (resmi kurum bahçeleri gibi) bitki çeşitliliği daha fazla olmasına rağmen, bu çeşitliliğin planlı ve ekolojik temelli yaklaşımlarla yönetilmediği görülmektedir. Bu durum, kentsel peyzaj tasarımlarının ekosistem temelli değil, daha çok görsel ya da rastlantısal tercihlere dayalı olduğunu ortaya koymaktadır.

Biyoçeşitliliğin artırılması, özellikle yerli türlerin kullanımı ile birlikte, kent ekosistemlerinin dayanıklılığını artırmakta,

kuşlar, böcekler gibi faunanın yaşam alanlarını desteklemekte ve ekolojik bağlantılar kurarak kentsel doğa ile insan arasında bütünleşik bir yapı oluşturmaktadır. Ayrıca çeşitli türlerin kullanımı, kentsel yeşil alanların estetik kalitesini ve iklimsel işlevlerini de olumlu yönde etkilemektedir.

Diyarbakır ve çevresine doğal olarak yayılış gösteren veya Türkiye florasına özgü yerli türler de önemli bir yer tutmaktadır. Bu yerli türlerin peyzaj tasarımlarında kullanımı, hem ekosistemle uyumlu hem de bakım ve adaptasyon açısından avantaj sağlamaktadır. Çalışma alanında yer alan doğal türler arasında; *Platanus orientalis* (Doğu çınarı), *Morus alba L.* (Beyaz dut), *Prunus armeniaca* (Kayısı), *Populus alba* (Ak kavak), *Crataegus orientalis* (Alıç), *Cedrus libani* (Lübnan sediri), *Elaeagnus angustifolia* (İğde), *Fraxinus excelsior* (Adi dişbudak), *Tilia tomentosa* (Gümüşi ıhlamur), *Viburnum opulus* (Kartopu) ve *Cercis siliquastrum* (Erguvan) gibi türler yer almaktadır. Bu bitkiler, bölgenin doğal florasına uyumlu olmalarının yanı sıra, görsel değerleri, gölgeleme kapasiteleri ve bazı türlerde meyve verimi ile de kent peyzajına katkı sağlamaktadır.

Yerli türlerin kullanımının artırılması, bölgesel peyzaj karakterinin korunması, su tasarrufu, iklim koşullarına uyum, biyolojik çeşitliliğin desteklenmesi gibi birçok ekolojik ve ekonomik avantaj sunmaktadır. Bu nedenle, özellikle yeni kentsel tasarımlarda doğal türlerin kullanımına öncelik verilmesi önerilmektedir.

Diyarbakır kentinin bitki materyalleri üzerinde çok fazla çalışma olmadığı için insanlar tarafından merak edilmektedir. Diyarbakır kentinde toplam 60 tür bitki farklı peyzaj kriterleri yönünden kullanılmış olup Tablo 1, Tablo 2 de bitkilerin sadece 18 türe yakını açık-yeşil alan tiplerinde yaygın olarak görülmektedir.Tüm kent alanında örnekleme yapılan alanlarda bu bitki taksonları tespit edilmiş olup, daha ayrıntılı bir çalışma bu sayı artabileceği kaçınılmazdır. Yaygın kullanılan bitkilerin çoğunluğu yaşça büyük bitkilerdir. Yeni yerleşim alanlarında farklı bitki türleride gözlemlenmiştir. En fazla tür çeşidine parklar sonrasında sırasıyla resmi kurumlar, ev bahçeleri ve yol ağaçları olduğu gözlemlenmiştir. Herdemyeşil iğne yapraklı bitki çeşidinin genel olarak çok az sayıda olduğu yeni yapılan mekanlarda bazı çalı ve ağaç türlerinden kullanılmasıyla az da olsa zenginlik sağlanmıştır. Kentsel ortamda ev bahçesinden, mahalle, kent ve bölge parklarına kadar her ölçekte bitkisel materyalin önemi büyük olup, aslında ağaçlar kentin birer bireyleri durumundadır. Kent biyoçeşitliliğin tanınması, gelişmesi ve sürdürülmesi için biyodostkent önerileri daha yaşanabilir kent alanları için önemli olacağı düşünülmüştür (Yılmaz, 2024). Aynı şekilde kentsel ekosistem içinde kentsel bitki materyalinin kent biyoçeşitliliği, kentsel ısı adasını engelleme, arsa değerinin, çevre sağlığına katkısı (gürültüyü azaltma, oksijen sağlama, havayı temizleme, nem sağlama vb. gibi) sağlık ve estetik açıdan birçok yararları bulunduğuna dair çok sayıda araştırmada (Yılmaz, 2024; Zari, 2018; Kendal, 2014) ortaya konmuştur.

Bitki kullanımında yöredeki fidanlıklarda doğal bitki türlerinin satışının teşvik edilmesi gerekmektedir. Nitekim yapılan bir araştırmada Erzurum kent halkının değişik süs bitkilerinin satışının yapılmadığı veya tanınmadığı için kullanmadığı, güzel görünümlü, gölge veren süs bitkilerini, meyve-sebze bahçelerine göre daha çok tercih ettikleri belirlenmiştir. Bu konuda yapılan benzer bir çalışmada (Yılmaz ve Zengin 2009) da benzer sonuçlar bulunmuş olup, fidanlıklarda bitki türlerinin çeşitliliği bitki satışlarını doğrudan etkilemektedir.

Kurakçıl peyzaj, hem çevresel sürdürülebilirlik hem de estetik açıdan etkili bir çözüm sunar. Bu yaklaşım, su kaynaklarının korunmasına ve kurak iklim koşullarında daha verimli peyzajlar oluşturulmasına yardımcı olur. Bundan dolayı kentlerde kurakçıl peyzajı oluşturabilecek bitkilerin tespit edilmesi ve kullanılması bir zorunluluk durumuna gelmiştir. Diyarbakır kent merkezinde kurakçıl peyzaj uygulamalarına yönelik bitkilerin yaşam formu, kent içindeki yetişme ortamları, doğallıkları peyzaj değerleri gibi özellikleri göz önüne alındığında aşağıdaki bitkilerin kullanılabileceği sonucuna varılmıştır. Bu amaçla; *Olea europaea* (Zeytin Ağacı), *Robinia pseudoacacia* (Beyaz çiçekli yalancı akasya), *Crataegus orientalis* (Alıç), *Pyracantha* coccinea (Ateş dikeni), *Pyrus communis (*Yaban armudu), *Cupressus arizonica* 'Glauca' (Mavi sedir), *Ceratonia siliqua* (Keçi boynuzu), *Elaeagnus angustifolia* (İğde), *Prunus amygladus (Badem), Ailanthus altissima* (Kokar ağaç)'ların kurakçıl peyzaj tasarımları uygulanabilecek ağaçlar olduğu görülmektedir. Bu bitki taksonlarının çoklu uygulamalarla çeşitliliği artırılmalıdır. *Juniperus horizontalis* (Yayılıcı ardıç), *Juniperus chinenesis*. (Ardıç), *Berberis thunbergii* (Bodur kadın tuzluğu), *Lavandula officinalis* (Lavanta), *Cornus alba* 'Sibirica' (Kızılcık)'ların kurakçıl peyzaj tasarımları uygulanabilecek çalılar olduğu tespit edilmiştir (Çorbacı ve Ekren, 2022). Kentsel biyoçeşitlilik açısından kentlerde ağaç türünün çoklu kullanılmasıyla ekosistem direncinin arttığı bilinmektedir (Kendal ve ark., 2014). Estetikten çok kent kent mikro iklimine katkı sağlayacak bitki türleri seçilmelidir (Çelik ve Yılmaz, 2023).

Diyarbakır kentinde sıcaklık faktörü önemli bir etken olduğu için bitkisel tasarımlarda termal konfora katkı sağlayacak taç genişliği, gölge verme durumu göz önüne alındığında *Platanus orientalis (*Doğu çınarı), *Acer saccharum* (Şeker akçaağacı), *Cedrus libani* (Lübnan sediri), *Tilia tomentosa* (Gümüşi ıhlamur), *Quercus rubra* (Kırmızı meşe), *Fraxinus excelsior* (Adi dişbudak) ağaçlarının kullanılabileceği sonucuna ulaşılmıştır.

Yapılan çalışmada 60 bitki taksonu içinde meyvesi yenen ağaç

türü sayısının %8.33 olduğu görülmüştür. Bu bitki taksonlarını daha çok *Ficus carica* (İncir), *Morus nigra* L. (Kara dut), *Morus alba* L. (Beyaz dut), *Punica granatum* (Nar) oluşturmakta olup, kentsel biyoçeşitlilik açısından meyvesi yenen ağaçların etkisi önemli olmakla birlikte kentlerde artırılması gereken bitki türleridir. Yenen bitki türlerinin peyzaj tasarımında kullanımı, estetik, ekolojik ve eğitsel katkılarının yanı sıra, kullanıcı güvenliği ve alanın işlevselliği açısından bazı riskleri de beraberinde getirmektedir. Özellikle meyve dökümünün yoğun olduğu dönemlerde, bu bitkilerin yakın çevresinde kayma tehlikesi oluşabileceği, çocukların ağaçlara tırmanma isteğinin düşme gibi fiziksel riskleri artırabileceği ve dökülen meyvelerin araç yollarına ulaşarak yüzeyde leke ya da zarara neden olabileceği göz önünde bulundurulmalıdır. Meyve ağaçları sert zeminlerden uzak konumlandırılıp genellikle çim alanlar üzerinde kullanılmalıdır.

Sonuçlar ve Öneriler

Elde edilen bulgular doğrultusunda, kentteki yeşil alanlarda toplam 44 ağaç ve ağaççık ile 16 çalı türünün kullanıldığı belirlenmiştir. En sık kullanılan türler arasında *Morus alba* L. (Beyaz dut), *Platanus orientalis* (Doğu çınarı), ve *Robinia pseudoacacia* (Beyaz çiçekli yalancı akasya) ön plana çıkmakta olup, bu türlerin gölgeleme, sınır belirleme ve maskeleme gibi peyzaj işlevleri açısından tercih edildiği görülmektedir.

Kentsel ekolojik planlamada açık ve yeşil alanların hem çevresel hem de sosyal açıdan hayati bir rol oynamaktadır. Yeşil alanlar sadece kentte oksijen sağlayan, iklimi düzenleyen fiziksel boşluklar değil; aynı zamanda insanların bir araya geldiği, sosyalleştiği, dinlendiği ve doğayla temas kurduğu çok yönlü mekânlardır. Kent ekosistemi, doğa ile insan yapımı sistemlerin iç içe geçtiği karmaşık bir yapıdır. Bu sistem içinde yeşil alanlar, ekolojik dengenin korunmasını sağlar; su döngüsü, toprak koruma, hava kalitesinin iyileştirilmesi gibi birçok ekosistem hizmeti sunar. Aynı zamanda kentin sosyal yapısını da doğrudan etkiler: kamusal yaşamın gelişmesini destekler, kent sakinlerinin fiziksel ve ruhsal sağlığına katkı sağlar ve sosyal eşitsizliklerin giderilmesine aracılık edebilir (Barbosa vd., 2007).

Kentsel mekanlar da ağaçlar yoğun teknolojinin ve çevre baskılarının olumsuz etkileri arasında yaşam mücadelesi vermektedir (Jim ve Liu 1997). Kent ekolojisi dengesi açısından kent içerisinde bitki çeşitliliği arttırılmalıdır. Bölgenin iklimine ekolojisine uygun bitki türleri kullanımıyla kentte peyzaj karakteri yüksek bitki türleri ile çalışmalar yapılmalıdır. Özellikle yol peyzajında yetersiz olan bitki türleri arttırılmalı ve gölge yapan ağaçlar kullanılmalıdır. Rastgele yapılan bitkisel tasarımların yeni yapılacak mekanlara taşınmaması için bu aşamada peyzaj mimarı ile çalışmalar sürdürülmelidir.

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Etik Komite Onayı: Bu çalışma için etik kurul onayına gerek yoktur.
Yazar Katkıları: Konsept - MÇ, HY; Tasarım - MÇ; Denetim – HY; Kaynaklar - MÇ; Malzemeler - MÇ; Veri Toplama ve/veya İşleme – MÇ; Analiz ve/veya Yorum – MÇ, HY; Literatür Taraması – MÇ, HY; Yazma - MÇ; Eleştirel İnceleme - HY; Diğer – MÇ, HY.
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Akçin, Ö. E., Kandemir, N., & Akçin, Y. (2004). A morphological and anatomical study on a medicinal and edible plant Trachystemon orientalis (L.) G. Don (Boraginaceae) in the Black Sea Region. *Turkish Journal of Botany*, 28(4), 435-442.

Arslan, M., Perçin, H., Barış, E., & Uslu, A. (1996). İç Anadolu Bölgesi iklim koşullarına uygun yeni bazı herdemyeşil bitki çeşitlerinin saptanması üzerine bir araştırma. *Ankara Üniversitesi Ziraat Fakültesi Yayınları*, No: 1470.

Askan, G., & Yılmaz, H. (2016). Erzincan kenti açık-yeşil alanlarında kullanılan bitkisel materyalin belirlenmesi. *Erzincan Üniversitesi Fen Bilimleri Enstitüsü Dergisi*, *9*(1), 57–74.

Barbosa, O., Tratalos, J. A., Armsworth, P. R., Davies, R. G., Fuller, R. A., Johnson, P., & Gaston, J. (2007). Who benefits from access to green space? A case study from Sheffield, UK. *Landscape and Urban Planning*, *83*, 187–195.

Berthon, K., Thomas, F., & Bekessy, S. (2021). The role of 'nativeness' in urban greening to support animal

biodiversity. *Landscape and Urban Planning*, *205*, 103959.

Çorbacı, L. Ö., & Ekren, E. (2022). Kentsel açık yeşil alanların kurakçıl peyzaj açısından değerlendirilmesi: Ankara Altınpark örneği. *PAUD - Peyzaj Uygulamaları ve Araştırmaları Dergisi*, *1*, 1–11.

Dirik, H. (1997). Kent ağaçları yönetimi. *Kent Ağaçlandırmaları ve İstanbul'96 Sempozyumu*, 29–40.

Diyarbakır Valiliği. (1990). İlk Kültür Turizm Müdürlüğü Broşürü. Diyarbakır.

Düzenli, T., Yılmaz, S., & Tarakçı Eren, E. (2018). Kentsel açık yeşil alanların kullanım türleri ve amaçları. *Social Sciences Studies Journal*, *4*(13), 222–228.

EEA/European Environment Agency. (2011). Green infrastructure and territorial cohesion: The concept of green infrastructure and its integration into policies using monitoring systems. Publications Office of the European Union. https://www.eea.europa.eu/publications/green-infrastructure-and-territorial-cohesion

Ekren, E., & Çorbacı, Ö. L. (2022). Kahramanmaraş kentsel açık yeşil alanlarında kullanılan bitki materyalinin değerlendirilmesi. *Düzce Üniversitesi Orman Fakültesi Ormancılık Dergisi*, *18*(1), 25-50.

Eroğlu, E., Akıncı Kesim, G., & Müderrisoğlu, H. (2005). Düzce kenti açık ve yeşil alanlarındaki bitkilerin tespiti ve bazı bitkisel tasarım ilkeleri yönünden değerlendirilmesi. *Tarım Bilimleri Dergisi*, *11*(3), 270-277.

Friedman, Y., & Lee, T. (2017). Cities taking action. http://100resilientcities.org/wp-content/uploads/2017/07/WEB_170720_Summit-report_100rc-1.pdf

Gartland, L. (2008). *Heat islands: Understanding and mitigating heat in urban areas*. London.

Ghahremaninejad, F., Hoseini, E., & Fereidounfar, S. (2021). Bitkiler için yapay koruma alanları olarak kurak alanlardaki şehirler. *Biyoçeşitliliği Koruma*, *30*, 243-248.

Grahn, P., & Stigsdotter, U. A. (2003). Landscape planning and stress. *Urban Forestry & Urban Greening*, *2*, 1-18.

Gülçin, D., & Van Den Bosch, C. C. K. (2021). Assessment of above-ground carbon storage by urban trees using LIDAR data: The case of a university campus. *Forests*, *12*(1), 62.

Hatipoğlu, İ. H., & Ekren, E. (2022). Kentsel yeşil alanlarında kullanılan bitki malzemelerinin değerlendirilmesi: Şanlıurfa ili Haliliye ilçesi örneği. *Türk Ormancılık Dergisi*, *23*(4), 341-347.

He, B. J., Wang, J., Liu, H., & Ulpiani, G. (2021). Localized synergies between heatwaves and urban heat islands: Implications on human thermal comfort and urban heat management. *Environmental Research*, *193*, 110584.

Kelkit, A. (2002). Çanakkale kenti açık-yeşil alanlarda kullanılan bitki materyali üzerinde bir araştırma. *Ekoloji Dergisi*, *43*, 17-21.

Kendal, D., Dobbs, C., & Lohr, V. I. (2014). Global patterns of diversity in the urban forest: Is there evidence to support the 10/20/30 rule? *Urban Forestry & Urban Greening*, *13*(3), 411-417.

Liu, J., Zhao, Y., Si, X., Feng, G., Slik, F., & Zhang, J. (2021). University campuses as valuable resources for urban biodiversity research and conservation. *Urban Forestry & Urban Greening*, *64*, 127255.

McConnachie, M. M., Shackleton, C. M., & McGregor, G. K. (2008). The extent of public green space and alien plant species in 10 small towns of the sub-tropical thicket biome, South Africa. *Urban Forestry & Urban Greening*, *7*, 1-13.

Oke, T. R., Mills, G., Christen, A., & Voogt, J. A. (2017). *Urban climates*. Cambridge University Press.

Önder, S., & Akbulut, Ç. D. (2011). Kentsel açık-yeşil alanlarda kullanılan bitki materyalinin değerlendirilmesi; Aksaray kenti örneği. *Selçuk Tarım ve Gıda Dergisi*, *25*(2), 93-100.

Panwar, H. (2021). Urban biodiversity. In R. Singh, V. T. G. Shankar, A. Kaur, & M. Bhaisare (Eds.), *Climate Centre for Cities National Institute of Urban Affairs India*.

Reyhani, M., Santolini, E., Tassinari, P., & Torreggiani, D. (2023). Malzeme kombinasyonu ve bitkilere dayalı yeşil duvar tasarım seçimlerinin çevresel değerlendirmesi. *International Journal of Life Cycle Assessment*, *28*, 1078-1091.

Saaroni, H., Amorim, J. H., Hiemstra, J. A., & Pearlmutter, D. (2018). Urban green infrastructure as a tool for urban heat mitigation: Survey of research methodologies and findings across different climatic regions. *Urban Climate*, *24*, 94-110.

Sakıcı, Ç., Karakaş, H., & Kesimoğlu, M. D. (2013). Kastamonu kent merkezindeki kamusal açık yeşil alanlarda kullanılan bitki materyali üzerine bir araştırma. *Kastamonu Üniversitesi Orman Fakültesi Dergisi*, *13*(1),

153-163.

Sandström, U. G., Angelstam, P., & Mikusiński, G. (2006). Ecological diversity of birds in relation to the structure of urban green space. *Landscape and Urban Planning*, *77*, 39-53.

Schwets, T. L., & Brown, R. D. (2000). Form and structure of maple trees in urban environments. *Landscape and Urban Planning*, *46*, 191-201.

Sjöman, H., Morgenroth, J., Sjöman, J. D., Sæbø, A., & Kowarik, I. (2016). Diversification of the urban forest—Can we afford to exclude exotic tree species? *Urban Forestry & Urban Greening*, *18*, 237-241.

Reyhani, M., Santolini, E., Tassinari, P., & Torreggiani, D. (2023). Malzeme kombinasyonu ve bitkilere dayalı yeşil duvar tasarım seçimlerinin çevresel değerlendirmesi. *International Journal of Life Cycle Assessment*, *28*, 1078-1091.

Tabassum, S., Ossola, A., Manea, A., Cinantya, A., Fernandez Winzer, L., & Leishman, M. R. (2020). Using ecological knowledge for landscaping with plants in cities. *Ecological Engineering*, *158*, 106042.

Türkiye İstatistik Kurumu (TÜİK). (2017). *Nüfus istatistikleri*. Ankara. https://www.tuik.gov.tr

Ürgenç, S. (1998). *Genel plantasyon ve ağaçlandırma tekniği*. İstanbul Üniversitesi Yayın No: 3997.

Yaltırık, F., Efe, A., & Uzun, A. (1997). *Tarih boyunca İstanbul'un egzotik ağaç ve çalıları*. İSFALT Yayını No: 4.

Yaltırık, F., Efe, A., & Uzun, A. (1993). *İstanbul Adalarının doğal ve ekzotik bitkileri*. İstanbul Adaları İmar ve Kültür Vakfı Yayın No: 1.

Yao, L., Li, T., Xu, M., & Xu, Y. (2020). How the landscape features of urban green space impact seasonal land surface temperatures at a city-block-scale: An urban heat island study in Beijing, China. *Urban Forestry & Urban Greening*, *52*, 126704.

Yiğit, A. (2002). Güneydoğu Torosların yöresel etüdü. *Fırat Üniversitesi Sosyal Bilimler Dergisi*, *12*(1), 47-77.

Yılmaz, H., & Irmak, M. A. (2004). Erzurum kenti açık-yeşil alanlarında kullanılan bitki materyalinin değerlendirilmesi. Ekoloji, *13*(52), 9-16.

Yılmaz, S., & Zengin, M. (2009). Erzurum kent halkının süs bitkilerine olan talebinin belirlenmesi. *Süleyman Demirel Üniversitesi Orman Fakültesi Dergisi*, *1*, 29-42.

Yılmaz, H., Karaşah, B., & Erdoğan Yüksel, E. (2009). Gülez yöntemine göre Kafkasör kent ormanının rekreasyonel potansiyelinin değerlendirilmesi. *Artvin Çoruh Üniversitesi Orman Fakültesi Dergisi*, *10*(1), 53–61.

Yılmaz, H. (2024). İklim değişikliğine karşı biyoçeşitliliğe dost yerleşke kavramı: Ata Botanik Bahçesi örneği. In A. Koç & G. Özkan (Eds.), *Kentsel yeşil alanların sürdürülebilir yönetimi* (pp. 290-326). Atlas Akademi Yayınları.

Yılmaz, S., Düzenli, T., & Dinçer, D. (2017). Evaluation of factors related to well-being effects of urban green spaces on users. *Fresenius Environmental Bulletin*, *26*, 174-185.

TÜBİVES. (2024). http://194.27.225.161/yasin/tubives/index.php.

Zari, M. P. (2018). The importance of urban biodiversity – An ecosystem services approach. *Biodiversity International Journal*, *2*(4), 357-360.

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Assessing Soil Degradation: A Comprehensive Study Using Soil Degradation Index (SDI) in Godrahav Watershed

Toprak Bozulmasının Değerlendirilmesi: Godrahav Havzasında Toprak Bozulma İndeksi (SDI) Kullanılarak Yapılan Kapsamlı Bir Çalışma

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ABSTRACT

Soil degradation is an important problem for watersheds that contain agricultural and natural areas within their border. This study was conducted to assess soil degradation using soil degradation index (SDI). The watershed was divided into transects at 500m intervals in the north-south and the east-west directions. Except for the hard-to-reach points because of topography, disturbed and undisturbed soil samples were taken from 138 sample points at the intersections of the transects. The SDI was calculated using the measured soil parameters including particle size distribution, aggregate stability, aggregation rate, mean weight diameter, dispersion rate, bulk density, porosity, field capacity, wilting point, organic matter content, pH and electrical conductivity. The spatial distribution patterns of these parameters were defined using geostatistical analyses. Slope, elevation, aspect and land use type of the watershed were also mapped using the Geographic Information System (GIS) technique. The results of the study showed that soil degradation can be quantified using an index value, and that basic soil properties can serve as parameters for this index. These parameters affect index values with different weighting, and these weighting values can be calculated by correlation analysis. Moreover, according to the distribution maps, SDI showed spatial variability due to the land use, altitude, and aspect, but it did not vary regularly due to the slope. Based on the findings, it is recommended to implement land use-specific soil management strategies across the watershed. Regular SDI-based monitoring and geospatial analysis can support early detection of degradation and guide sustainable land use planning.

Keywords: Correlation, Physiographic factors, Soil degradation, Soil mapping, Spatial variability

ÖZ

Toprak bozulması, sınırları içinde tarımsal ve doğal alanlar bulunduran su havzaları için önemli bir sorundur. Bu çalışma, bir su havzasında toprak bozulma durumunu değerlendirmek amacıyla Toprak Bozulma İndeksi (SDI) adlı ampirik bir yöntem kullanılarak gerçekleştirilmiştir. Bu amaçla, havza kuzey-güney ve doğu-batı yönlerinde 500 m aralıklarla transektlere bölünmüştür. Topografya nedeniyle ulaşılması zor olan noktalar çıkarıldıktan sonra, transektlerin kesişim noktalarından 138 örnek noktasından bozulmuş ve bozulmamış toprak örnekleri alınmıştır. SDI hesaplamasında tanecik boyu dağılımı, agregat stabilitesi, agregasyon oranı, ağırlıklı ortalama çapı, dispersiyon oranı, hacim ağırlığı, porozite, tarla kapasitesi, solma noktası, organik madde içeriği, pH ve elektriksel iletkenlik gibi parametreler kullanılmıştır. Bu çalışma aynı zamanda bu parametrelerin mekânsal dağılımını belirlemiştir. Havzanın eğim, yükselti, bakı ve arazi kullanımı gibi bazı özellikleri Coğrafi Bilgi Sistemleri (CBS) tekniği kullanılarak haritalandırılmıştır. Jeoistatistiksel teknikler, bu özellikler ve SDI'nin enterpolasyonu için kullanılmıştır. Çalışmanın sonuçları, toprak bozulmasının bir indeks değeri ile ifade edilebileceğini ve temel toprak özelliklerinin bu indeks için parametre olarak kullanılabileceğini göstermiştir. Bu parametreler indeks değerlerini farklı ağırlıklarda etkilemekte olup, bu ağırlık değerleri korelasyon analizi ile hesaplanabilmektedir. Ayrıca, dağılım haritalarına göre SDI, arazi kullanımı, yükseklik ve bakıya bağlı olarak mekânsal değişkenlik göstermiştir; ancak eğime bağlı olarak düzenli bir değişim göstermemiştir. Elde edilen bulgular doğrultusunda, havza genelinde arazi kullanımına özgü toprak yönetim stratejilerinin uygulanması önerilmektedir. SDI temelli düzenli izleme ve mekânsal analizler, bozulmanın erken tespiti ile sürdürülebilir arazi kullanım planlamasına katkı sağlayabilir.

Anahtar Kelimeler: Korelasyon, Fizyografik faktörler, Toprak bozulması, Haritalama, Mekânsal değişkenlik

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Introduction

Soil degradation, defined as the change in physical, chemical and biological properties of the soil resulting in a diminished capacity of the ecosystem to provide goods and services for its beneficiaries (FAO, 2020), leads to the degradation of ecosystem services (Cerretelli et al., 2018). Soil degradation includes erosion (such as soil loss due to deforestation or overgrazing), salinization, compaction, crusting caused by cattle trampling, and waterlogging with impaired water movement (Scanes, 2018).

The soil properties play a crucial role in determining soil health and degradation. Different soil properties directly influence the physical, chemical, and biological characteristics of the soil, which in turn affect its ability to support plant growth, retain water, and nutrient cycle, and resist degradation. Thus, various soil properties, such as soil texture, structure, water holding capacity, organic matter content, soil reaction, and electrical conductivity contribute to the vulnerability of soil to degradation processes (Barcelos et al., 2022; Lorenz et al., 2019; Rabot et al., 2018; Zhang et al., 2022).

A watershed is a topographic unit containing aquatic and terrestrial ecosystems, with various land-use types such as forest, pasture, and agriculture. Watersheds play a major role in the important requirements in human life, such as water supply, and agricultural and animal production. Besides, watersheds are also important for other creatures that benefit from ecosystem services. Godrahav watershed consists of different land-use types. Forestry, animal husbandry, and agricultural production are carried out in the watershed. The problem of soil degradation may disrupt the ecosystem services provided by the watershed.

Researchers reported the main reasons for the soil degradation in the watershed as degraded forest, water erosion, and shifting cultivation (Amundson et al., 2015; Baul et al., 2023; Hattori et al., 2019; Mo et al., 2023). Different methods and models are used to evaluate soil degradation. In many previous studies, the loss of organic matter, decrease in carbon and nitrogen contents, change in particle size distribution, salinization, acidification, compaction, and erosion have been evaluated as degradation separately. For example, plant nutrient deficiency was considered as chemical degradation, and soil compaction as physical degradation.

Multivariate models are used based on the approach that more than one type of degradation can be seen in an area. A global evaluation of soil degradation requires sampling and evaluation methodology, and a degradation metric meets the needs and interests of multiple different groups (Hatfield et al., 2017).

Multicriteria decision analysis (MCDA) is an umbrella term to describe a collection of formal approaches which seek to take explicit account of multiple criteria in helping individuals or groups explore decisions that matter (Belton & Stewart, 2002). The MCDA provides a compatible methodological framework for deliberate valuation, which is considered helpful in addressing plural value dimensions related to common goods such as ecosystem services.

The novelty of this study lies in its integrated approach to assessing soil degradation by combining multiple soil physical and chemical properties with topographic and land use variables through a Geographic Information System (GIS)-based multicriteria decision analysis (MCDA). Unlike conventional methods that consider soil degradation components in isolation, this study develops a comprehensive Soil Degradation Index (SDI) to spatially evaluate and classify degradation severity within the watershed. This approach enhances the accuracy and applicability of soil degradation assessments for sustainable land management.

This study was carried out in a watershed to determine the soil properties and their spatial variability and distribution. It was also aimed to calculate the soil degradation index with different weighting methods and determine the spatial variability and spatial distribution of the soil degradation index. Besides, determining the effect of topography and land use differences on soil degradation index is another purpose of the present study. A model was developed using the GIS-based MCDA to determine the spatial distribution of the soil degradation index. Created GIS-MCDA models are based on established soil properties that affect soil productivity. The model was used to classify watersheds of low, medium, and high soil degradation index. The hypothesis was that some topographic factors such as altitude, aspects and slope, and land use correlate to the soil degradation index.

Methods

The Godrahav watershed has a catchment area of 6750 ha and is in the Black Sea Region. It lies in the north-south direction between the Karçal mountains and the Çoruh River (Figure 1A). Its climate is semi-humid with a long-term average rainfall of 1000 mm year-1 and a temperature of 12ºC. The watershed was divided into 500 × 500 m transects, and a total of 274 disturbed and undisturbed soil samples were taken from 138 cross points of transects (Figure 1).

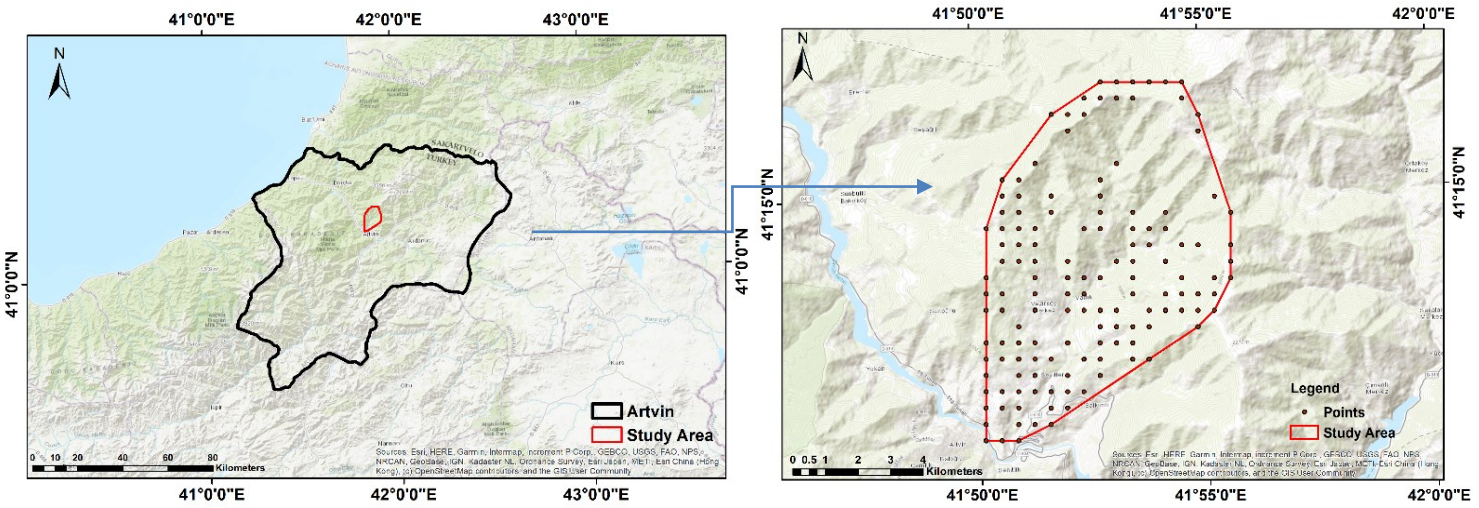


Figure 1.

The geographic position of the study area is named Godrahav watershed in Artvin province, Turkiye. According to the Universal Transverse Mercator system (UTM), the coordinates of the midpoint of the watershed are 37 T, 742040E, 4569701N. B. The sampling points were created with 500x500 m transects to take soil sample

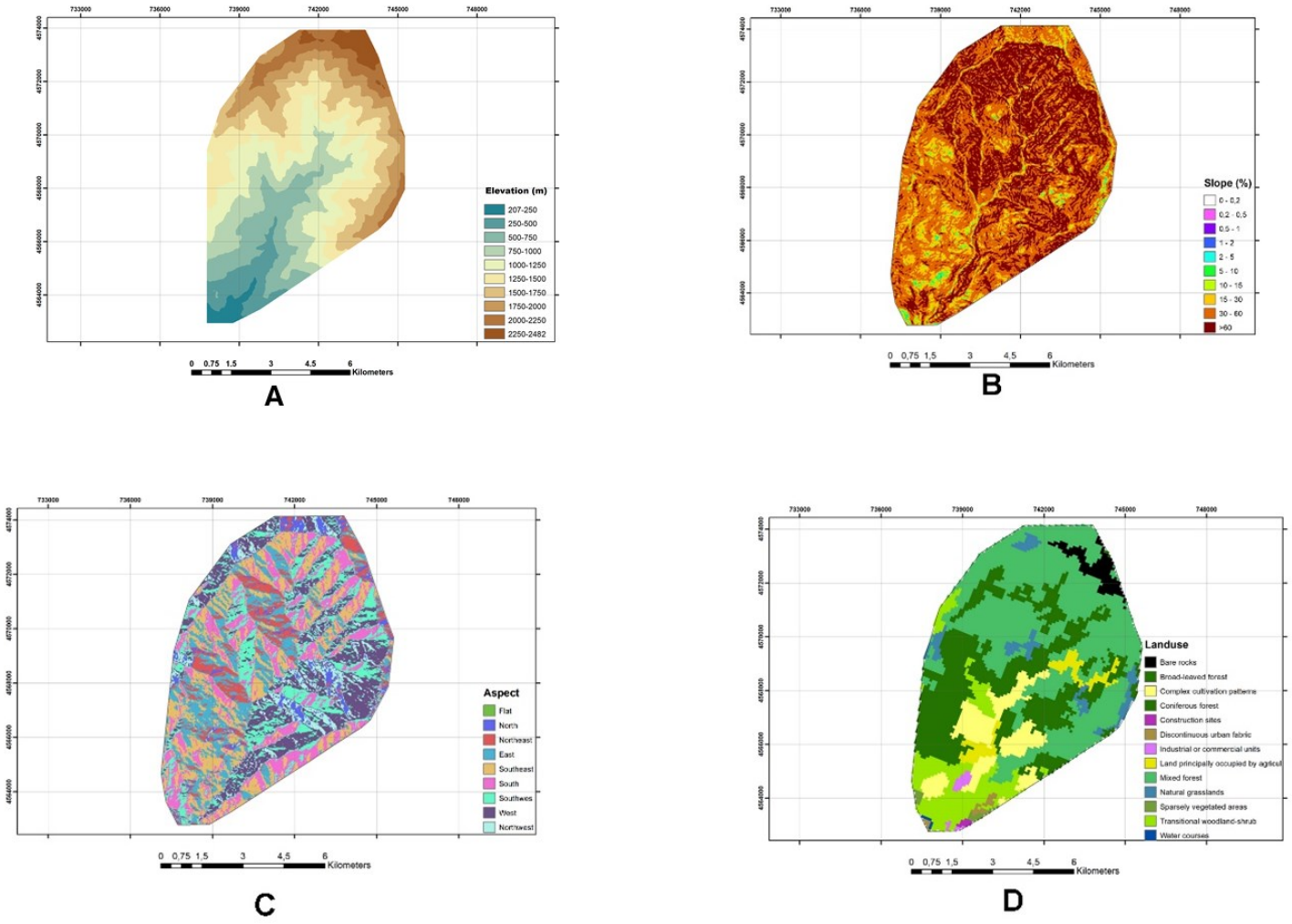


Figure 2.

The landforms and land use of Godrahav watershed. A. Digital elevation model; B. Slope map; C. Aspect map; D. Land use map.

The elevation of the study area varies between 207 m-2482 m (Figure 2A), has a very steep slope (Figure 2B) and mainly the east aspect (Figure 2C). The main land uses are forest, grassland, and agricultural field (Figure 2D).

Soil texture was determined by the Bouyoucos hydrometer method (Gee & Bauder, 1986). Water-stable aggregates were determined using the wet sieving method (Kemper & Rosenau, 1986), and the aggregation rate was calculated accordingly (Turgut & Ateş, 2017). The mean weight diameter and the dispersion rate were also calculated based on standard procedures. Bulk density was determined by the cylinder method (Blake and Hartge, 1986), and total porosity was calculated accordingly (Danielson & Sutherland, 1986). The field capacity and wilting point were determined by applying pressures of 33 kPa and 1500 kPa to the initially saturated samples (Cassel & Nielsen, 1986). Organic matter content was determined by the Smith-Weldon method (Nelson and Sommers, 1983), and pH was measured using a pH meter in a 1:2.5 soil-water suspension (Mclean, 1983). Electrical conductivity was measured by an EC meter (Rhoades, 1983). XLSTAT software was used to calculate descriptive statistics.

The data set was submitted to descriptive statistics (mean, standard deviation, coefficient of variation, maximum and minimum values). The coefficient of variation (CV) of each data set was classified as low variability (CV ≤ 15%), moderate variability (15% < CV ≤ 35%), and high variability (CV > 35 %) (Wilding & Drees, 1983). Geostatistical methods were used to assess the spatial variability of the Soil Degradation Index (SDI) and the soil properties used in its calculation. For visualization purposes, ordinary kriging with an exponential semivariogram model was applied to estimate values across the study area, and the resulting prediction maps were generated using the Kernel Smoothing method. All spatial analyses were conducted using the ArcGIS Geostatistical Analyst extension.

Calculation

Weighting, scoring, and calculation stages were followed to determine the soil degradation index and create the distribution map.

i. Weighting the indicators: In this step, the correlation coefficients between the indicators were determined by Pearson correlation analysis, then the calculation matrix was created by taking the absolute values of the correlation coefficients (Table 1), the correlation coefficients with the indicators themselves were not included in this matrix, and finally, the weighting coefficients were calculated using equation 1.

ii. Scoring the indicators: Indicators were scored with linear functions, such as “more is better”, “optimum range”, and “less is better” (Table 2).

iii. Calculating degradation index: After the variables were scored between 0 and 1, final scores (SDI) were computed using weighting and function scores (Eq. 2). (Güler, 2020)

Table 1.
The matrix model was created by using the absolute values of the correlation coefficients obtained from the Pearson correlation analysis at the stage of weighting the indicators.

	A	B	C	D	N	
A		$\|k_{AB}\|$	$\|k_{AC}\|$	$\|k_{AD}\|$	$\|k_{An}\|$	
B	$\|k_{BA}\|$		$\|k_{BC}\|$	$\|k_{BD}\|$	$\|k_{Bn}\|$	
C	$\|k_{CA}\|$	$\|k_{CB}\|$		$\|k_{CD}\|$	$\|k_{Cn}\|$	
D	$\|k_{DA}\|$	$\|k_{DB}\|$	$\|k_{DC}\|$		$\|k_{Dn}\|$	
n	$\|k_{nA}\|$	$\|k_{nB}\|$	$\|k_{nC}\|$	$\|k_{nD}\|$		
Total	$\sum_{i=A}^{n}\|k\|$	$\sum_{i=B}^{n}\|k\|$	$\sum_{i=C}^{n}\|k\|$	$\sum_{i=D}^{n}\|k\|$	$\sum_{i=n}^{n}\|k\|$	$\sum\sum\|k\|$

$$A_A = \frac{\sum_{i=A}^{n}|k|}{\sum\sum|k|} \quad (1)$$

$$SDI = \sum_{i}^{n} w_i \times s_i \quad (2)$$

A_A, the weight of indicator A; |k|, the absolute value of the correlation coefficient between properties.

Where SDI is soil degradation index; w_i is the weighting and s_i is the score of the ith parameter.

The values of the parameters, weight coefficients, and score values used to determine the SDI are given in the supplementary file.

To explain the relationship between SDI and land properties, “zonal statistics as table” ArcTOOL was used.

Table 2.
Functions and function parameters used in the scoring of indicators.

Indicators	Function	x_1	r_1	r_2	x_2	Equation
Electrical conductivity	More is better	0.00			0.69	$f(x) = \frac{(x - x_1)}{(x_2 - x_1)}$
Bulk density		0.19			1.47	
Dispersion rate		13.48			92.71	
Clay content	Optimum range	3.79	30	35	59.56	$f(x) = 1 - \frac{(x - x_1)}{(r_1 - x_1)}; x_1 < x < r_1$ $f(x) = 0; r_1 < x < r_2$ $f(x) = \frac{(x - r_2)}{(x_2 - r_2)}; r_2 < x < x_2$
Silt content		0.78	30	35	44.02	
Sand content		9.12	30	35	82.59	
pH		3.71	6.8	7.2	7.66	
Aggregate stability	Less is better	57.59			98.91	$f(x) = 1 - \frac{(x - x_1)}{(x_2 - x_1)}$
Aggregation rate		18.75			96.75	
Mean weight diameter		0.28			1.16	
Porosity		24.69			87.38	
Field capacity		15.26			91.62	
Wilting point		8.48			75.97	
Organic matter content		0.15			5.90	

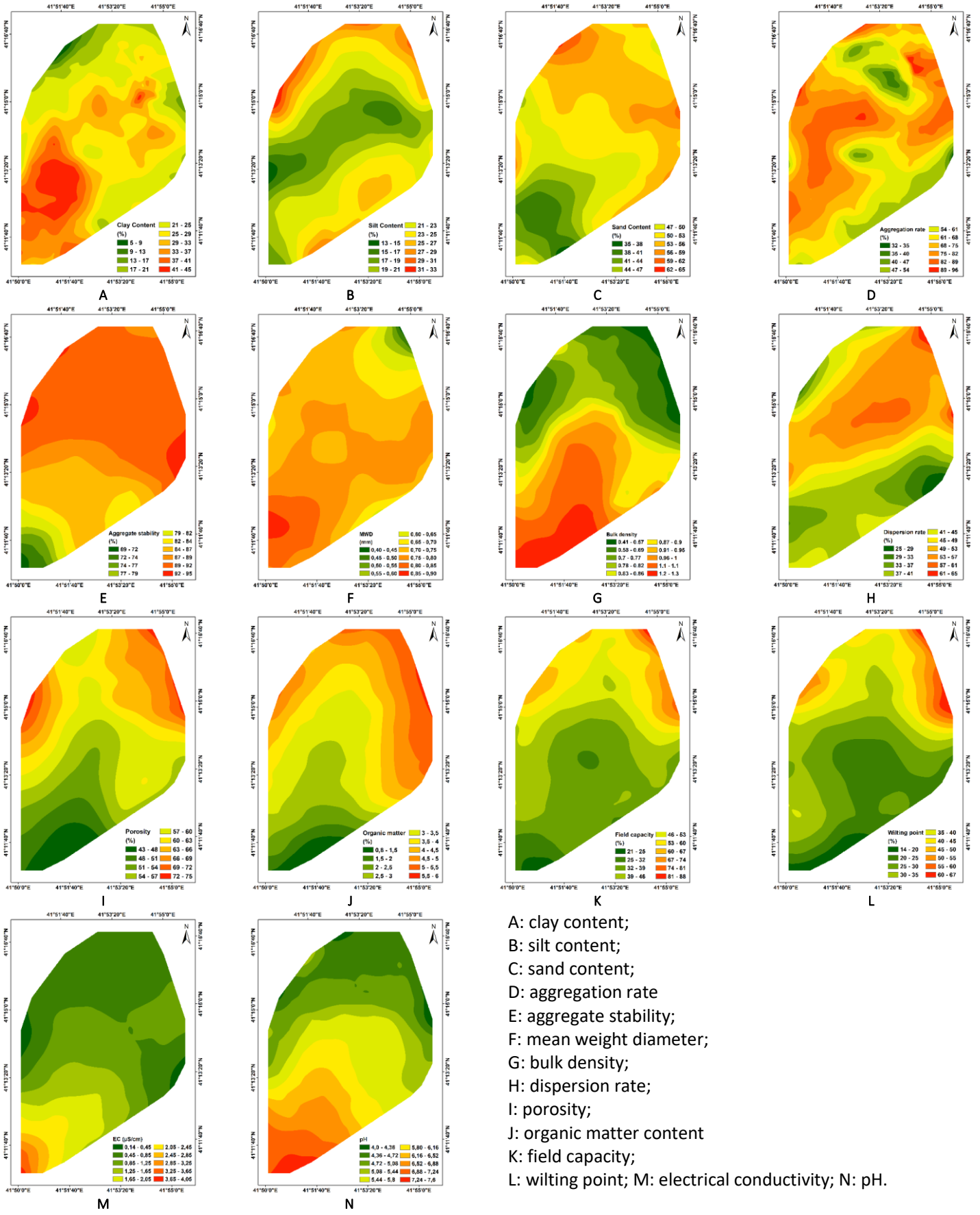
Results and Discussion

The descriptive statistics showed that the range of data was from 3.79 to 59.56% for clay content, from 0.78 to 44.02 % for silt content, from 9.12 to 82.59% for sand content, from 18.75 to 96.75% for aggregation rate (AR), from 57.59 to 98.91% for aggregate stability (AS), from 0.28 to 1.16 (mm) for mean weight diameter (MWD), from 0.19 to 1.47 (g/cm^3) for bulk density (BD), from 13.48 to 92.71% for dispersion rate (DR), from 24.69 to 87.38% for total porosity (f), from 15.26 to 91.62% for field capacity (FC), from 8.48 to 75.97 % for wilting point (WP), from 0.15 to 5.90 % for organic matter content (OM), from 0.0 to 6.89 (µS/cm^1) for electrical conductivity (EC), and from 3.71 to 7.66 for pH. Sand content and AS showed low variability; MWD, BD, f, and pH indicated moderate variability; clay, silt, DR, FC, WP, OM, and EC had high variability (Table 3).

Table 3.
Descriptive statistics of soil properties (n=137) used as indicators for determining soil degradation index.

Properties	Min	Max	Mean	Standard deviation	Coefficient of variation
Clay (%)	3.79	59.56	29.24	10.76	36.80
Silt (%)	0.78	44.02	22.02	10.41	47.28
Sand (%)	9.12	82.59	48.74	13.82	28.35
AR (%)	18.75	96.75	69.81	18.78	26.90
AS (%)	57.59	98.91	86.97	8.15	9.37
MWD (mm)	0.28	1.16	0.76	0.14	18.42
BD (g cm^{-3})	0.19	1.47	0.91	0.29	31.87
DR (%)	13.48	92.71	44.15	18.01	40.79
f (%)	24.69	87.38	57.10	11.96	20.95
FC (%)	15.26	91.62	41.47	15,31	36.92
WP (%)	8.48	75.97	30.32	12.66	41.75
OM (%)	0.15	5.90	3.41	1.60	46.92
EC (µS/cm^1)	0.00	6.89	1.28	1.22	95.90
pH	3.71	7.66	5.77	1.01	17.50

The variation of soil properties depending on the physiographic characteristics of the basin and the differences in land use is seen in the distribution maps (Figure 3). Clay content, electrical conductivity and pH were low in the upper zones of the basin and high in the accumulation zones due to runoff. On the other hand, organic matter was high in forest areas and low in agricultural areas and settlements. Other soil properties, such as aggregate stability, porosity, bulk density, varied across the basin depending on the associated properties.



A: clay content;
B: silt content;
C: sand content;
D: aggregation rate
E: aggregate stability;
F: mean weight diameter;
G: bulk density;
H: dispersion rate;
I: porosity;
J: organic matter content
K: field capacity;
L: wilting point; M: electrical conductivity; N: pH.

Figure 3.
Distribution maps of soil properties used as indicators in the Godrahav watershed.

The soil properties and Soil Degradation Index (SDI) values obtained in this study are consistent with findings from similar research conducted in the Black Sea Region of Türkiye. For instance, in the Deviskel Stream Watershed located in Borçka, Artvin, a study investigating the effects of different land use types on soil properties found that agricultural lands had an average organic matter content of 6.20%, a pH of 7.22, and an electrical conductivity of 448.99 µS/cm. These values were considerably higher compared to forest and pasture areas, indicating the significant impact of agricultural practices on soil characteristics (Erdoğan & Yavuz, 2021).

Similarly, a study conducted around Kaz Lake in Tokat Province reported significant changes in soil properties following drainage activities. Notably, the clay content ranged between 25.40% and 62.90%, with an average of 50.65%. The authors emphasized that such high clay content may negatively affect water infiltration and plant growth (Acir et al., 2021).

In addition, a study carried out in the Alaca Watershed revealed that the spatial distribution of soil organic carbon (SOC) stocks was influenced by both land use and topographic features. Higher SOC stocks were reported in forested areas, while lower values were observed in agricultural lands, confirming the role of land cover in shaping soil carbon dynamics (Yılmaz, 2021).

These findings corroborate the current study's results, suggesting that land use and physiographic factors such as elevation and slope play a crucial role in shaping soil quality and degradation patterns in the Black Sea Region

Weights of indicators

The weights determined using the absolute values of the binary correlation coefficient are given below (Table 4). pH had the highest weight coefficient, followed by Pb, f, OM, FC, clay, sand, WP, EC, MWD, DR, AS, AR, and silt, respectively. Since the weight coefficient was determined by dividing the absolute value of the correlation coefficient of each property by the total correlation absolute value, the weighting values were in the same order (Table 5).

Table 4.
Absolute values of correlation coefficients were obtained from Pearson correlation analysis performed among soil properties.

Indicator	Clay	Silt	Sand	AR	AS	MWD	P_b	DR	F	FC	WP	OM	EC	pH
Clay		0.13	0.63	0.38	0.31	0.35	0.29	0.28	0.27	0.12	0.04	0.29	0.36	0.53
Silt	0.13		0.62	0.07	0.05	0.03	0.13	0.36	0.1	0.17	0.1	0.1	0.1	0.11
Sand	0.63	0.62		0.32	0.25	0.27	0.13	0.51	0.16	0.01	0.1	0.17	0.18	0.32
AR	0.38	0.07	0.32		0.02	0.27	0.23	0.05	0.22	0.37	0.51	0.13	0.06	0,02
AS	0.31	0.05	0.25	0.02		0.22	0.31	0.04	0.1	0.19	0.03	0.27	0.44	0.45
MWD	0.35	0.03	0.27	0.27	0.22		0.26	0.48	0.28	0.04	0.04	0.1	0.29	0.38
BD	0.29	0.13	0.13	0.23	0.31	0.26		0.11	0.83	0.65	0.57	0.65	0.33	0.69
DR	0.28	0.36	0.51	0.05	0.04	0.48	0.11		0.22	0.02	0.03	0.13	0.23	0.25
f	0.27	0.1	0.16	0.22	0.1	0.28	0.83	0.22		0.48	0.43	0.5	0.21	0.54
FC	0.12	0.17	0.01	0.37	0.19	0.04	0.65	0.02	0.48		0.81	0.62	0.2	0.52
WP	0.04	0.1	0.1	0.51	0.03	0.04	0.57	0.03	0.43	0.81		0.6	0.01	0.37
OM	0.29	0.1	0.17	0.13	0.27	0.1	0.65	0.13	0.5	0.62	0.6		0.16	0.57
EC	0.36	0.1	0.18	0.06	0.44	0.29	0.33	0.23	0.21	0.2	0.01	0.16		0.52
pH	0.53	0.11	0.32	0.02	0.45	0.38	0.69	0.25	0.54	0.52	0.37	0.57	0.52	
∑	3.98	2.07	3.67	2.65	2.68	3.01	5.18	2.71	4.34	4.20	3.64	4.29	3.09	5.27

$$\sum = \mathbf{50.78}$$

AR: aggregation rate; AS: aggregate stability; MWD: mean weight diameter; BD: bulk density; DR: dispersion rate; f: porosity; FC: field capacity; WP: wilting point; OM: organic matter content; EC: electrical conductivity.

Table 5.
Total correlation coefficients of indicators calculated with absolute values of correlation coefficients, and weights of indicators.

Indicator	Σ correlation coefficient	Weight of indicator	Indicator	Σ correlation coefficient	Weight of indicator
Clay	3.98	0.078	DR	2.71	0.053
Silt	2.07	0.041	f	4.34	0.085
Sand	3.67	0.072	FC	4.20	0.083
AR	2.65	0.052	WP	3.64	0.072
AS	2.68	0.053	OM	4.29	0.084
MWD	3.01	0.059	EC	3.09	0.061
BD	5.18	0.102	pH	5.27	0.104

AR: aggregation rate; AS: aggregate stability; MWD: mean weight diameter; BD: bulk density; DR: dispersion rate; f: porosity; FC: field capacity; WP: wilting point; OM: organic matter content; EC: electrical conductivity.

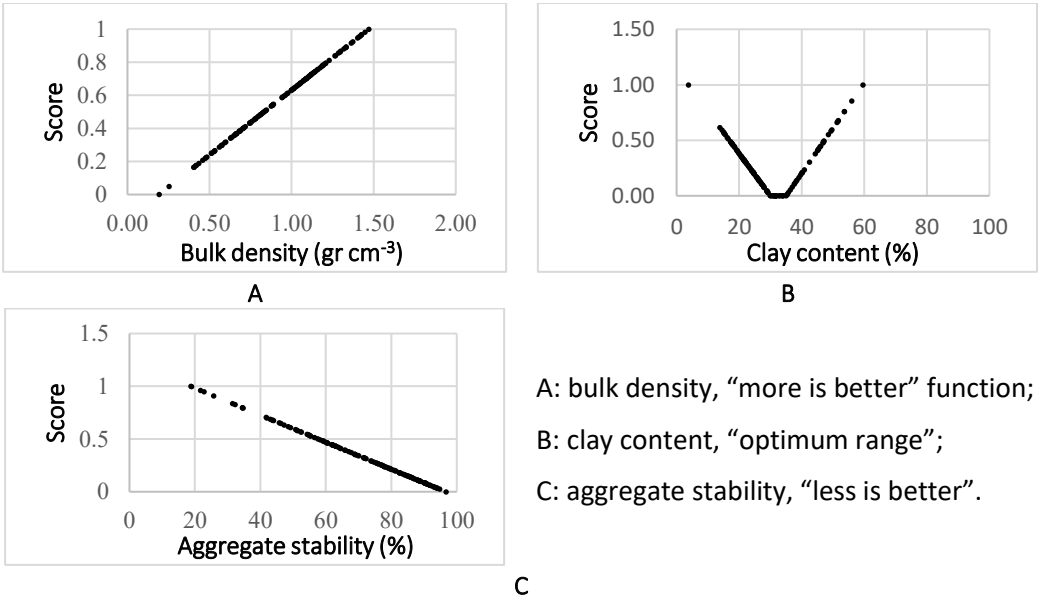
Scores of indicators

The scores were calculated for each indicator using the functions specified in methods. Here are examples of functions (more is better, optimum range, and less is better) used (Figure 4).

Soil Degradation Index

The SDI varied between 0.297 and 0.620 in the basin. According to the values obtained by the ratio of SDI classes to the whole area, SDI values in the range of 0.422–0.455 were seen to be the most common class, followed by 0.389–0.422, 0.455–0.488, 0.356–0.389, and 0.323–0.356, respectively (Figure 5). It can be said that a significant portion of the basin land (95%) is below 0.5 on the 0–1 scale (Figure 6). This indicates that while soil degradation is present, it has not yet reached critical levels in most parts of the basin.

Similar SDI distributions were reported by Yılmaz and Korkanç (2021) in the Devrekani Basin (Kastamonu), where over 85% of the land had SDI values below 0.6. Their study also found that agricultural practices and topographic position were the major drivers of spatial variability in degradation. Likewise, in the Arhavi watershed (Artvin), Gürsoy and Şahin (2020) identified low to moderate SDI values predominantly in forest and pasture lands, but observed significant increases in SDI in settlement and agriculture-dominated zones. These studies emphasize that although natural landscapes maintain relatively better soil quality, human-induced activities such as tillage and deforestation markedly elevate SDI levels.



A: bulk density, “more is better” function;

B: clay content, “optimum range”;

C: aggregate stability, “less is better”.

Figure 4.
Graphs show the relationship between the measurement values of the indicators and the score values calculated with linear functions.

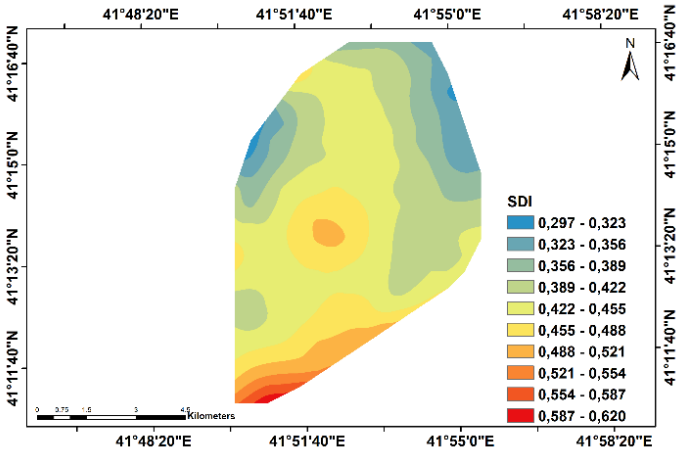


Figure 5.
Spatial distribution map of soil degradation index in Godrahav watershed.

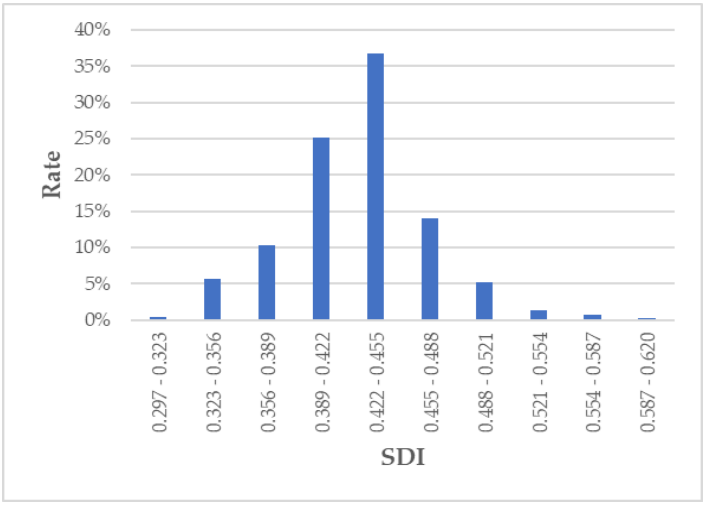


Figure 6.
Proportions of Soil degradation index (SDI) classes in Godrahav watershed

The consistency of SDI values with findings from different parts of the Black Sea region confirms that basin-specific factors such as slope, vegetation cover, and land management practices play crucial roles in soil degradation processes (Aydın & Kara, 2019; Yıldız et al., 2017).

To understand the reasons for the change of the SDI in the study area, it was associated with the watershed characteristics, such as land use differences, topographic factors, and cover rate.

The effect of land use on SDI

The first watershed characteristic that affects the SDI is the differences in land use. The area with the highest SDI is the settlement (0.54) followed by the waterside (0.53) used for recreational activities. These areas are followed by agriculture (0.46), forest (0.43) and meadow (0.39), respectively (Figure 7). Human settlement activities are often associated with land degradation through the depletion of essential soil nutrients (e.g., nitrogen, phosphorus) and the accumulation of pollutants such as heavy metals and other chemical residues (Asare et al., 2021; Fenger-Nielsen et al., 2019; Šmejda et al., 2018). Management practices such as soil tillage and field traffic in the agricultural areas lead to negative changes in soil properties (Poesen, 2018; Tian et al., 2023; Wang et al., 2023) and an increase in SDI.

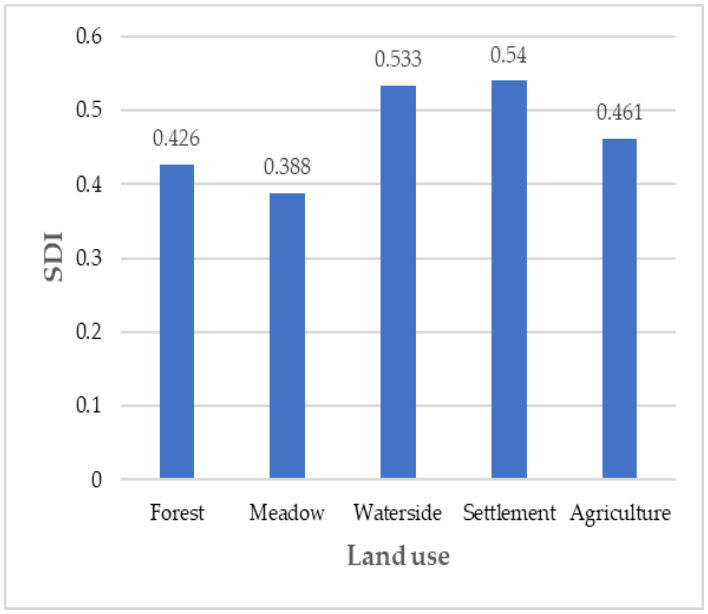


Figure 7.
Variation of the soil degradation index (SDI) in the study area according to land use.

Factors causing soil degradation in the forest are reduction in plant cover, decrease in soil fertility, weak soil structure, erosion, recurrent forest fire, and reduction of beneficial microorganisms (Bax & Francesconi, 2018; Guo et al., 2019; Navarro Rau et al., 2023; Roth et al., 2023; Sabogal, 2012). The low human activities in the forest of the study area have prevented these factors. For this reason, it is expected that the SDI will be low in this area. The same situation has been observed in meadow areas, the low grazing pressure has prevented the negative changes in the soil properties, and accordingly, the SDI is also placed in the low class.

According to this result, land use practices can significantly impact soil degradation, leading to changes in soil degradation indices (Buraka et al., 2023; Leul et al., 2023; Zahedifar, 2023). Like our results, the researchers report that the soil degradation problem was less common in forest and meadow areas than agricultural fields (Kidron et al., 2010; Leul et al., 2023; Moebius-Clune et al., 2011; Yousefi et al., 2016; Zhang et al., 2019).

The effect of altitude on SDI

Altitude constitutes another watershed characteristic that exerts an influence on the Soil Degradation Index (SDI). As altitude increases across the watershed (Figure 8), a concomitant reduction is observed in the SDI values. The regions characterized by lower altitudes within the watershed exhibit a heightened susceptibility to human activities such as settlements and recreation due to their enhanced accessibility. Consequently, these areas are marked by the presence of settlements and extensive agricultural fields. Conversely, the areas dominated by forest and meadows situated at higher altitudes remain relatively less accessible, playing a pivotal role in the preservation of their innate natural attributes. Within these elevated natural zones, distinguished by their high altitudes, the soil demonstrates a noteworthy organic matter content as well as significant total nitrogen levels, finer soil texture, and a more stable aggregate structure (Mujiyo et al., 2022; Zhu et al., 2020). Consequently, soil degradation in these elevated natural areas is notably limited Our results are consistent with previous studies that reported a gradual increase in soil degradation from higher to lower altitudes (Wang et al., 2020).

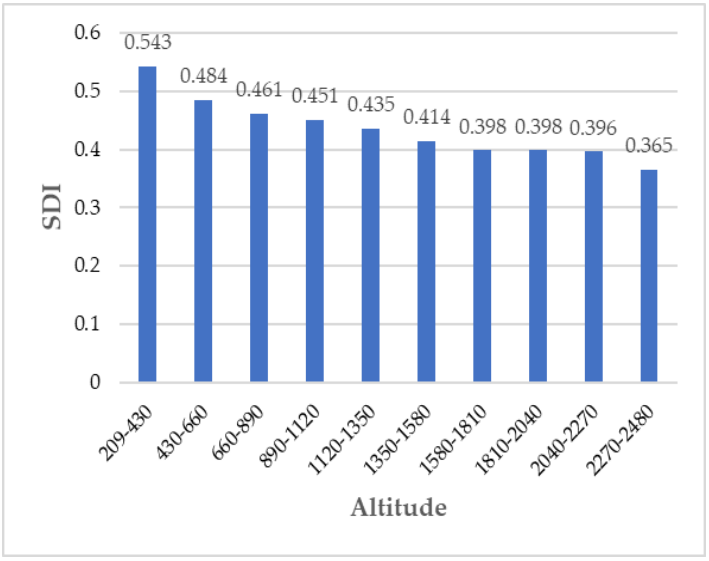


Figure 8.
Variation of the soil degradation index (SDI) in the study area according to altitude.

The effect of slope on SDI

The SDI values exhibited variations based on the gradient of slopes within the research area. The alteration in SDI with respect to distinct slope categories is illustrated in Figure 9. Corresponding to an escalating incline across the watershed, a progressive decrease in SDI is observed. The 0-18 slope class yielded the highest SDI value (0.439), whereas the >100 slope class displayed the lowest value (0.422) (Figure 9). This disparity can be attributed to the infrequent occurrence of human activities in rugged terrains. Consequently, these steep terrains are predominantly covered by forests, thereby affording protection against soil erosion (Šamonil et al., 2023; Wiśniewski & Märker, 2019) and losing organic matter content (Pan et al., 2023). Erosion, a well-acknowledged agent of environmental degradation (Wiśniewski & Märker, 2019), is mitigated through this natural safeguard.

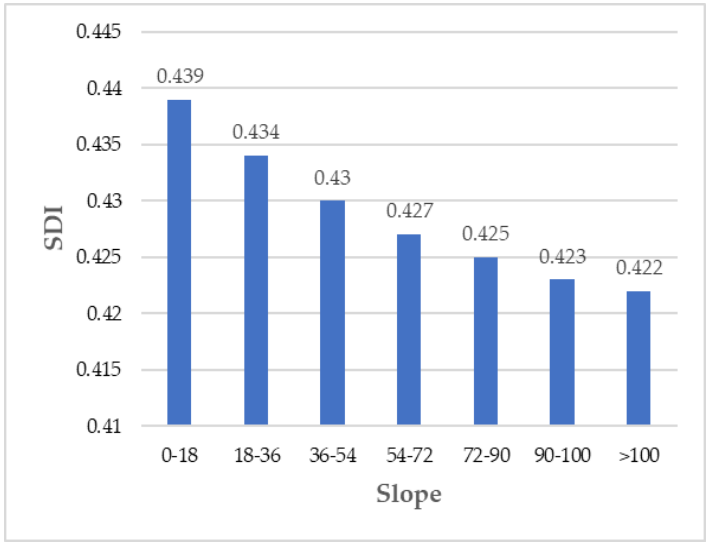


Figure 9.
Variation of the soil degradation index (SDI) in the study area according to the slope.

The effect of aspect on SDI

SDI showed variability across different aspects within the watershed. The most elevated SDI values were observed in east-facing regions, contrasting with the lowest values recorded in northeast-facing areas. Stated differently, throughout the watershed, shaded zones exhibited lower SDI values compared to sun-exposed areas (Figure 10). This phenomenon can be attributed to the augmented vegetation density on the northern and western facets of the land, resulting from diminished evaporation rates (Griffiths et al., 2009; Han et al., 2022). Greater vegetation density is associated with increased levels of organic matter and clay content, primarily attributed to reduce erosion rates (Tian et al., 2023). Consequently, it is normal for regions displaying lower Soil Degradation Index (SDI) values in the northern and western peripheries of the study area to exhibit broader spatial coverage. Although it varies depending on the climate and land use, this is a common phenomenon, as supported by our findings, and aligns with previous research (Lenka et al., 2013), which also reported diminished degradation parameters in north-facing areas.

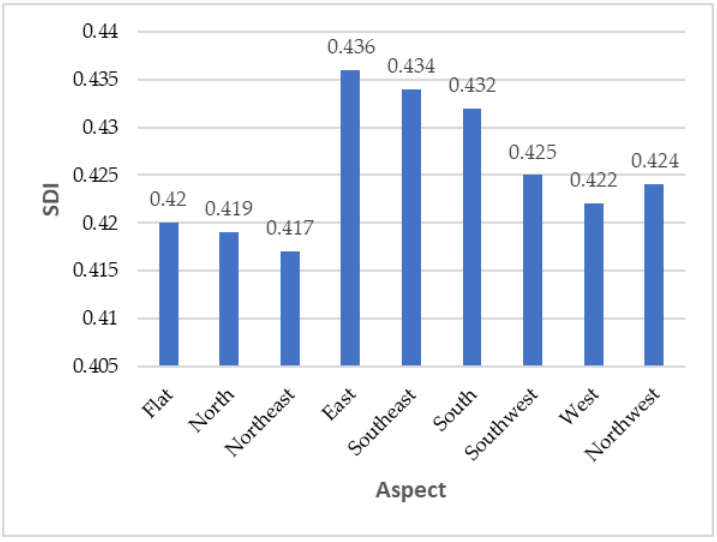


Figure 10.
Variation of the soil degradation index (SDI) in the study area according to the aspect.

Conclusion

While this study provides a comprehensive framework for assessing soil degradation through the Soil Degradation Index (SDI), it lacks a clear articulation of practical recommendations for decision makers. Identifying degraded zones is valuable, yet the study could be strengthened by translating these findings into actionable land management strategies. For instance, in areas with high SDI values, specific restoration techniques such as organic matter amendment, conservation tillage, or afforestation could be suggested. Moreover, land use planning decisions could benefit from prioritizing conservation in highly degraded areas and limiting intensive agriculture or construction in zones with vulnerable soils.

Additionally, the study does not fully address the limitations of the SDI approach. One key limitation is the potential subjectivity in assigning weights to soil parameters, even when supported by correlation analysis. The empirical scoring functions, though useful, may not fully capture the complexity and interactions of soil processes across diverse landscapes. To improve robustness, future studies could incorporate machine learning algorithms or multi-criteria decision analysis (MCDA) to refine parameter weighting and scoring. Another limitation is the temporal static nature of the data; soil degradation is a dynamic process, and repeated sampling or remote sensing integration over time would allow for monitoring trends and evaluating the effectiveness of management interventions.In conclusion, while the SDI provides a valuable snapshot of soil health, future research should enhance its predictive and prescriptive power by integrating socio-economic factors, land management histories, and time-series data. This would help guide sustainable land use policies and adaptive management practices more effectively.

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Yazar Katkıları: SG ve BT, toprak örneklerinin alınmasında, laboratuvar analizlerinin yapılmasında, istatistiksel analizlerin gerçekleştirilmesinde ve makalenin yazım aşamasında, BT makalenin başvuru ve revizyon aşamalarında görev almıştır.
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References

Acir, N., Günal, H., Mutlu, N., Cankar, S., & Akyol, N. (2013) Drenaj Faaliyetleri Sonrası Kaz Gölü Çevresindeki Toprak Özellikleri ve Vejetasyonun Mesafeye Bağlı Değişimleri. III. National Soil and Water Resources Congress, 22-24 October 2013, Tokat, Türkiye.

Amundson, R., Berhe, A.A., Hopmans, J.W., Olson, C., Sztein, A.E & Sparks, D.L. (2015). Soil science. Soil and human security in the 21st century. *Science*, 348(126-1071). https://doi.org/10.1126/science.1261071

Asare, M.O., Ondřej, S., & Afriyie, J.O. (2021). Chemical properties and magnetic susceptibility as proxy indicators of past settlement activities on contemporary arable soil in the Czech Republic. *Geoderma Regional*, *24*, e00357. https://doi.org/https://doi.org/10.1016/j.geodrs.2021.e00357

Aydın, A., & Kara, F. (2019). Spatial assessment of land degradation using soil quality index: A case study from the Middle Black Sea Region. *Environmental Monitoring and Assessment*, *191*(5), 1–15. https://doi.org/10.1007/s10661-019-7390-3

Barcelos, J. P. de Q., de Souza, M., Nascimento, C. A. C. do, & Rosolem, C. A. (2022). Soil acidity amelioration improves N and C cycles in the short term in a system with soybean followed by maize-guinea grass intercropping. *Geoderma*, *421*, 115909. https://doi.org/10.1016/j.geoderma.2022.115909

Baul, T. K., Chowdhury, A. I., Uddin, M. J., Hasan, M. K., Kilpeläinen, A., Nandi, R., Karmakar, S., & Akhter, J. (2023). Effects of fragmentation and shifting cultivation on soil carbon and nutrients: A case study in Sitapahar forest, Bangladesh. *Rhizosphere*, *27*, 100756. https://doi.org/10.1016/j.rhisph.2023.100756

Bax, V., & Francesconi, W. (2018). Environmental predictors of forest change: An analysis of natural predisposition to deforestation in the tropical Andes region, Peru. *Applied Geography*, *91*, 99-110. https://doi.org/10.1016/j.apgeog.2018.01.002

Belton, V., & Stewart, T. J. (2002). *Multiple criteria decision analysis: An integrated approach*. Springer, Boston, MA, USA. http://dx.doi.org/10.4236/ajor.2016.64030

Blake, G. R., & Hartge, K. H. (1986). Bulk Density. In: Klute A (ed.). Methods of Soil Analysis Part I. *Physical and Mineralogical Methods*. Madison, WI, USA pp: 363-375. https://doi.org/10.2136/sssabookser5.1.2ed.c13

Blake, G. R., & Hartge, K. H. (1986). Bulk density. In A. Klute (Ed.), Methods of soil analysis: Part I. *Physical and mineralogical methods* (pp. 363–375). Madison, WI, USA: Soil Science Society of America. https://doi.org/10.2136/sssabookser5.1.2ed.c13

Buraka, T., Elias, E., & Lelago, A. (2023). Effects of land-use-cover-changes on selected soil physicochemical properties along slope position, Coka watershed, Southern Ethiopia. *Heliyon*, *9*(5), e16142. https://doi.org/10.1016/j.heliyon.2023.e16142

Cassel, D. K., & Nielsen, D. R. (1986). Field capacity and available water capacity. In A. Klute (Ed.), *Methods of soil analysis. Part I. Physical and mineralogical methods* (pp. 901–926). Madison, WI, USA: Soil Science Society of America. https://doi.org/10.2136/sssabookser5.1.2ed.c36

Cerretelli, S., Poggio, L., Gimona, A., Yakob, G., Boke, S., Habte, B., Coull, M., Peressotti, A., & Black, H. (2018). Spatial assessment of land degradation through key ecosystem services: The role of globally available data. *Science of the Total Environment*, 628-629, 539-555. https://doi.org/10.1016/j.scitotenv.2018.02.085

Danielson, R. E., & Sutherland, P. L. (1986). Porosity. In A. Klute (Ed.), Methods of soil analysis. Part I. *Physical and mineralogical methods* (pp. 443-461). Madison, WI, USA: Soil Science Society of America. https://doi.org/10.2136/sssabookser5.1.2ed.c18

Erdoğan Yüksel, E., & Yavuz, G. (2024). Evaluating the Soil Properties of Different Land Use Types in the Deviskel Watershed in the Hilly Region of Northeast Türkiye. *Sustainability (Switzerland)*, *16*(22). https://doi.org/10.3390/su16229732

FAO (Food and Agriculture Organization). (2020). Soil degradation. FAOSTAT. *FAO Database on food and agriculture*. United Nations Food and Agriculture Organization, Rome, Italy. Retrieved July 2021, from https://www.fao.org/soils-portal/soil-degradation-restoration/en/

Fenger-Nielsen, R., Hollesen, J., Matthiesen, H., Andersen, E. A. S., Westergaard-Nielsen, A., Harmsen, H., Michelsen, A., & Elberling, B. (2019). Footprints from the past: The influence of past human activities on vegetation and soil across five archaeological sites in Greenland. *Science of the Total Environment*, *654*, 895-905. https://doi.org/10.1016/j.scitotenv.2018.11.018

Gee, G., & Bauder, J. (1986). Particle size analysis. In A. Klute (Ed.), *Methods of soil analysis, Part I. Physical and mineralogical methods* (pp. 383-411). Madison, WI, USA: Soil Science Society of America. https://doi.org/10.2136/sssabookser5.1.2ed.c15

Griffiths, R. P., Madritch, M. D., & Swanson, A. K. (2009). The effects of topography on forest soil characteristics in the Oregon Cascade Mountains (USA): Implications for the effects of climate change on soil properties. *Forest Ecology and Management*, *257*, 1-7. https://doi.org/10.1016/j.foreco.2008.08.010

Guo, Y., Peng, C., Zhu, Q., Wang, M., Wang, H., Peng, S., & He, H. (2019). Modelling the impacts of climate and land use changes on soil water erosion: Model applications, limitations, and future challenges. *Journal of Environmental Management*, *250*, 109403. https://doi.org/10.1016/j.jenvman.2019.109403

Gürsoy, S., & Şahin, U. (2020). Assessment of soil degradation in Arhavi watershed using a soil quality index approach. *Turkish Journal of Agriculture - Food Science and Technology*, *8*(10), 2150-2157. https://doi.org/10.24925/turjaf.v8i10.2150-2157.3725

Güler, S. (2020). *Godrahav Havasında toprak bozulma katsayısındaki değişimin belirlenmesi* (Tez No: 636346). [Yüksek Lisans Tezi, Artvin Çoruh Üniversitesi]. YÖK Tez Merkezi.

Han, X., Liu, J., Shen, X., Liu, H., Li, X., Zhang, J., Wu, P., & Liu, Y. (2022). High relief yield strong topography-soil water-vegetation relationships in headwater catchments of southeastern China. *Geoderma*, *428*, 116214. https://doi.org/10.1016/j.geoderma.2022.116214

Hatfield, J. L., Sauer, T. J., & Cruse, R. M. (2017). *Soil: The forgotten piece of the water, food, energy nexus*. In Advances in Agronomy (pp. 1-46). Academic Press, Oxford, UK. https://doi.org/10.1016/bs.agron.2017.02.001

Hattori, D., Kenzo, T., Shirahama, T., Harada, Y., Kendawang, J. J., Ninomiya, I., & Sakurai, K. (2019). Degradation of soil nutrients and slow recovery of biomass following shifting cultivation in the heath forests of Sarawak, Malaysia. *Forest Ecology and Management*, *432*, 467-477. https://doi.org/10.1016/j.foreco.2018.09.051

Kemper, W. D., & Rosenau, R. C. (1986). Aggregate stability and size distribution. In A. Klute (Ed.), *Methods of Soil Analysis Part I. Physical and Mineralogical Methods* (pp. 425-442). Madison, WI, USA: Soil Science Society of America. https://doi.org/10.2136/sssabookser5.1.2ed.c17

Kidron, G. J., Karnieli, A., & Benenson, I. (2010). Degradation of soil fertility following cycles of cotton–cereal cultivation in Mali, West Africa: A first approximation to the problem. *Soil and Tillage Research*, *106*(2), 254-262. https://doi.org/10.1016/j.still.2009.11.004

Lenka, N. K., Sudhishri, S., Dass, A., Choudhury, P. R., Lenka, S., & Patnaik, U. S. (2013). Soil carbon sequestration as affected by slope aspect under restoration treatments of a degraded Alfisol in the Indian sub-tropics. *Geoderma*, 204–205, 120-130. https://doi.org/10.1016/j.geoderma.2013.04.009

Leul, Y., Assen, M., Damene, S., & Legass, A. (2023). Effects of land use types on soil quality dynamics in a tropical sub-humid ecosystem, western Ethiopia. *Ecological Indicators*, *147*, 110024. https://doi.org/10.1016/j.ecolind.2023.110024

Lorenz, K., Lal, R., & Ehlers, K. (2019). Soil organic carbon stock as an indicator for monitoring land and soil degradation in relation to United Nations' Sustainable Development Goals. *Land Degradation & Development*, *30*(7), 824–838. https://doi.org/10.1002/ldr.3270

McLean, E. O. (1983). Soil pH and lime requirement. In A. L. Page (Ed.), *Methods of Soil Analysis Part 2: Chemical and Microbiological Properties* (pp. 199-224). Madison, WI, USA: American Society of Agronomy. https://doi.org/10.2134/agronmonogr9.2.2ed.c12

Mo, L., Yang, H., Hou, R., Wu, W., Song, X., Yang, H., Yang, Z., Zheng, W., & Qi, D. (2023). Forest degradation caused by dwarf bamboo overabundance reduces soil C, N, and P stocks in giant panda habitat. *CATENA*, *231*, 107377. https://doi.org/10.1016/j.catena.2023.107377

Moebius-Clune, B. N., van Es, H. M., Idowu, O. J., Schindelbeck, R. R., Kimetu, J. M., Ngoze, S., Lehmann, J., & Kinyangi, J. M. (2011). Long-term soil quality degradation along a cultivation chronosequence in Western Kenya. *Agriculture, Ecosystems & Environment*, *141*, 86–99. https://doi.org/10.1016/j.agee.2011.02.018

Mujiyo Nariyanti, S., Suntoro, Herawati, A., Herdiansyah, G., Irianto, H., Riptanti, E. W., & Qonita, A. (2022). Soil fertility index based on altitude: A comprehensive assessment for the cassava development area in Indonesia. *Annals of Agricultural Sciences*, *67*(2), 158–165. https://doi.org/10.1016/j.aoas.2022.10.001

Navarro Rau, M. F., Calamari, N. C., & Mosciaro, M. J. (2023). Dynamics of past forest cover changes and future scenarios with implications for soil degradation in Misiones rainforest, Argentina. *Journal for Nature Conservation*, *73*, 126391. https://doi.org/10.1016/j.jnc.2023.126391

Nelson, D., & Sommers, L. E. (1983). Total carbon, organic carbon, and organic matter. In A. L. Page (Ed.), *Methods of Soil Analysis Part 2: Chemical and Microbiological Properties*. Madison, WI, USA: American Society of Agronomy. https://doi.org/10.2134/agronmonogr9.2.2ed.c29

Pan, S., Shi, J., Peng, Y., Wang, Z., & Wang, X. (2023). Soil organic carbon pool distribution and stability with grazing and topography in a Mongolian grassland. *Agriculture, Ecosystems & Environment*, *348*, 108431. https://doi.org/10.1016/j.agee.2023.108431

Poesen, J. (2018). Soil erosion in the Anthropocene: Research needs. *Earth Surface Processes and Landforms*, *43*(1), 64–84. https://doi.org/10.1002/esp.4250

Qiao, X., Li, Z., Lin, J., Wang, H., Zheng, S., & Yang, S. (2023). Assessing current and future soil erosion under changing land use based on InVEST and FLUS models in the Yihe River Basin, North China. *International Soil and Water Conservation Research*. https://doi.org/10.1016/j.iswcr.2023.07.001

Rabot, E., Wiesmeier, M., Schlüter, S., & Vogel, H. J. (2018). Soil structure as an indicator of soil functions: A review. *Geoderma*, *314*, 122–137. https://doi.org/10.1016/j.geoderma.2017.11.009

Rhoades, J. D. (1983). Soluble salts. In A. L. Page (Ed.), *Methods of soil analysis: Part 2. Chemical and microbiological properties* (pp. 933–951). Madison, WI, USA: American Society of Agronomy. https://doi.org/10.2134/agronmonogr9.2.2ed.c10

Roth, E. M., Karhu, K., Koivula, M., Helmisaari, H. S., & Tuittila, E. S. (2023). How do harvesting methods applied in continuous-cover forestry and rotation forest management impact soil carbon storage and degradability in boreal Scots pine forests? *Forest Ecology and Management*, *544*, 121144. https://doi.org/10.1016/j.foreco.2023.121144

Sabogal, C. (2012). Site-level rehabilitation strategies for degraded forest lands. In J. Rietbergen-McCracken, S. Maginnis, & A. Sarbe (Eds.), *The Forest Landscape Restoration Handbook* (pp. 109–118). Earthscan, London, UK.

Scanes, C. G. (2018). Impact of agricultural animals on the environment. In C. G. Scanes (Ed.), *Animals and human society* (pp. 427-449). Academic Press. https://doi.org/10.1016/C2014-0-03860-9

Šamonil, P., Jaroš, J., Daněk, P., Tikhomirov, D., Novotný, V., Weiblen, G., Christl, M., & Egli, M. (2023). Soil erosion affected by trees in a tropical primary rainforest, Papua New Guinea. *Geomorphology*, *425*, 108589. https://doi.org/10.1016/j.geomorph.2023.108589

Šmejda, L., Hejcman, M., Horák, J., & Shai, I. (2018). Multi-element mapping of anthropogenically modified soils and sediments at the Bronze to Iron Ages site of Tel Burna in the southern Levant. *Quaternary International*, *483*, 111-123. https://doi.org/10.1016/j.quaint.2017.11.005

Tian, M., Whalley, W. R., Zhou, H., Ren, T., & Gao, W. (2023). Does no-tillage mitigate the negative effects of harvest compaction on soil pore characteristics in Northeast China? *Soil and Tillage Research*, *233*, 105787. https://doi.org/10.1016/j.still.2023.105787

Turgut, B., & Ateş, M. (2017). Factors of soil diversity in the Batumi Delta (Georgia). *Solid Earth*, *8*, 1-12. https://doi.org/10.5194/se-8-1-2017

Wang, J., Wei, H., Cheng, K., Ochir, A., Davaasuren, D., Li, P., Shun Chan, F. K., & Nasanbat, E. (2020). Spatio-temporal pattern of land degradation from 1990 to 2015 in Mongolia. *Environmental Development*, 100497. https://doi.org/10.1016/j.envdev.2020.100497

Wang, Q., Zhang, S., Zhang, M., Liu, P., McLaughlin, N. B., Jia, S., Chen, X., Zhang, Y., & Liang, A. (2023). Soil biotic associations play a key role in subsoil C mineralization: Evidence from long-term tillage trial in the black soil of Northeast China. *Soil and Tillage Research*, *234*, 105859. https://doi.org/10.1016/j.still.2023.105859

Wilding, L. P., & Drees, L. R. (1983). Spatial variability and pedology. In L. P. Wilding, N. E. Smeck, & G. F. Hall (Eds.), *Pedogenesis and soil taxonomy I: Concepts and interactions* (pp. 83-116). Elsevier, Amsterdam.

Wiśniewski, P., & Märker, M. (2019). The role of soil-protecting forests in reducing soil erosion in young glacial landscapes of Northern-Central Poland. *Geoderma*, *337*, 1227-1235. https://doi.org/10.1016/j.geoderma.2018.11.035

Yılmaz, M., & Dengiz, O. (2021). Bazı toprak özellikleri İle İlişkili olarak arazi kullanımı ve arazi örtüsünün toprak organik karbon stokuna etkisi. *Türkiye Tarımsal Araştırmalar Dergisi*, *8*(2), 154-167.

Yılmaz, R., & Korkanç, S. Y. (2021). Evaluation of soil degradation index and its relationship with land use and topography in Devrekani Basin. *Anadolu University Journal of Science and Technology - C Life Sciences and Biotechnology, 11*(2), 397-408.

Yıldız, O., Temizel, İ., & Günal, H. (2017). Determination of soil quality index in different land use types: A case from Black Sea region, Turkey. *Catena, 156*, 19–28. https://doi.org/10.1016/j.catena.2017.03.020

Yousefi, S., Moradi, H., Boll, J., & Schönbrodt-Stitt, S. (2016). Effects of road construction on soil degradation and nutrient transport in Caspian Hyrcanian mixed forests. *Geoderma*, *284*, 103-112. https://doi.org/10.1016/j.geoderma.2016.09.002

Zahedifar, M. (2023). Assessing alteration of soil quality, degradation, and resistance indices under different land uses through network and factor analysis. *CATENA*, *222*, 106807. https://doi.org/10.1016/j.catena.2022.106807

Zhang, Y., Zhang, G., Pan, J., Fan, Z., Chen, F., & Liu, Y. (2019). Soil organic carbon distribution in relation to terrain and land use: A case study in a small watershed of Danjiangkou Reservoir Area, China. *Global Ecology and Conservation*, *20*, e00731. https://doi.org/10.1016/j.gecco.2019.e00731

Zhang, S., Sun, L., Jamshidi, A. H., Niu, Y., Fan, Z., Zhang, H., & Liu, X. (2022). Assessment of the degree of degradation of sloping cropland in a typical black soil region. *Land Degradation and Development*, *33*(13), 2220-2230. https://doi.org/10.1002/ldr.4255

Zhang, W. C., Wu, W., Li, J. W., & Liu, H. B. (2023). Climate and topography controls on soil water-stable aggregates at regional scale: Independent and interactive effects. *CATENA*, *228*, 107170. https://doi.org/10.1016/j.catena.2023.107170

Zhu, M., Yang, S., Ai, S., Ai, X., Jiang, X., Chen, J., Li, R., & Ai, Y. (2020). Artificial soil nutrient, aggregate stability, and soil quality index of restored cut slopes along altitude gradient in Southwest China. *Chemosphere*, *246*, 125687. https://doi.org/10.1016/j.chemosphere.2019.125687

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The Current Situation, Problems and Proposed Solutions of Aquarium Businesses in Erzurum Province

Erzurum İlinde Yer Alan Akvaryum İşletmelerinin Mevcut Durumu, Sorunları ve Çözüm Önerileri

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ABSTRACT

This research was conducted to reveal the general situation of aquarium businesses operating in Erzurum, identify current problems and propose solutions to these issues. It was observed that the 10 active aquarium businesses in the province were concentrated in three central districts. A questionnaire, consisting of both open-ended and closed-ended questions tailored to the research objectives, was administered to these 10 businesses through face-to-face interviews. The research findings indicated that 60% of the aquarium businesses were tenants, all personnel were male, the owners were older and more experienced than the employees, and 70% of them were university graduates. It was determined that all operators sourced their fish domestically, made retail sales, experienced an increase in sales during the winter months, sold a total of 9 fish species, with Japanese (*Carassius auratus*) and guppy (*Poecilia reticulata*) fish being the most sold, and that the most common disease observed was white spot disease, affecting 80% of the fish. The majority of operators (60%) stated that aquarium cooperatives should be established. Among the most significant problems identified were high feed and material costs, high rent and electricity expenses, and low customer demand. In light of the data obtained, it has been concluded that organizing activities to increase interest in the aquarium sector nationwide and providing financial and educational support to entrepreneurs by public institutions and universities would be beneficial for the development of the sector and the resolution of existing problems.

Keywords: Aquarium fish, Business, Erzurum, Retail sales, Survey

ÖZ

Bu araştırma, Erzurum'da faaliyet gösteren akvaryum işletmelerinin genel durumunu ortaya koymak, mevcut sorunlarını tespit etmek ve bu sorunlara çözüm önerileri sunmak amacıyla yapılmıştır. İlde yer alan ve aktif durumda olan 10 adet akvaryum işletmesinin üç ilçede toplandığı görülmüştür. Bu 10 adet işletmeye yüz yüze görüşme yöntemi ile amaca uygun hazırlanmış açık ve kapalı uçlu sorulardan oluşan anket uygulanmıştır. Araştırma sonunda akvaryum işletmelerinin %60'ının kiracı olduğu, personelin tamamının erkek olduğu, işletme sahiplerinin çalışanlardan yaşça büyük, tecrübeli ve %70'inin üniversite mezunu oldukları belirlenmiştir. İşletmecilerin tamamının sattıkları balıkları yurt içinden temin ettiği, perakende satış yaptıkları, kış aylarında satışların arttığı, toplam 9 tür balık satışı yapıldığı ve en çok satılan türlerin Japon (*Carassius auratus*) ve lepistes (*Poecilia reticulata*) balığı olduğu ve en fazla beyaz benek hastalığının (%80) görüldüğü tespit edilmiştir. İşletmecilerin çoğunluğu akvaryum kooperatifçiliğinin kurulması gerektiğini (%60), en önemli sorunları arasında; yem ve malzeme maliyetleri ile kira ve elektrik giderlerinin yüksek olduğunu, müşteri talebinin ise düşük olduğunu belirlenmiştir. Sektörün gelişebilmesi ve mevcut sorunların çözülebilmesi için ülke genelinde akvaryum sektörüne ilgi artırılmalı, girişimciler desteklenerek süs balığı üretimine yönlendirilmeli ve bu konuda dışa olan bağımlılık azaltılmalıdır.

Anahtar Kelimeler: Akvaryum balığı, İşletme, Erzurum, Perakende satış, Sürvey

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Introduction

Today, aquariums range from small glass bowls in our homes to massive public aquariums (Göreci & Demirarslan, 2021). Ornamental fish attract people's attention with their vibrant colors, different shapes, patterns, and behaviors (Shraborni et al., 2024). For all these reasons, the aquarium hobby is among the preferred hobbies in the world (Sharma, 2020; Shraborni et al., 2024). Although aquarium hobbies are considered as a leisure activity, it is a sector that covers 125 countries in the world and has a trade volume of approximately 15-30 billion US dollars every year (Evers et al., 2019). Aquarium businesses offer both domestic and international market opportunities, contribute foreign exchange to the country, and provide employment opportunities for thousands of people (Anjur et al., 2021; Wijaya & Huda, 2021).

The global ornamental fish industry generates approximately 333 million USD in revenue, including export and import activities, and trades more than 2 billion live ornamental fish (Satam et al., 2018; Raja et al., 2019;Willis & Bakuwel, 2018). The leading importers of ornamental fish in the world are the USA, the UK, Japan, Germany, Belgium, China, and Australia (Yue, 2019; Sharma, 2020). According to ITC 2020 data, in 2018, 82 countries exported freshwater aquarium fish, while 130 countries imported them. The top three countries in freshwater aquarium fish exports were Japan (39.4 million USD), Singapore (36.8 million USD), and Indonesia (24.6 million USD), with a total export value of 251 million USD (ITC, 2020).

In Türkiye, although the history of the aquarium hobby dates back to the 1960s, it is known that the first fish farming facility for aquarium fish was established in the 1980s (Tolon & Emiroğlu, 2014). Imports began in 1989, and over time, both species diversity and price competition emerged (Tolon & Emiroğlu, 2014). Looking at Türkiye's aquarium fish import rankings, it is ranked 42nd in freshwater species and 37th in marine species (ITC, 2020).

Previously, aquarium shops were only seen in large cities, but in recent years, they have spread to provinces and districts (Özlüer Hunt & Koca, 2014). There is a need for accurate, reliable, and systematic information about the number, capacity, fish species, sales status, and staff characteristics of aquarium businesses in Türkiye (Kılıçerkan & Çek, 2011). Profiling aquarium businesses and identifying their needs and deficiencies is important. This way, the necessary steps for the development of the sector can be determined, and a perspective can also be created. In this context, survey studies conducted by provinces and regions are highly important. In this context, the aim of this research is to determine the current status of aquarium businesses in Erzurum, identify their structural characteristics and available resources, analyze the problems they face, and propose solutions.

Methods

The data utilized in the study originated from aquarium enterprises that sell live fish and are registered with the Erzurum Provincial Directorate of Agriculture and Forestry. While there are 11 aquarium businesses registered with the Provincial Directorate of Agriculture and Forestry in Erzurum, 10 of them are actively operating. Data were collected from these 10 businesses, located in the central districts of Aziziye, Palandöken, and Yakutiye, using the survey method. A questionnaire, consisting of both open-ended and closed-ended questions tailored to the research objectives, was conducted through face-to-face interviews. The questionnaire covered topics such as the structural characteristics of the businesses, fish species, water quality, diseases, aquariums, feeding, encountered problems, and marketing. Before the surveys were conducted, necessary explanations regarding the purpose of the survey and its content were provided. The responses given by business owners and employees to the questions were recorded by the surveyors on the questionnaire forms. The data obtained in the study were analyzed using the Microsoft Excel software, with percentages calculated and interpreted in tables and graphs.

All applicable international, national, and institutional guidelines for the care and use of animals were followed. This study was approved by the Social and Human Sciences Ethics Committee of Ordu University (Ethics approval number: 2024-161, Date: 30/10/2024). Consent was obtained from all participants in the study.

Results and Discussion

The investigation revealed that aquarium enterprises registered with the Erzurum Provincial Directorate of Agriculture and Forestry were mainly located in three central districts, with no aquarium firms present in other districts. When the general distribution of the 10 aquarium businesses in Erzurum province was examined; it was determined that 80% were located in Yakutiye, 10% in Aziziye, and 10% in Palandöken. Evaluating the entire province, it is clear that aquarium businesses are not located in the center, but are instead found in three districts with large populations. In the research carried out Pala and Yılmaz (2020), it was determined that

aquarium enterprises were predominantly situated in areas with elevated population densities and greater economic development. Conversely, Olgunoğlu et al. (2021) reported that 70% of these businesses were established in the central and most populous district of the province. Bulut and Özcan (2022) also reported that nearly all the businesses were located in the city center.

In the study, it was found that 60% of the aquarium businesses were established between 2011 and 2018, while 40% were established between 2019 and 2023. It was also determined that 30% of the businesses were property owners, while a large proportion (70%) were tenants (Figure 1). The ownership status of the businesses has also been identified as predominantly tenant-based (73-94%) in previous studies (Table 1) (Bulut & Özcan, 2022; Büyüktaş & Kızak, 2018; Çelik et al., 2010; Hekimoğlu et al., 2005; Olgunoğlu et al., 2021; Özlüer Hunt & Koca, 2014; Pala & Yılmaz, 2020). Additionally, it has been reported that rental expenses were among the significant costs for these businesses (Bulut & Özcan, 2022; Olgunoğlu et al., 2021; Pala & Yılmaz, 2020).

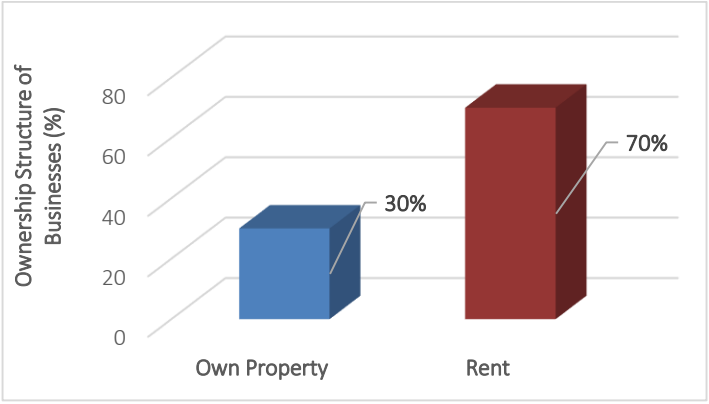

Figure 1.
Ownership structure of aquarium businesses

The study found that 100% of aquarium business owners did not have any other source of income. In previous studies, it has been reported that business owners provided their livelihoods with the income from aquarium business at varying rates such as 47% (Hekimoğlu et al., 2005), 62.1% (Çelik et al., 2010), 78.3% (Özlüer Hunt & Koca, 2014), 100% (Büyüktaş & Kızak, 2018), 82% (Pala & Yılmaz, 2020), 80% (Olgunoğlu et al., 2021), 93% (Bulut & Özcan, 2022).

When looking at the gender ratios in the enterprises, it was determined that all of the business owners and employees (100%) were male. In previous studies, it was reported that all of the staff were male at high rates, ranging from 85.7% to 100% (Bulut & Özcan, 2022; Büyüktaş & Kızak, 2018; Çelik et al., 2010; Hekimoğlu et al., 2005; Kılıçerkan & Çek, 2011; Olgunoğlu et al., 2021; Özlüer Hunt & Koca, 2014; Pala & Yılmaz, 2020), and the results are presented in Table 1.

An analysis of the results from previous studies and the current study on women's employment, as shown in Table 1, reveals that the Black Sea Region has the highest number of female employees, while the Southeastern Anatolia Region has the lowest. According to the results of the Turkish Statistical Institute (TURKSTAT) Household Labour Force Survey, the highest female employment rate in 2022 was in TR90 (Trabzon, Ordu, Giresun, Rize, Artvin, Gümüşhane) region with 37.4% and the lowest female employment rate was in TRC3 (Mardin, Batman, Şırnak, Siirt) region with 18.2%, and this result coincides with the findings of the study (TURKSTAT, 2022). In the studies conducted on aquarium establishments in our country, the average rate of female employees is 6.7% and it is seen that female employment in this sector is quite low. In addition, Ayta and Şen (2023), in their study on the general outlook of women's employment in Türkiye, reported that Türkiye lags behind all EU and OECD countries in women's employment and labour force participation rates.

Data on the ages and work experiences of aquarium business owners and employees are shown in Table 2. It was determined that the average age of the business owners was 37 years and 14 years of experience, while the average age of the employees was 28 years and 8 years of experience. Analysis of the data from previous studies in Table 1 indicates that business owners possess greater age and experience compared to employees (Hekimoğlu et al., 2005; Özlüer Hunt & Koca, 2014; Pala & Yılmaz, 2020).

Analysis of Table 3, which presents the educational status of the business owners and employees, reveals that 70% of business owners are university graduates, whereas all employees possess high school diplomas. In this study, it was determined that 12% of all personnel were primary school graduates, 47% were high school graduates and 41% were university graduates. Büyüktaş and Kızak (2018) reported in their study on enterprises located on the European side of Istanbul that a very low rate of 2% of aquaculture engineering graduates operate in the sector and that this low rate causes the failure of information transfer to the customer and the decrease in the amount of sales.

The data on the educational status of enterprise owners and employees in previous studies are given in Table 1. Analysis of prior studies reveals that high school graduates represent the highest rates, while primary school graduates present the lowest rates (Çelik et al., 2010; Hekimoğlu et al., 2005; Özlüer Hunt & Koca, 2014; Pala & Yılmaz, 2020). Unlike other studies, the highest rate of university graduates was found in this study.

Table 1.
General overview of the results of studies conducted with aquarium businesses in various provinces of Türkiye.

References	City	Number of Businesses	Rent Status (%)	Being the Primary Source of Income (%)	Female/Male Ratio (%)	Business Owners Average Age/Experience (years)	Employees Average Age/Experience (years)	Education Status (Primary School-High School-University Graduate Rate) (%)	Fish Supply Location (Domestic-International-Both) (%)	Winter Sales Rate (%)	Disease (White Spot-Fungus-Other)	Cooperative (Positive-Negative) View Rate (%)
Current study	Erzurum	10	70	100	100	37/14	28/8	12 -* 47 - 41	100 - -	62	80 - 20 - 0	60 - 40
Hekimoğlu et al., (2005)	İzmir (Center)	34	79	47	6/94	38/14	31/7	21 - 53 - 26	44-3-53	67	32 - 49 - 19	-
Çelik et al., (2010)	İstanbul	19	88.1	62.1	10.1/89.9	-		32.7 - 38.2 -29.1	12 -21-67	90.9	-	-
Kılıçerkan & Çek, (2011)	Hatay	31	-	-	7.1/92.9	-		-	-	-	90 (WS+F)-10	55 - 45
Özlüer Hunt & Koca, (2014)	Mersin (Center)	23	82.4	78.3	5/95	33/11.4	27/5.3	40 - 47.5 - 12.5	-	65.3	70 (WS+F)-30	-
Büyüktaş & Kızak, (2018)	İstanbul (European side)	52	94	100	5/95	-		-	-	-	-	-
Pala & Yılmaz, (2020)	Ordu	11	73	82	13/87	43/10	27/4	46.6 - 46.6 - 6.6	91 - 9	55	45 - 50 - 5	73 - 27
Olgunoğlu et al., (2021)	Adıyaman	10	80	80	100	36.57/10+		-	90 - -	-	-	-
Bulut & Özcan, (2022)	Elazığ	14	93	93	14.3/85.7	-	-	-	-	-	-	-

* The "–" sign in the table indicates that there is no data for the relevant section.

Table 2.
Age and work experience of the owner and employees (years)

	Business Owner		Business Employee	
	Age	Experience	Age	Experience
Minimum	24	10	20	3
Maximum	52	25	57	27
Average	37	14	28	8
Standart deviation	7.26	5.35	10.73	7.21

Table 3.
Educational status of aquarium business owners and employees

	Education Status		
	Primary School+ High School	University	Total
Owner	3	7	10
Employee	7	-	7
Total	10	7	17

In the study, it was determined that none of the aquarium businesses sold live plants, and all of the fish sold by the businesses (100%) were obtained from domestic markets. Table 1 shows the fish supply locations of previous studies. When the data are analysed, it is seen that the rate of domestic fish procurement is higher in this study than the other studies.

The fish species offered for sale by the enterprises are goldfish, guppy, swordtail, moli, dolphin cichlid, scavenger, stingray, gourami and beta fish. The fish species sold in the enterprises and the average monthly fish sales of the enterprises are given in Table 4. Looking at the enterprises in general, it was determined that a total of 9 species of fish were sold, the most sold species was goldfish, followed by guppy in the second place, and the least sold species was gourami. This finding in Erzurum province is similar to the results of studies conducted in various provinces of Türkiye. Kılıçerkan and Çek (2011), Özlüer Hunt and Koca (2014), Pala and Yılmaz (2020), Olgunoğlu et al. (2021), Bulut and Özcan (2022) reported that the most sold fish species was goldfish, followed by guppy in Hatay, Mersin, Ordu, Adıyaman and

Elazığ provinces, respectively. The high sales rate of these two types of aquarium fish is associated with the fact that they are economic species, easy to maintain, easy to breed, easy to supply and easy to import (Bulut & Özcan, 2022; Büyüktaş & Kızak, 2018). In addition, in studies conducted in different countries of the world, it has been emphasised that goldfish and guppies are among the most popular and demanded species and are widely available in aquarium businesses (Faruk et al., 2012; Rixon et al., 2005; Sinha, 2016).

Table 4.
Fish species sold in aquarium businesses and monthly average number of fish sales

Latin Name	Name	Min	Max	Average Sales	Standard Deviation
Carassius auratus	Goldfish	50	500	157	135.26
Poecilia reticulata	Guppy	0	150	73	58.32
Xiphophorus helleri	Swordtail	30	120	66	49.20
Poecilia sphenops	Moli	0	120	63	46.20
Cyrtocara moorii	Dolphin Cichlid	0	100	54	41.15
Corydoras sp.	Scavenger	0	100	42	36.15
Pterygoplichthys gibbiceps	Stingray	0	100	44	35.96
Colisa unicolor	Gourami	0	40	20	16.33
Betta splendens	Beta	0	100	43	38.02
Total	9 species			562	

Only 10% of the enterprises stated that they breed fish and the species they breed is scavenger fish. Çelik et al. (2010) reported that 35.7% of the enterprises and Hekimoğlu et al. (2005) reported that 23.5% of the enterprises produced fish and the species produced were guppy, swordtail, plati, moli, ray, cichlid, goldfish, scavenger, beta, discus and gourami. In our study, it was observed that the fish production rate was lower than in other studies, with 90% of the enterprises citing high costs related to electricity, water, medicine, and feed, as well as low demand for fish, as the reasons for not raising fish.

It was determined that all of the businesses in Erzurum (100%) sold aquariums, air motors, heaters, filters, air stones, scoops, sand, siphon hoses and aquarium decoration materials. As seen in Table 1, aquarium material sales rates were determined as high as 91-97% in previous studies (Hekimoğlu et al., 2005; Kılıçerkan & Çek, 2011; Özlüer Hunt & Koca, 2014; Pala & Yılmaz, 2020). However, in this study, it was determined that 60% of the businesses sold different types of animals (birds, rabbits, dogs and turtles) and their feed and other items. Özlüer Hunt and Koca (2014) stated that 96% of the businesses sold live animals other than fish or materials related to these animals, and Olgunoğlu et al., (2021) stated that these rates were higher than the research findings.

Fifty percent of businesses has a website; however, only one engages in online sales, while the remainder does not utilize these sites actively. Furthermore, ten percent of businesses hold a favorable perspective on online fish sales, in contrast to ninety percent who regard it negatively. E-commerce, which has become an increasingly widespread and developing sector today, provides the advantage of reaching a large number of consumers simultaneously and effectively, in addition to the convenience it offers (Yılmaz et al., 2016). Despite all these positive features of e-commerce, it was seen in the research that the number of businesses selling fish online is very few and the negative perspective on online fish sales is quite high.

It has been determined that all of the businesses engage in retail sales, that fish sales vary seasonally, and that the highest sales, at a rate of 62%, occur in the winter season (Figure 2). In line with the results of this study, Pala and Yılmaz (2020) reported that 91% of businesses engage in retail sales, and the highest fish sales, at 55%, occur during the winter months. Other researchers who reported that fish sales are highest in winter have sales rates ranging from 65.3% to 90.7% (Çelik et al., 2010; Hekimoğlu et al., 2005; Özlüer Hunt & Koca, 2014) (Table 1). The high sales rates in winter can be explained by the fact that, as people's time spent indoors increases, they are more likely to engage in soothing and visually appealing hobbies.

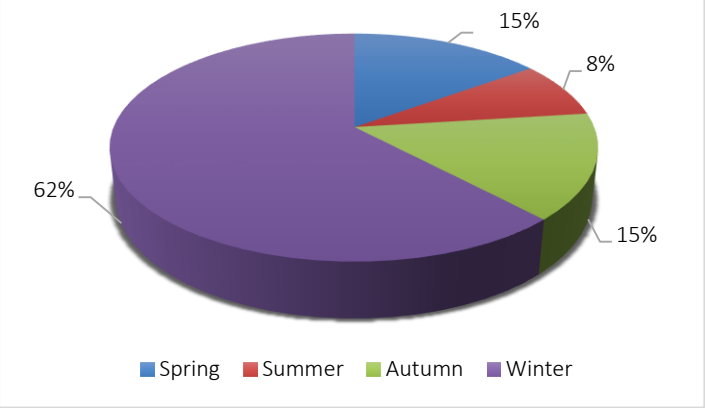

Figure 2.
Distribution rates of fish sales according to seasons

It was determined that the number of glass aquariums used in aquarium businesses varies between 4-15, has an average volume of 80 liters, and only 1 business uses two aquariums with a volume of 130 and 200 liters for display purposes. It was determined that all of the businesses use dry feed and do not use any live feed. It was also determined that the fish are fed twice a day and in small amounts (60%).

It was determined that 80% of the fish diseases seen in aquarium businesses are white spot, 20% are fungal diseases, and parasites and fungicides are used in the treatment of the diseases. When Table 1 is examined, it is seen that the disease types detected at a high rate in other studies are white spot and fungus, and these results are parallel to the research findings. Barata et al., (2017) reported in their research that problems caused by protozoan parasites have an important place among the pathogenic diseases of aquarium fish, and that one of the most important of these is *Ichthyophthirius multifilis*, the cause of white spot disease. Taner and Yıldız (2018) pointed out in their study that pathogen transfer via aquatic organisms, including aquarium fish, should be regularly monitored.

Among aquarium businesses, the rate of those who want aquarium cooperatives to be established in order to develop the sector further and solve its problems is 60%, while 40% have a negative view of cooperatives. In similar studies; Pala and Yılmaz (2020) reported that 73% of business owners have a positive view and 27% have a negative view of the establishment of cooperatives, while Kılıçerkan and Çek (2011) reported that 55% have a positive view and 45% have a negative view. When we look at the studies in general, it is seen that the rate of those who have a positive view of cooperatives is high. Doğan (2018) emphasized that, just like in other branches of agriculture, organizational structures and cooperatives can be applied in aquarium fish production, and through this, significant achievements can be made as civil initiatives in both national and international markets, as well as in decisions to be made by central governments. From this point of view, it should be considered that cooperatives will contribute to the development of the aquarium business sector.

60% of the business owners have a positive view on the obligation to employ a responsible veterinarian when opening a business, while 40% have a negative view. However, it has been determined that the business owners who find this positive do not receive consultancy services from veterinarians on any issue (disease, death, quarantine, etc.). Pala and Yılmaz (2020) stated that the majority of the business owners (64%) have a negative view on this question, and that similar to the research findings, business owners who had a positive view did not receive consultancy services from veterinarians, and that this situation was quite thought-provoking. Büyüktaş and Kızak (2018) emphasized the importance of removing the mandatory employment of veterinarians in this field and granting this authority to individuals who have received engineering education in aquaculture and possess real authority.

The operators stated that there is a shortage of educated and trained personnel in the sector, this negatively affects the development of the sector, the demand for fish, feed, materials, etc. They stated that costs are high, demand for aquarium fish is low, expenses such as rent and electricity are high, and the fact that feeds for other animals are sold in markets negatively affects their sales. They also emphasized that the knowledge and experience level of business owners and employees must increase in order for this sector to develop. 60% of business owners think that those who engage in clandestine aquarium hobby negatively affect fish sales, do not comply with the maintenance and feeding conditions of the fish, produce as a side business with hearsay information and disrupt price stability. They also stated that many people who sell without a tax plate negatively affect the market by selling fish cheaper than aquarium shops.

When aquarium business owners were asked about their perspective on illegal fish entry, 20% of the operators thought that it had a positive effect and stated that there was illegal fish entry from Iran, and that this increased their chances of buying fish at a low price. 80% stated that they had no information on this subject. Many researchers have pointed out that fish are entering our country from Syria, that fish are transported in unhealthy and unsuitable conditions, that diseases are spread, that market conditions are shaped according to the prices of incoming fish, and that illegal fish entry should be prevented (Kılıçerkan & Çek, 2011; Gümüş et al., 2013; Kanyılmaz et al., 2013; Özlüer Hunt & Koca, 2014). 60% of the businesses stated that they apply quarantine procedures when they buy fish, while 40% stated that they do not apply any procedures. It has been emphasized in studies conducted in İzmir (Hekimoğlu et al., 2005) and Mersin (Özlüer Hunt & Koca, 2014) that imported fish and plants cause problems in businesses by spreading diseases because they are not quarantined. The fact that the number of businesses applying quarantine as a result of the research is high shows that aquarium owners are somewhat aware of the problems that businesses may encounter when fish are not quarantined when purchased from abroad.

Conclusion and Recommendations

As a result of the findings obtained from the research, the problems experienced by aquarium owners in Erzurum province were determined and solution suggestions were developed for these problems. The first of these problems is the high costs. The main costs are rent, electricity, fish, feed and aquarium material expenses. The operators, who are tenants at a high rate of 70% and only deal with this business, experience financial difficulties from time to time and have difficulty in surviving in the sector. As a result of high bills due to electricity usage, there is also a loss of work efficiency. This situation causes an increase in expense costs and decreases the profit and income of the operator. For this reason, not being left alone with incentives or supports on rent, electricity, etc. through the Ministry of Agriculture and Forestry will encourage the increase in initiatives and activities to be carried out in the sector.

Another problem detected in the sector is that there is not enough fish sales to minimize the high cost disadvantage. In this regard, it is thought that it would be beneficial to carry out some entrepreneurial activities that will increase the interest and curiosity of people living in Erzurum province in aquarium fish. These include the establishment of city aquariums that can attract people of all ages and the establishment of large aquarium businesses in city shopping malls. Such businesses are areas where students of various educational institutions can visit and families can spend time on weekends and can accelerate the development of the sector.

In the study, it was determined that aquarium operators complain about the inadequacy of the knowledge and experience levels of people working in this sector, that this situation negatively affects the development of the sector and that they want more educated people to be employed and take part in the sector. It is possible to close the gap in educated personnel through lifelong learning programs and seminars to be organized by universities or the Ministry. It would be beneficial to encourage the participation of existing aquarium operators and employees in these trainings and seminars. Through these training programs and seminars, the knowledge levels of the fish species they sell, feeding programs, fry production, broodstock care, recognizing diseases, knowing the methods of combating them, hygiene and also sales and marketing can be increased and conscious and professional aquarium management can be ensured. Especially being able to produce fry from their own broodstock can provide great benefits in terms of disease control and preventing the spread of diseases, which is one of the important problems of the enterprises. In addition, it would be more functional for the consultancy work in aquarium enterprises to be given by aquaculture and fisheries technology engineers who have knowledge and experience in both fish farming techniques and diseases, instead of veterinarians.

In this research and similar studies conducted in different provinces, it has been frequently emphasized that aquarium enterprises do not have a professional chamber or cooperatives that will have the power to represent them. In fact, it has been determined that the enterprises are registered to different chambers. It is seen that it is necessary to realize the cooperative organization as soon as possible, which will enable them to take faster steps in order to prevent this confusion and solve the existing problems. The segment that is not keen on cooperativism also needs to be enlightened about the opportunities that cooperativism will offer them. In this context, there is a need for projects that will enlighten the operators about the importance of cooperatives to be established between university and sector members and the opportunities they will offer them.

The breeding and trade of aquarium fish not only meets the demands of hobbyists, but also creates employment opportunities for thousands of people in rural areas of developing countries, as in the Far East. Therefore, supporting entrepreneurs and directing them to ornamental fish production in order to increase interest in this sector throughout the country is important in terms of reducing external dependency and providing employment. At the same time, large enterprises can be encouraged to invest in this field, and foreign exchange input can be provided to the country's economy.

It is a fact that our country is not in the place it deserves in the aquarium fish sector. Numerous academic studies have been conducted on aquarium fish and their breeding to date. The studies and the data from this research show that serious steps need to be taken to remove the obstacles to the development of the sector. Considering the data obtained from the scientific studies conducted, conducting a regional and countrywide current situation analysis will be an important step towards eliminating the deficiencies. Paving the way for the development of aquarium fish management with projects to be carried out jointly by the University, the General Directorate of Fisheries and Aquatic Products of the Ministry of Agriculture and Forestry and sector representatives is of great importance in terms of the professionalization of the sector.

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References

Anjur, N., Sabran, S. F., Daud, H. M., & Othman, N. Z. (2021). An update on the ornamental fish industry in Malaysia: *Aeromonas hydrophila* associated disease and its treatment control. *Veterinary World*, *14*(5), 1143-1152. https://doi.org/10.14202/vetworld.2021.1143-1152.

Ayta, F. & Şen, M. (2023). Türkiye'de kadın istihdamının genel görünümü: İstihdamın artırılması kapsamında seçilmiş ülke örnekleri. *Uluslararası Ekonomi ve Yenilik Dergisi*, *9*(2), 421-454.

Barata, S., Dörücü, M., & Özcan, M. (2017). Hastalık belirtisi gösteren Japon balıkları (*Carassius auratus*)'nda rastlanan ektoparazitler ve tedavisi. *Fırat Üniversitesi Fen Bilimleri Dergisi*, *29*(1), 15-19.

Bulut, H. & Özcan, E. İ. (2022). Current status of aquarium fish (ornamental fish) enterprises during the pandemic period (Elazig city sample). *Turkish Journal of Agriculture - Food Science and Technology*, *10*(1), 37-41. https://doi.org/10.24925/turjaf.v10i1.37-41.4763

Büyüktaş, E., & Kızak, V. (2018). İstanbul Avrupa yakasında bulunan akvaryum işletmelerinin genel profilinin belirlenmesi. *Süleyman Demirel Üniversitesi Eğirdir Su Ürünleri Fakültesi Dergisi*, *14*(3), 196-207.

Çelik, İ., Yılmaz, S., Çelik, P., Saygı, H., Onal, U., & Bashan, T. (2010). The general profile of aquarium sector in Istanbul (Turkey). *Journal of Animal and Veterinary Advances*, *9*(23), 2973-2978.

Doğan, K. (2018). Akvaryum balıkçılığında kooperatifleşmenin önemi. Türkiye'de Süs Balıkçılığına Yeni Bir Bakış Çalıştayı, Milli Eğitim Bakanlığı, Beykoz Barbaros Hayrettin Paşa Mesleki ve Teknik Anadolu Lisesi, 30 Kasım 2018, İstanbul, http://acikerisim.istanbul.edu.tr/xmlui/handle/20.500.12627/542 (Erişim tarihi: 10.11.2024)

Evers, H-G, Pinnegar, J.K. & Taylor, M.I. (2019). Where are they all from? – sources and sustainability in the ornamental freshwater fish trade. *Journal of Fish Biology*,94, 909-916. https://orcid.org/0000-0001-5061-9520

Faruk, M., Hasan, M. M., Anka, I. Z., & Parvin, M. K. (2012). Trade and health issues of ornamental fishes in Bangladesh. *Bangladesh Journal of Progressive Science and Technology*, *10*(2), 163-168.

Göreci, N. E. & Demirarslan, D. (2021). Kamusal iç mekânlarda akvaryum. *Journal of Social and Humanities Sciences Research*, *8*(72), 1651-1670. http://dx.doi.org/10.26450/jshsr.2555

Gümüş, E., Kanyılmaz, M., Gülle, İ., & Sevgili, H. (2013). Antalya bölgesindeki süs balığı üreten işletmelerin yapısal ve teknik analizi: II. teknik özellik ve pazarlama durumları. *Biyoloji Bilimleri Araştırma Dergisi*, *6*(2), 35-41.

Hekimoğlu, M. A., Şenol, Ş., & Saygı, H. (2005). İzmir merkez ilçelerinde akvaryum işletmelerinin genel profilinin çıkarılması üzerine bir araştırma. *Ege Journal of Fisheries and Aquatic Sciences*, *22*(1-2), 119-123.

ITC, (2020). Trade Map - List of products for the selected product (Live fish). International Trade Center.

Kanyılmaz, M., Gümüş, E., Sevgili, H., & Gülle, İ. (2013). Antalya bölgesindeki süs balığı üreten işletmelerin yapısal ve teknik analizi: I. yapısal özellikleri. *Biyoloji Bilimleri Araştırma Dergisi*, *6*(2), 55-60.

Kılıçerkan, M., & Çek, Ş. (2011). Hatay ilçelerindeki akvaryum işletmelerinin genel profilinin çıkarılması üzerine bir araştırma. *Iğdır Üniversitesi Fen Bilimleri Enstitüsü Dergisi*, *1*(4), 77-82.

Olgunoğlu, İ., Artar, E., Perçin Olgunoğlu, M., & Ukav, İ. (2021). Covid-19 pandemi döneminde Adıyaman ilinde akvaryum balığı satış işletmelerinin genel durumu. *Ecological Life Sciences (NWSAELS)*, *16*(1), 18-24. http://dx.doi.org/10.12739/NWSA.2021.16.1.5A0145.

Özlüer Hunt, A., & Koca, Y. (2014). Mersin merkezindeki akvaryum sektörünün genel profilinin çıkarılması üzerine

bir çalışma. *Ege Journal of Fisheries and Aquatic Sciences*, *31*(3), 145-150. http://dx.doi.org/10.12714/egejfas.2014.31.3.05

Pala, S., & Yılmaz, E. (2020). Ordu ilinde akvaryum sektörünün durumu, sorunları ve çözüm önerileri. *Acta Aquatica Turcica*, *16*(3), 387-395. https://doi.org/10.22392/actaquatr.695032

Raja, K., Aanand, P., Padmavathy, S., & Sampathkumar, J. S. (2019). Present and future market trends of Indian ornamental fish sector. *International Journal of Fisheries and Aquatic Studies*, *7*(2), 6-15.

Rixon, C. A. M., Duggan, I. C., Bergeron, N. M. N., Ricciardi, A., & Macisaac, H. J. (2005). Invasion risks posed by the aquarium trade and live Fish markets on the Laurentian Great Lakes. *Biodiversity and Conservation*, 14, 1365-1381, http://dx.doi.org/10.1007/s10531-004-9663-9

Satam, S. B., Sawant, N. H., Ghughuskar, M. M., Sahastrabuddhe, V. D., Naik, V. V., Pagarkar, A. U., Chogale, N. D., Metar, S. Y., Shinde, K. M., Sadawarte, V. R., Sawant, A. N., Singh, H., Sawant, P. A., Patil, V. K., Rane, D., Haldankar, P. M., & Bhattacharyya, T. (2018). Ornamental fisheries: a new avenue to supplement farm income. *Advanced Agricultural Research and Technology Journal*, *2*(2), 193-197.

Sharma, M. (2020). Ornamental fish rearing and breeding-a new dimension to aquaculture entrepreneurship in Himachal Pradesh. *International Journal of Fisheries and Aquatic Studies*, *8*(2), 157-162.

Shraborni, A., Mandal, S. C., & Parhi, J. (2024). Freshwater Ornamental Fishes of India: Sustainable Management and Conservation. In: Sarma, D., Chandra, S., Mallik, S.K. (eds) Aquaculture and Conservation of Inland Coldwater Fishes. pp 155–173 Springer, Singapore. https://doi.org/10.1007/978-981-97-1790-3_10

Sinha, A. (2016). Evolution, trend and status of ornamental fisheries in India and their commercialization. *Social Entrepreneurship in Aquaculture*, 225-240.

Taner, G., & Yıldız, H. (2018). Digenetic *Centrocestus* sp. Metacercariae (Trematoda: Heterophyidae) were detected on two freshwater ornamental fish species imported into Turkey: Disease profile and risk. *Aquatic Sciences and Engineering*, *33*(3), 106-109. https://doi.org/10.26650/ASE201816

Tolon, T., & Emiroğlu, D. (2014). Akvaryum balıkları pazar yapısı ve tüketici tercihlerinin değerlendirilmesi. I. Ulusal Akvaryum Balıkçılığı ve Sorunları Çalıştayı Sonuç Raporu. Antalya, 119-124.

TURKSTAT, (2022). Hanehalkı İşgücü Araştırması, 2022 https://data.tuik.gov.tr/Bulten/Index?p=Istatistiklerle-Kadin-2023-53675 (Erişim tarihi: 29.11.2024)

Willis, S., & Bakuwel, P. (2018). Update on the ornamental aquatic export industry 2016: Trade data and conservation. OFI Journal 86: February 2018.

Wijaya, R. A., & Huda, H. M. (2021). Potential and problems of ornamental fish farming development in Depok City (Case study: neon tetra, cardinal and red nose ornamental fish farmer in Bojongsari District). In IOP Conf Ser: *Environmental Earth Sciences*, *718*(1), 012072. https://doi.org/10.1088/1755- 1315/718/1/012072

Yılmaz, V., Arı, E., & Doğan, R. (2016). Online alışverişte müşteri şikâyet niyetleri ve davranışlarının yapısal eşitlik modeli ile incelenmesi. *Journal of Yasar University*, *11*(42), 102-112.

Yue, G. (2019). The ornamental fish industry in Singapore. *J. Fish. China*, *43*(1), 116-127. https://doi.org/10.11964/jfc.20180911442.

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Effect of Altitude on Cold Damage and Phenophase Durations in cv. Karaerik

Karaerik Üzüm Çeşidinde Rakımın Soğuk Zararı ve Fenofaz Üzerine Etkisi

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ABSTRACT

Karaerik, the only standard table grape variety of Erzincan, distinguishes itself from other grape varieties with its training system and unique taste. This variety, which has a high commercial value, is also a natural heritage and is an important example of Türkiye in terms of sustainable viticulture. In Erzincan Üzümlü district, where Karaerik grape cultivation is widespread, the vineyards are located between 1150 m and 1650 m altitude. In this study, the damage levels caused by low winter frosts in vineyards at different altitudes and the effectiveness of the methods used to determine these damage levels were investigated. In addition, the phenophase stages of the grapevines that occur between the pruning and harvest periods depending on the altitude were determined. Within the scope of the study, frost damage in Karaerik vineyards located at 1200 m, 1300 m, 1400 m and 1500 m altitudes throughout the district was determined by cross sectioning, shooting and real-time shooting methods and tests, and it was revealed to what extent the sectioning and shooting methods and damage detection confirmed real-time shooting. In all of the methods used, it was determined that the most frost damage occurred in the bottom buds (first 3 buds) of the vineyard at an altitude of 1200 m, and in terms of bud type, the damage in the primary buds was greater than the secondary and tertiary buds. The cross sectioning method confirmed 83.02% of real-time shooting test, while the shooting method confirmed 93.06%. The number of days between pruning-bud break, bud break-full bloom, full bloom-veraison, veraison and beginning of harvest increased from 1200 m altitude to 1500 m altitude. Taking the altitude factor into account in cultural processes in Karaerik vineyards will both increase the sustainability of local viticulture and carry a genetic heritage to future generations.

Keywords: Altitude, Cold damage, Karaerik, Phenophase

ÖZ

Erzincan'ın tek standart sofralık üzüm çeşidi olan Karaerik; terbiye sistemi ve eşsiz tadı ile diğer üzüm çeşitlerinden ayrılmaktadır. Ticari değeri yüksek olan bu çeşit aynı zamanda doğal bir miras niteliğinde olup sürdürülebilir bağcılık açısından Türkiye'nin önemli örneklerindendir. Karaerik üzüm yetiştiriciliğinin yaygın olarak yapıldığı Erzincan'ın Üzümlü ilçesinde bağlar 1150 m ile 1650 m rakımları arasında yer almaktadır. Bu çalışmada, farklı rakımlarda kış donlarının bağlarda meydana getirdiği hasar düzeyleri ve bu hasar düzeylerini belirlerken kullanılan yöntemlerin etkinliği incelenmiştir. Ayrıca asmaların budama ile hasat dönemleri arasında rakıma bağlı olarak gerçekleşen fenofaz evreleri tespit edilmiştir. Çalışma kapsamında İlçe genelinde 1200 m, 1300 m, 1400 m ve 1500 m rakımda bulunan Karaerik üzüm bağlarındaki don zararı kesit alma, sürdürme ve gerçek zamanlı sürme yöntem ve testleri ile belirlenmiş, kesit alma ve sürdürme yöntemleri ile hasar tespitinin gerçek zamanlı sürmeyi hangi oranda doğruladığı ortaya koyulmuştur. Kullanılan yöntemlerin tamamında en fazla don zararının 1200 m rakımdaki bağın dip gözlerinde (ilk 3 göz) gerçekleştiği ayrıca tomurcuk tipi bakımından primer tomurcuklarda meydana gelen zararın sekonder ve tersiyer tomurcuklardan daha fazla olduğu tespit edilmiştir. Kesit alma yöntemi %83,02, sürdürme yöntemi ise %93,06 oranında gerçek zamanlı sürme sayımını doğrulamıştır. Budama-gözlerin uyanması, uyanma-tam çiçeklenme, tam çiçeklenme-ben düşme, ben düşme ve hasat başlangıcı arasında geçen gün sayısı 1200 m rakımdan 1500 m rakıma doğru artış göstermiştir. Karaerik üzüm bağlarında kültürel işlemlerde rakım faktörünün dikkate alınması, hem yöre bağcılığının sürdürülebilirliğini artıracak hemde genetik bir mirası gelecek nesillere taşıyacaktır.

Anahtar Kelimeler: Rakım, Soğuk zararı, Karaerik, Fenofaz

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Introduction

Grapes one of the oldest fruits that have existed since prehistoric times and have survived to the present day (Ekhvaia & Akhalkatsi 2010; Naqinezhad et al., 2018; Zohary & Spiegel-Roy, 1975). Vine and wine are frequently mentioned in the holy books of monotheistic religions such as the Torah and the Bible. From the mythological period to the present, grapes and grape by-products have always been included in artistic works. As a matter of fact, the archaeological excavations carried out to date have been the greatest proof of the importance societies give to grapes (Deliorman et al., 2011). It is thought that the vine began to be cultivated in the Neolithic period (6000-5000 BC) in the region known as Transcaucasia in the eastern part of the Black Sea. Türkiye, which is located in the world's most suitable climate zone for viticulture, has a very old and deep-rooted viticulture culture. Grapevine, which was first cultivated in Anatolia, has been one of the most important agricultural products for all civilizations that made this geography their home (Candar et al., 2021; Doğan, 1996).

Grape, one of the most diverse fruit species in the world, is still facing the negative effects of the climate in some regions, even though it has survived to the present day. Especially in regions where the continental climate prevails, winter cold is one of the most important abiotic factors that limits economic viticulture. Therefore, producers face serious problems when they aim to obtain high quality grapes in areas where short vegetation and cold climate prevail (Fennel, 2004). Although Türkiye has a significant advantage for viticulture due to its climate, low temperatures and frost events cause yield loss and economic losses in vineyards (Küpe, 2019). Especially in the Eastern Anatolia Region, viticulture is faced with many negative effects of the continental climate. For *Vitis vinifera* L. varieties, low temperatures in winter cause damage at -12°C in winter buds, -16°C in shoots and -20°C in branches (Köse & Güleryüz, 2009). The threshold values of this damage vary depending on factors such as altitude, location of the vineyard, rootstock, variety, dormancy period temperatures, pruning time and method, training method, cultural control, product load, genetic factors, and adaptability of the variety. In fact, according to research, it is estimated that approximately 5-15% of world grape production is lost each year due to frost damage (Evans, 2000).

One of the regions most affected by winter frosts in terms of viticulture in Türkiye is the Üzümlü District of Erzincan. Although the grape microclimate is a suitable region for viticulture, the short vegetation period and winter frosts in the region cause economic losses in grapes. The Karaerik grape variety, which is thought to be one of the grape varieties with the high commercial value in Türkiye. Karaerik grown in Üzümlü as the only standard table grape variety of Erzincan and is marketed at a high demand (Köse, 2002). The vineyard areas in Üzümlü start from 1150 m altitude and go up to 1650 m altitude. In a study conducted by Köse and Güleryüz (2009) in Karaerik vineyards, it was reported that there were significant differences between the damage levels occurring at different altitudes. Another factor that changes with altitude is phenological periods. It has been reported that altitude drives phytophenological stages through a temperature decrease of about 0.6°C per 100 m (Barry, 1981; Koch et al., 2007; Ziello et al., 2009).Phenological stages includes processes such as the growth, development, and fruiting of a vine throughout the year (Nasirovic, 2024). Monitoring phenological periods is important for quality grape and wine production. In a study conducted by Alikadic et al. (2019) on the phenological periods of altitude in grapevines, it was reported that bud burst was delayed by 0.85 to 2.88 days and harvest was delayed by 6.27 to 7.16 days for every 100 m increase in altitude, thus the increase in altitude on a global scale caused a delay in phenological stages and the main effect of the increase in altitude was seen in bud burst and the beginning of harvest. Agricultural science uses phenological data for the timing of agricultural work and the selection of suitable products and varieties. Nowadays phenological data are usually used in providing valuable input data for crop yield modelling, they provide important support to frost warnings and are essential for pest control measures (Koch et al., 2007).

Within the scope of this study, the level of damage caused by low winter temperatures on the Karaerik grape variety in Erzincan Province Üzümlü District, where the continental climate prevails but exhibits microclimate characteristics, was examined in laboratory, greenhouse and field conditions in vineyards at 4 different altitudes (1200 m, 1300 m, 1400 m and 1500 m). It was tried to detected by cross-sectioning, shooting and real-time shoot counting tests. In addition to determining the level of damage that occurs depending on altitude, the study also tried to reveal the difference between the methods used to determine these damage levels and the effect of altitude on the time between phenological stages of grapevine was evaluated.

Methods

Meteorological data for Üzümlü District were obtained from Erzincan Meteorology Station. According to long-term (1929-2022) climate data, the annual average temperature in Erzincan is 10.9°C, the annual average highest temperature is

17.4°C, the annual average lowest temperature is 4.8°C, the average number of rainy days is 102.1, and the annual average rainfall is 367.2 mm. According to the long-term temperature average, the temperature values in summer are between 20°C and 24.1°C, and in winter the temperature is between 1.2°C and -3°C. The number of cloudy days per year was determined as 197.9 and the number of sunny days as 105.4 (Anonymous, 2022a). As of 2022, there are 38,672 acres of planted land in Erzincan Province, 9478 acres of which are vineyards, and 58% of these vineyards are located in Üzümlü. In 2022, 4190 tons (67.5%) of the 6202 tons of grapes produced in the province were produced in Üzümlü (Anonymous, 2022 b).

Material

The Karaerik (*Vitis vinifera* L.) grape variety that we used as material in the study is the only standard table grape variety of Erzincan and is widely grown in Üzümlü (Cimin) District. Karaerik is a table grape variety with black color, flattened oval shape, an average weight of berries is 3-4 g, an average number of seeds of 1-4, medium skin thickness, plump density and an average cluster weight of 300 g-500 g (Köse,2002; Küpe,2013; Özoğul, 2024). It has a unique mist on its berries and aroma that is not seen in other grape varieties, meeting at a very fine point between tart and sweet in taste (Karadeniz & Altınbilek, 2016).

The training method for the Karaerik grape variety is the baran system, which is a method specific to the region. The Baran system can be described as a system in which the grape trunk is taken underground, the branches and rods are left above the soil, and the soil is raised from the ground in a herringbone shape. In recent years, due to global warming, the decrease in snow cover in the region and climate changes, the Karaerik grape variety has been seriously affected by winter frosts (Köse & Güleryüz, 2009; Küpe, 2012).

Determination of Frost Damage

The level of frost damage was determined using 3 different methods: cross sectioning, shooting and real-time shoot counting tests in greenhouse, laboratory and field conditions. As a matter of fact, carrying out frost damage detection studies in viticulture comparatively in the laboratory, greenhouse and field triangle will increase the accuracy of the studies.

Cross-Sectioning Test

In this method, a total of 72 number 1-year-old healthy branches with 9 buds were taken from 4 different altitudes in January and February. The samples were brought to the laboratory on the same day and kept at room temperature for 1 day to allow enzymatic browning to occur and to more clearly determine the level of damage. In this method, the damage level in primary, secondary and tertiary buds was examined according to the positions of the buds (bottom, middle, end) on January and February 24, a total of 648 number of buds, according to their positions and altitude. Then, the winter buds on 1-year-old branches were cut with a scalpel and the vitality of the primary, secondary and tertiary buds was determined (Çelik et al., 2008; Köse & Güleryüz, 2009; Küpe, 2013; Odneal, 1984). Primary, secondary and tertiary buds with green tissue were considered alive and brown ones were considered dead (Küpe, 2013) (Figure 1).

Figure 1.
Determination of vitality in buds by cross sectioning method

Shooting Test

In the shooting test, a total of 72 number 1-year-old healthy branches with 9 buds were taken from 4 different altitudes in 2 different periods in January and February. Branches brought to the laboratory were grouped according to their altitude and position, and the 1st, 2nd, and 3rd buds of the 9-bud branches were accepted as bottom buds; the 4th, 5th, and 6th buds were accepted as middle buds; and the 7th, 8th, and 9th buds were accepted as end buds. After the branches were cut into 1-bud cuttings and kept in room temperature water for 24 hours, they were planted in shooting boxes prepared from a 1:1:1 mixture of sand, perlite and soil in a greenhouse environment according to the bud position and altitude (Özgür et al., 2021). In this method, a total 324 number of 1-bud cuttings were used from 4 different altitudes, including 27 bottom, 27 middle and 27 end buds for each period. Cuttings with buds were considered as living and cuttings without buds were considered as dead (Figure 2).

Figure 2.
Determination of vitality in buds by shooting method

Real-Time Shoot Counting Tests

In Karaerik vineyards located at altitudes of 1200 m, 1300 m, 1400 m and 1500 m, buds that have completed their blooming were counted on different vines in the vineyard on May 20. The number of shoots on all the remaining 3- bud branches after pruning on the 3 number of vines detected at each altitude was counted directly in real time. In this method, the buds that have completed their bud burst stage and formed leaves and green shoots are considered alive, and the buds that have not formed are considered dead. Because of only 3 number of buds are usually left during pruning of the Karaerik grape variety in the region, the damage level was determined at the bottom buds according to the bud position (Figure 3).

Figure 3.
Real-time viability detection in buds

Differences Between Methods in Determining Frost Damage

In frost damage determinations made by sectioning method, the situation in which all three primary, secondary and tertiary buds within the winter bud were dead at the same time was evaluated as final death. As a matter of fact, in the shooting and real time shooting methods, in cases where none of the buds in the eyes erupt, the eye is considered dead and the damage rate is determined accordingly. Therefore, final mortality rates were taken into account when comparing frost damage between methods. However, since the frost damage detection with the ploughing method is done after pruning and generally 3 buds are left in the traditional pruning carried out in the region, the damage difference comparison was made on the bottom buds.

Phenophase Durations

Bud Burst

In spring, as the daily average air temperature rises above 10°C and the soil temperature increases, the buds begin to swell, internal development accelerates, the protective scales on the bud separate from the tip, and first the brown woolly bud hairs, then the green shoot tip, begin to appear, and the bud completes its bud burst process (Ağaoğlu, 2002; Coombe, 1995; Eichhorn & Lorenz, 1977; Lorenz et al., 1994). This period was recorded as the period when the buds burst.

Full Bloom

The period when 50% of the caliper was shed was taken as basis (Ağaoğlu, 2002; Coombe, 1995; Eichhorn & Lorenz, 1977; Lorenz et al., 1994).

Veraison

In order to determine the veraison date, the vines in the vineyard were visited one by one and the bunches were examined, and the date when the coloration was first observed was determined as the veraison (Coombe, 1995; Eichhorn & Lorenz, 1977; Lorenz et al., 1994;).

Harvest

The harvest date is based on the variety's unique appearance and taste are formed and the first product is brought to the market (Coombe, 1995; Eichhorn & Lorenz, 1977; Lorenz et al., 1994).

Yield (kg/da)

Yield was calculated as kg/decare by multiplying the number of clusters on the vine by the average weight of 3 clusters representing the vine and by 200 (it is assumed that there are 200 vines on average in the vineyard).

Results and Discussion

As a result of cross sectioning and shooting tests made in January, it was determined that the air temperatures in this period did not drop significantly below the critical limit (Figure 4), and in parallel, frost damage was not significant (p>.05) (Table 1, Table 2).

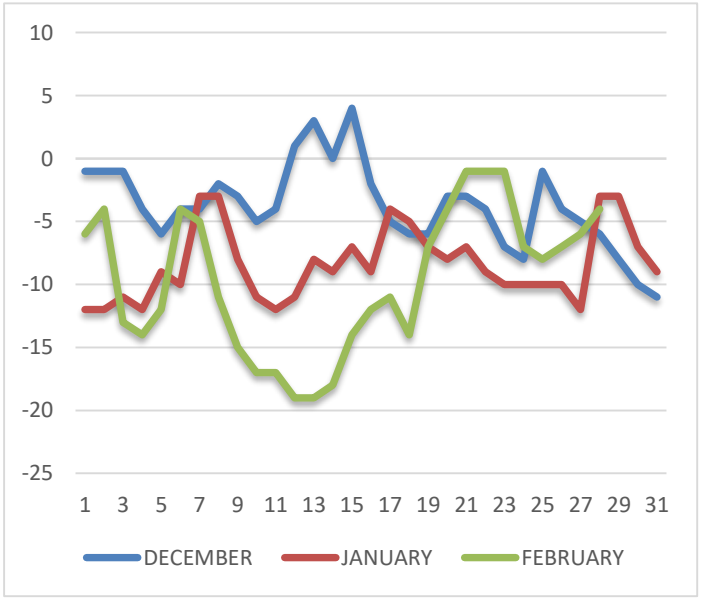

Figure 4.
Minimum temperatures for the cold damage in study period (Anonymous, 2023)

In the February period, frost damage determinations were made by taking into account the positions of the buds using the sectioning method, and among the bottom, middle and top buds. The highest damage occurred in the primary buds in the bottom buds of the vineyard at an altitude of 1200 m with 63%. This was followed by the primary bud of the middle buds of the vineyard at 1200 m altitude with 62%, and then by the primary bud of the end buds with 55.6%. The total damage rate in the bottom buds was found to be statistically significant (p<.05) according to altitude. After 1200 m altitude, the highest damage was detected in the primary buds of the middle buds of the vineyard at 1300 m altitude with 40.7%. Among all groups and bud positions, the most damage was detected in primary buds. Among all vineyards where damage was determined by the cross sectioning method, the highest average damage was determined in the vineyard at 1200 m altitude with 31.98%, followed by the vineyard at 1300 m altitude with 12.7% and at 1400 m and 1500 m altitude with 7.4% (Table 1).

Table 1.

Vitality rate of buds according to cross sectioning method (%)

Period	Position bud type		1200 m	1300 m	1400 m	1500 m	X^2 Test
January (n=108)	Bottom	Primary	96.3	100.0	96.3	100.0	0.565
		Secondary	100.0	100.0	100.0	100.0	
		Tertiary	100.0	100.0	100.0	100.0	
	Middle	Primary	100.0	100.0	96.3	100.0	0.387
		Secondary	96.3	100.0	100.0	100.0	0.387
		Tertiary	100.0	100.0	100.0	100.0	
	End	Primary	96.3	100.0	100.0	100.0	0.387
		Secondary	96.3	100.0	100.0	100.0	0.387
		Tertiary	96.3	100.0	100.0	100.0	0.387
February (n=108)	Bottom	Primary	37.0	59.3	81.5	74.1	0.004
		Secondary	66.7	96.3	92.6	92.6	0.004
		Tertiary	85.2	100.0	100.0	100.0	0.006
	Middle	Primary	38.0	55.6	81.5	77.8	0.002
		Secondary	66.7	85.2	92.6	96.3	0.011
		Tertiary	100.0	96.3	100.0	100.0	0.387
	End	Primary	44.4	96.3	85.2	96.3	0.000
		Secondary	77.8	96.3	100.0	96.3	0.008
		Tertiary	96.3	100.0	100.0	100.0	0.387

In the determination of frost damage made by taking into account the positions of the buds with the shooting method in the February period, the highest damage occurred in the bottom buds of the vineyard at 1200 m altitude with 38.9%, followed by the middle buds of the same vineyard with 33.3%. In four different altitudes examined with the shooting method, the average damage was detected to be the highest at 1200 m altitude with 28.6%, followed by 16.1% at 1300 m altitude, 6.6% at 1400 m altitude and 5.9% at 1500 m altitude (Table 2).

Table 2.

Vitality rate according to bud position with shooting method

Period	Altitude	N	Bottom	Middle	End	X^2 Test
January	1200 m	96	93.90%	97.00%	90.00%	0.521
	1300 m	126	95.20%	95.20%	95.20%	1.000
	1400 m	93	97.00%	96.80%	96.60%	0.996
	1500 m	101	97.00%	94.10%	97.10%	0.780
February	1200 m	123	61.10%	66.70%	86.30%	0.019
	1300 m	158	71.40%	91.80%	88.30%	0.012
	1400 m	117	91.90%	97.10%	93.30%	0.624
	1500 m	151	82.00%	100.0%	98.10%	0.000

When the results obtained from the determinations made with the real-time shoot counting method in the vineyard were examined, it was determined that the highest damage occurred at 1200 m altitude with 34.2%, at 1300 m altitude with 20.12%, at 1500 m altitude with 10.71% and at 1400 m altitude with 5.71%, respectively. Thus, it was determined that the most frost damage in the real-time shoot counting method, as in the cross sectioning and shooting methods, occurred in the bottom buds of the 1-year-old shoots of the vineyard at an altitude of 1200 m.

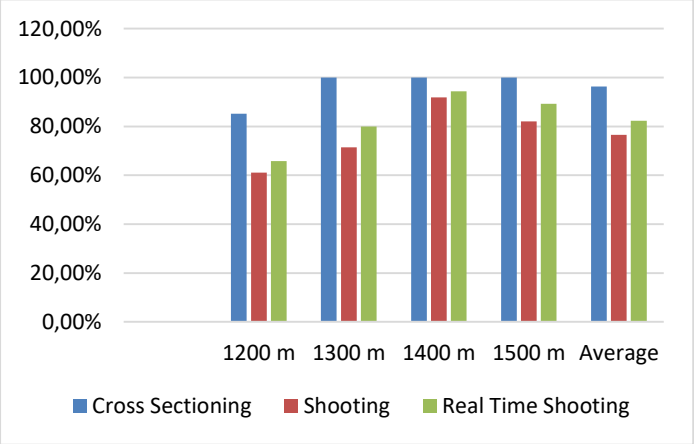

Figure 5.

Vitality rate of buds according to different methods

In this study, in which frost damage was determined with 3 different methods in vineyards at different altitudes, it was observed that although the frost damage level determined with the cross sectioning and shooting methods was generally parallel to the frost damage determined with the real-time shoot counting method, there were some differences between the methods. It was observed that the shooting test

conducted under greenhouse conditions confirmed the real-time shoot counting in the vineyard to a higher extent compared to the sectioning method applied under laboratory conditions. When the altitudes were evaluated together, it was determined that the sectioning method was 83.02% similar to the real-time shoot counting test, while the shooting method was 93.06% similar (Figure 5). In fact, in a similar study conducted by Küpe and Köse (2019) low temperature damages occurring on winter buds of vines in the Karaerik grape variety were determined under vineyard (burst test) and laboratory conditions (sectioning method) and it was investigated whether there was a difference between the two methods. As a result of the study, the researchers reported that there were 7.9%, 14.56% and 0.1% differences in primary, secondary and tertiary buds between the sectioning method and the burst test, respectively. However, in a study conducted by Korkutal et al. (2023) investigating the productivity of buds growing in climate chamber and vineyard conditions, it was stated that there may be differences in terms of bud growth and bud productivity in climate chamber and vineyard conditions. These different results show that conducting bud productivity studies in viticulture in the triangle of greenhouse, vineyard and laboratory will increase the accuracy of the study and explain why three different techniques were used in this study. In this study, it was determined that the bottom buds were more sensitive than the middle and end buds in the damage detections made by sectioning and continuing methods (Table 1, Table 2). Köse and Güleryüz (2009) investigated frost damage in Karaerik vineyards located at 6 different altitudes (between 1197 m and 1650 m) using the cross-section method and found that the highest damage occurred at 1197 m and 1660 m altitudes, while the lowest damage occurred at 1360 m and 1460 m altitudes. In a study conducted by Khanizandeh et al. (2005) in a study conducted with 20 grape varieties at 3 different altitudes (43 m, 125 m and 205 m) in Quebec, Canada; It has been reported that winter cold damage is greater in the low-altitude C'Orpailleur and Dietrich-Joos regions compared to vineyards at higher altitudes, and this is due to the cold air draining and settling in low areas this study where cold damage was determined in vineyards. In this study where cold damage was determined in vineyards, it was determined that the highest cold damage occurred at 1200 m altitude, followed by 1300 m altitude in all of the cross sectioning, shooting and real-time shooting tests, and that there were differences in cold damage at 1400 m and 1500 m altitude depending on the applied method (Table 1, Table 2). These results are similar to previous cold damage studies conducted by taking altitude into account. It should not be overlooked that the vineyard, which is located at an altitude of 1200 m, is located at the bottom of the plain and that the cold air mass may accumulate here and cause more frost damage as a result of radiational cooling. In addition, the topographic structure of Üzümlü and the spread of vineyards from the hillsides to the bottom lands also support this situation. Indeed, Geiger et al. (1965) reported that under radiation cooling conditions, the Earth loses heat to space and cools the air mass, thanks to light winds and clear skies. Similarly, it has been reported that most of the winter frosts that cause damage in vineyards are usually caused by radiational frost, and that vineyards in frost lakes are more exposed to winter cold damage than vineyards at higher altitudes (Korkutal et al., 2012). In the frost damage determinations we made at different altitudes, another reason why the most damage occurs at the lowest altitude (1200 m). It should not be ignored that it may be related to the more limited protective effect of snow cover on vineyards in the bottom land. As a matter of fact, in Erzincan Üzümlü, our study was carried out, cultivation is carried out with the baran training system and it is known that one of the main advantages of the system is to benefit from the protective effect of the snow cover against low temperatures in the winter (Figure 6). However, the decrease in snowfall in recent years and the shortening of the duration of snow cover at low altitudes exposes the winter buds on 1-year-old branches directly to cold air on frost days and increases frost damage. Davenport et al. (2008) reported that although the Pacific Northwest has a mild climate, in addition to the small amount of snow cover and low temperatures, in some winter periods when snowfall is limited, this situation causes damage to grapevine buds and complete death of the grapevine, thus making the selection of suitable site and variety critical in viticultural activities.

Figure 6.
Baran training system under snow

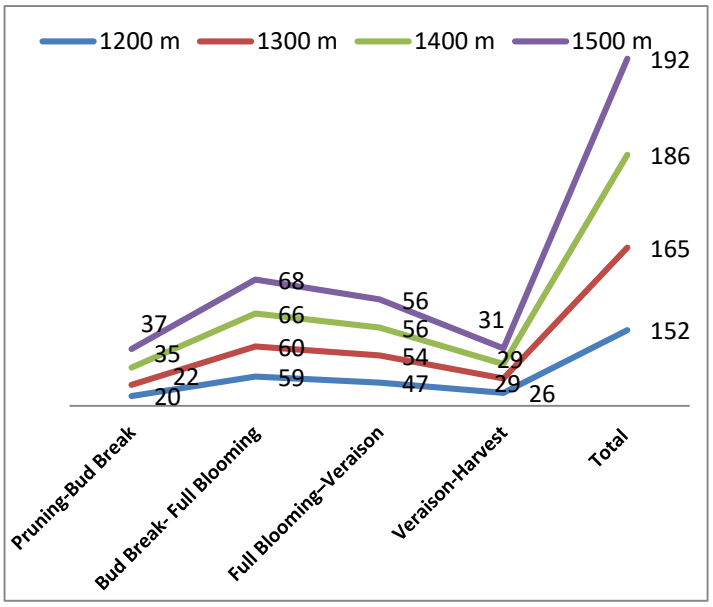

Figure 7.
Change of phenophases depending on altitude

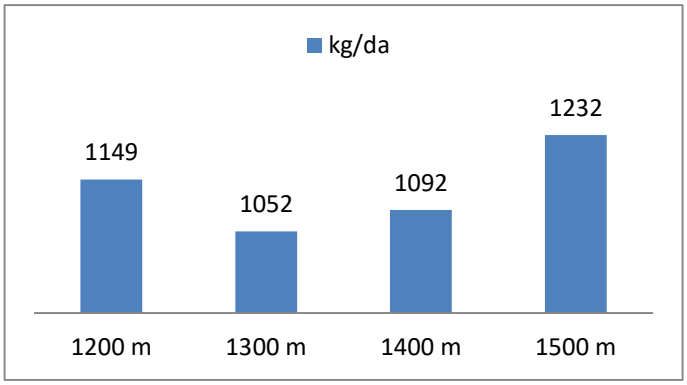

Figure 8.
Yield change depending on altitude (kg/da)

In the Karaerik vineyards examined at 4 different altitudes, it was observed that the shortest period between pruning and bud break was 20 days at 1200 m altitude and the longest period was 37 days at 1500 m altitude. From bud break to full bloom, 59 days passed at 1200 m altitude and 68 days at 1500 m altitude. After full blooming, veraison occurred in 47 days at 1200 m altitude and in 56 days at 1500 m altitude. After veraison in the vineyards, harvest started 26 days later at 1200 m altitude and 31 days later at 1500 m altitude (Figure 7). A 40-day difference was determined between 1200 m and 1500 m altitude from pruning to harvest. In terms of the duration of phenological stages, it was determined that the longest period at all altitudes was the phase from bud break to full blooming, and the shortest phase was the bud break phase after pruning. In Karaerik vineyards at 1200 m, 1300 m, 1400 m and 1500 m altitudes where phenological periods were examined, it was determined that the shortest number of days in phenological periods were at 1200 m altitude and the longest number of days were at 1500 m altitude (Figure 9).

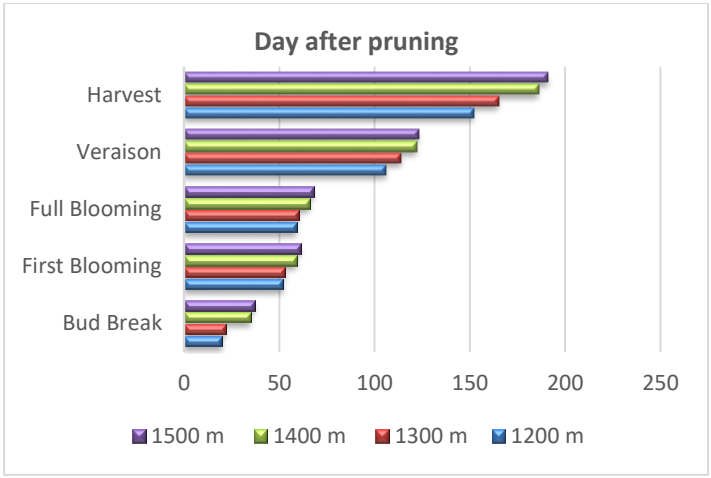

Figure 9.
Difference between phenological stages according to altitude

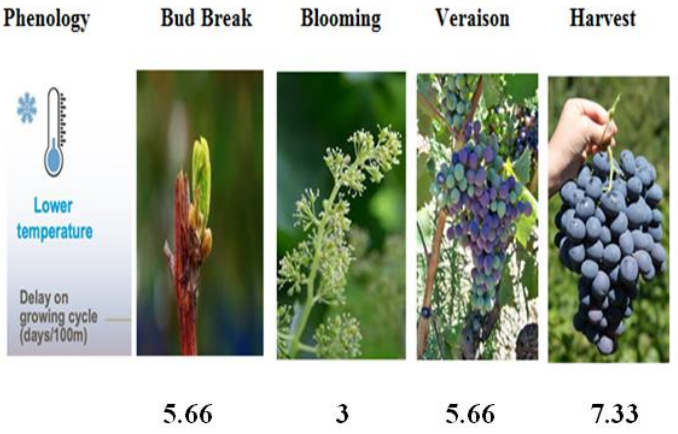

Figure 10.
Average phenological delay per 100 m after bud burst stage (days) (Bud Break: After pruning)

In this study carried out in Üzümlü, Erzincan, it was determined that for an average increase of 100 m in altitude, there was a delay of 5.66 days in bud burst, 3 days in flowering, 5.66 days in veraison and 7.33 days in harvest (Figure 10). It is considered that the sum of the decreasing air temperature and low effective heat summations (EHS) due to altitude increase is effective in this difference. In fact, the results of this study are similar to previous studies. For example, in a study conducted by Pellerin et al. (2012) to examine the phenology of grapevines in the Western Alps, it was investigated how air temperature, altitude and other topographic factors affect phenological processes. The study reported that altitude was the main determinant of bud burst dates with delays ranging from 2.4 to 3.4 days per 100 m as expected. Again, Cornelius et al. (2013) made phenological observations on grapes in 24 regions at an altitude of 680 to 1425 meters. The study found that the phenophases of the species were highly dependent on interannual temperature changes and altitude, with an average delay of 3.8 days reported for every 100 m increase in altitude. In a study

conducted by Muniz et al. (2015) in the southern region of Brazil, it was reported that the air temperature of the vineyard at 1400 m altitude was 4.4°C lower than the vineyard at 950 m altitude and received 12% higher total radiation, and that this altitude difference in the growing regions caused a 50-56 day delay in the harvest date and a 37 day delay from bud break to full bloom for both Merlot and Cabernet Sauvignon grape varieties, and that phenophases were significantly affected by altitude. Similarly, Ruml et al. (2016) examined the bud burst, flowering, veraison and harvest periods of 20 grape varieties, and as a result of the study, it was reported that an average 1°C increase in these periods brought the harvest period 7.4 days earlier on average. In a study conducted by Alikadic et al. (2019) bud break and harvest periods of five varieties (Pinot Noir, Sauvignon Blanc, Chardonnay, Merlot, Pinot Gris) were examined in vineyards located at an altitude of 67 m above sea level and 950 m above sea level in the Trento Region of Italy. As a result of the research, it was reported that the beginning of harvest was significantly affected by altitude and that the harvest was delayed by 6.27 to 7.16 days for every 100 m increase in altitude, while the bud break period advanced by 0.85 to 2.88 days for every 100 m. All these results obtained from previous studies support our study and show that altitude is an important factor in phenological periods for Karaerik vineyards.

Conclusion

As a result of the study, it was concluded that there are differences between the methods used to determine frost damage in buds, that the shooting method confirms a higher rate of real-time shooting than the cross sectioning method, and therefore it would be more accurate to evaluate the two methods together in frost damage determinations. In Üzümlü, where the continental climate prevails, it is considered that the possibility of the vines being damaged by winter frosts is quite high and that it would be more advantageous in the long term for producers to establish their vineyards on sloping lands in order to minimize frost damage. It is thought that in years where frost damage is experienced, the number of buds left on the branches during the pruning period can be increased and the negative effect of damage to the bottom buds on yield can be reduced. It has been observed that there are significant differences between the phenophase stages of vineyards located at different altitudes in the Üzümlü region. These differences occurring in phenological periods make the cultural processes that need to be carried out during the vegetation period (irrigation, fertilization, spraying, pruning, etc.) a necessity that pushes for periodic planning. For these reasons, it has been concluded that in grape cultivation carried out at different altitudes in the region, carrying out cultural processes such as the time and intensity of pruning, irrigation frequency, and fertilization within a periodic plan, taking into account the altitude factor, will allow producers to produce more economically with less input and will contribute to the sustainability of local viticulture.

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References

Acir, N., Günal, H., Mutlu, N., Cankar, S., & Akyol, N. (2013) *Drenaj Faaliyetleri Sonrası Kaz Gölü Çevresindeki Toprak Özellikleri ve Vejetasyonun Mesafeye Bağlı Değişimleri.* III. National Soil and Water Resources Congress, 22-24 October 2013, Tokat, Türkiye.

Ağaoğlu, Y. S. (2002). *Scientific and Applied Viticulture (Grapevine Physiology-I)* (Vol. II). Kavaklıdere Education Publications No: 5, Ankara.

Alikadic, A., Pertot, I., Eccel, E., Dolci, C., Zarbo, C., Caffarra, A., & Furlanello, C. (2019). The impact of climate change on grapevine phenology and the influence of altitude: A regional study. *Agricultural and Forest Meteorology, 271*, 73-82.

Anonymous. (2022a). https://www.mgm.gov.tr/veridegerlendirme/il-ve-ilceler-istatistik.aspx?k=A&m=ERZINCAN (Accessed: 13 January 2024).

Anonymous. (2022b). https://biruni.tuik.gov.tr/medas/?locale=tr (Accessed: 3 January 2024).

Anonymous. (2023). https://weather.com/tr-TR/weather/monthly (Accessed: 3 January 2024).

Barry, R. G. (1981). *Mountain weather and climate*. Methuen, London.

Candar, S., Uysal, T., Ayaz, A., Akdemir, U., Korkutal, İ., & Bahar, E. (2021). Viticulture tradition in Turkey. *Viticulture Studies, 1*(1), 39-54.

Çelik, H., Erdemir, D., & Değirmenci, D. (2008). Determination of damage caused by winter cold in 2005–2006 winter varieties of grapes grown in Klecik (Ankara). In *V. National Horticultural Congress of Turkey*, Vol. II, 451-454, Erzurum.

Coombe, B. G. (1995). Adoption of a system of identifying grapevine growth stages. *Australian Journal of Grape and Wine Research, 1*, 104-110.

Cornelius, C., Estrella, N., Franz, H., & Menzel, A. (2013). Linking altitudinal gradients and temperature responses of plant phenology in the Bavarian Alps. *Plant Biology, 15*, 57-69.

Davenport, J. R., Keller, M., & Mills, L. J. (2008). How cold can you go? Frost and winter protection for grape. *HortScience, 43*(7), 1966-1969.

Deliorman, D., Orhan, N., & Ergun, F. (2011). Vine (Vitis vinifera L.) in Anatolian civilizations. *Journal of Historical Research, 30*(50), 69-80.

Doğan, A. (1996). A research on the effects of IBA (Indole Butyric Acid), NAA (Naphthalene Acetic Acid) and plastic mulch applications on seedling yield and quality in grafted grapevine seedling production. PhD Thesis, Yüzüncü Yıl University, Van.

Eichhorn, K. W., & Lorenz, H. (1977). Phänologische Entwicklungsstadien der Rebe. *Nachrichtenblatt des Deutschen Pflanzenschutzdienstes, 29*, 119-120.

Ekhvaia, J., & Akhalkatsi, M. (2010). Morphological variation and relationships of Georgian populations of *Vitis vinifera* subsp. *sylvestris*. *Flora, 205*, 608-617.

Evans, R. G. (2000). The art of protecting grapevines from low temperature injury. In *Proc. ASEV 50th Anniversary Annual Mtg.*, Seattle WA, 60-72.

Fennell, A. (2004). Freezing tolerance and injury in grapevines. In R. Arora (Ed.), *Adaptations and Responses of Woody Plants to Environmental Stresses* (pp. 201-235). Hawthorn Press.

Geiger, R., Aron, R. H., & Todhunter, P. (1965). *The climate near the ground*. Harvard University Press, Cambridge.

Karadeniz, V., & Altınbilek, M. S. (2016). Administrative geography analysis of Erzincan province and problems arising from administrative borders. *International Erzincan Symposium*, 89.

Khanizandeh, S., Rekika, D., Levasseur, A., Groleav, Y., Richer, C., & Fisher, H. (2005). The effects of different cultural and environmental factors on grapevine growth, winter hardiness and performance in three locations in Canada. *Small Fruits Review, 4*(3), 3-28.

Koch, E., Bruns, E., Chmielewski, F. M., Defila, C., Lipa, W., & Menzel, A. (2007). *Guidelines for plant phenological observations*. World Climate Data and Monitoring Programme.

Korkutal, İ., Bahar, E., & Kaymaz, Ö. (2012). Effects of altitude on grape quality. *Trakya University Journal of Engineering Sciences, 13*(1), 17-29.

Köse, C. (2002). *An investigation on clonal selection of grapevine cv. Karaerik*. (Thesis No: 121459). [PhD Thesis, Atatürk University].

Köse, C., & Güleryüz, M. (2009). Damages caused by the cold winter of 2007–2008 on winter buds of Karaerik grape variety grown in Erzincan. *Journal of Atatürk University Faculty of Agriculture, 40*(1), 55-60.

Küpe, M. (2019). *Characteristic structures of low temperature exotherms in grapevine buds and determination of their relationship with bud structure*. (Thesis No: 335060). [PhD Thesis, Atatürk University].

Küpe, M., & Köse, C. (2019). Determination of cold damage in field and laboratory conditions in dormant buds of Karaerik grape cultivar. *Atatürk University Journal of Agricultural Faculty, 50*(2), 115-121.

Lorenz, D. H., Eichhorn, K. W., Bleiholder, H., Klose, R., Meier, U., & Weber, E. (1994). Phänologische Entwicklungsstadien der Weinrebe. *Viticultural and Enological Science, 49*, 66-70.

Naqinezhad, A., Ramezani, E., Djamali, M., Schnitzler, A., & Arnold, C. (2018). Wild grapevine in the Hyrcanian relict forests of northern Iran: An overview. *Journal of Forestry Research, 29*, 1757-1768.

Nasirovich, F. J. (2024). Transition periods of the phenophase processes of the introduced grape cultivars. *Web of Agriculture: Journal of Agriculture and Biological Sciences, 2*(12), 37-42.

Odneal, M. B. (1984). Cold hardiness of grapes. Bulletin 41, State Fruit Experiment Station, Missouri State University.

Özbek, S. (1977). *General fruit growing*. Çukurova University, Faculty of Agriculture Publications: 111.

Özgür, A., Cangi, R., & Uzun, T. (2021). Effect of pickling leaves on annual branch quality and bud productivity in Narince grape variety. *Academic Journal of Agriculture, 10*(1), 1-10.

Özoğul, Ü. (2024). *Determination of frost damage in Karaerik grape variety at different altitudes in Erzincan* (Thesis No: 880691). [Master's Thesis, Atatürk University].

Pellerin, M., Delestrade, A., Mathieu, G., Rigault, O., & Yoccoz, N. G. (2012). Spring tree phenology in the Alps: Effects of air temperature, altitude and topography. *European Journal of Forest Research, 131*(6), 1957-1965.

Ruml, M., Korać, N., Vujadinović, M., Vuković, A., & Ivanišević, D. (2016). Response of grapevine phenology

to recent temperature change in Serbia. *Journal of Agricultural Science, 154*, 186-206.

Ziello, C., Estrella, N., Kostova, M., Koch, E., & Menzel, A. (2009). Influence of altitude on phenology of selected plant species in the Alpine region (1971–2000). *Climatic Research, 39*, 227-234.

Zinni, A., Bahar, E., & Korkutal, İ. (2023). The effects of leaf removal and tip removal on bud productivity of Michele Palieri grape variety. *Garden, 52*(Special Issue 1), 138-146.

Zohary, D., & Spiegel-Roy, P. (1975). Beginnings of fruit growing in the Old World. *Science, 187*(4174), 319-327.

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Contributions to the Aphid Fauna of Türkiye from the Thracian Region

Trakya Bölgesinden Türkiye'nin Yaprak Biti Faunasına Katkılar

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ABSTRACT

Aphids are obligatory phytophagous insects specific to the host plant. The aphids have attracted the attention of researchers because of their increasing damage levels due to their invasion of new host plants and new regions. The study was conducted in Kırklareli, Tekirdağ and Istanbul provices from July to November 2024. Some important distinguishing characters were measured for the identification of the samples. As a result of this study, nine aphid species, *Aphis* (*Aphis*) *eupatorii* Passerini, 1863; *Aphis* (*Aphis*) *parietariae* Theobald, 1923; *Capitophorus mitegoni* Eastop, 1956; *Dysaphis* (*Dysaphis*) *ranunculi* (Kaltenbach, 1843); *Illinoia* (*Illinoia*) *liriodendri* (Monell, 1879; *Macrosiphoniella* (*Asterobium*) *asteris* (Walker, 1849); *Protaphis carthami* (Das, 1918); *Tiliaphis shinae* (Shinji, 1924) and *Yamatochaitophorus yichunensis* Jiang, Chen & Qiao, 2016 were added to the Türkiye aphid fauna and the number of listed species increased to 685. However, the detection of *A.* (*A.*) *eupatorii* on the host plant *Chromolaena odorata* (L.) King and Robinson were observed for the first time in this study.

Keywords: Aphid, New host plant, New record, Thracian, Türkiye

ÖZ

Yaprak bitleri, konak bitkiye özgü zorunlu fitofag böceklerdir. Yaprak bitleri, yeni konak bitkileri ve yeni bölgeleri istila etmelerinden dolayı zarar seviyeleri giderek arttığından araştırmacıların ilgisini çekmiştir. Çalışma Temmuz-Kasım 2024 tarihleri arasında Kırklareli, Tekirdağ ve İstanbul illerinde yürütülmüştür. Örneklerin tanımlanması için bazı önemli ayırt edici karakterler ölçülmüştür. Bu çalışma sonucunda dokuz yaprak biti türü, *Aphis* (*Aphis*) *eupatorii* Passerini, 1863; *Aphis* (*Aphis*) *parietariae* Theobald, 1923; *Capitophorus mitegoni* Eastop, 1956; *Dysaphis* (*Dysaphis*) *ranunculi* (Kaltenbach, 1843); *Illinoia* (*Illinoia*) *liriodendri* (Monell, 1879); *Macrosiphoniella* (*Asterobium*) *asteris* (Walker, 1849); *Protaphis carthami* (Das, 1918); *Tiliaphis shinae* (Shinji, 1924) ve *Yamatochaitophorus yichunensis* Jiang, Chen & Qiao, 2016 Türkiye yaprak biti faunasına eklenmiş ve listelenen tür sayısı 685'e yükselmiştir. Ek olarak, konak bitki *Chromolaena odorata* (L.) King and Robinson üzerinde *A.* (*A.*) *eupatorii*'nin tespiti ilk kez bu çalışmada gözlemlenmiştir.

Anahtar Kelimeler: Afit, Yeni konak bitki, Yeni kayıt, Trakya, Türkiye

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Introduction

The world aphid fauna has recently been represented by approximately 6080 species belonging to 781 genera (Blackman & Eastop, 2025; Favret, 2025) and the Türkiye aphid fauna by 676 species and 28 subspecies. (Görür et al., 2025; Kök et al., 2024). One of the world's most important pests, aphids cause serious damage to crops by feeding on plant sap. It is reported that aphids cause about 40 to 45 per cent yield loss in developing countries and 30 to 35 per cent in developed countries. (Ruberson, 1999). In addition to the direct and indirect damage caused by aphids to host plants, their most important characteristics, telescopic generations and cyclic parthenogenesis, allow them to take advantage of global warming to increase their spread and damage (Görür et al., 2023; Hulle et al., 2010). Türkiye is an important geographical region in terms of geographical location between continents, geological structure, different climate characteristics and rich floristic richness. These properties of the Türkiye resulted in both insect and plant diversity. Approximately 12,000 plant species are listed in Türkiye and 31% of them are endemic (Güner et al., 2012). This floristic shows that more aphid species and new records are possible.

In this study, 9 aphid species from Istanbul, Kırklareli and Tekirdağ were identified for the first time from Türkiye.

Methods

This study was conducted in Kırklareli, Tekirdağ and Istanbul provinces in July to November 2024. Samples from nine different plants were preserved in eppendorf tubes containing 96% alcohol. The permenant slides of the samples were made according to in Martin (1983). These specimens were identified by Blackman & Eastop (2025) using an Olympus BX51 microscope and the current taxonomic status was checked by Favret (2025). The voucher samples were stored at the Biotechnology Department of the Nigde Omer Halisdemir University.

Results

In the study conducted to evaluate the aphid population, nine aphid species were identified on nine plants from the study area. These species are new records for the aphid fauna of Türkiye.

Aphidoidea Latreille, 1802
Aphididae Latreille, 1802
***Aphis* Linnaeus, 1758**

It is the largest genus of aphids and contains around 500 species. About 106 species belonging to this genus have been recorded in Türkiye (Blackman & Eastop, 2025; Görür et al., 2025).

***Aphis (Aphis) eupatorii* Passerini, 1863**

General features: Distributed in Italy and Germany. Dark green or whitish yellow aptera individuals were feeding underside of leaves of *Eupatorium cannabinum* L. The populations were ant attended. Body length (BL): 0.9-2.0 mm (Blackman & Eastop, 2025; Holman, 2009).

Material examined: Kırklareli/Üsküp-Demirköy-Kadınkule pass, 22.VIII.2024. Green or yellow 30 apterae individuals (♀) feeding on the trunk and underside of leaves of *Chromolaena odorata* (L.) King and Robinson. The new host plant *C. odarata* was recorded for the first time. The populations were ant attended. Morphometric measurements of *Aphis (Aphis) eupatorii* are as follows: Body length (BL): 1.05 mm. Sixth antennal segment processus terminalis/sixth antennal segment base (PT/Base): (0.25/0.10): 2.5 mm. Siphunculi length (SIPHL): 0.18 mm. Length of rostrum segment VI + V (RIV+V): 0.10 mm (Figure 1).

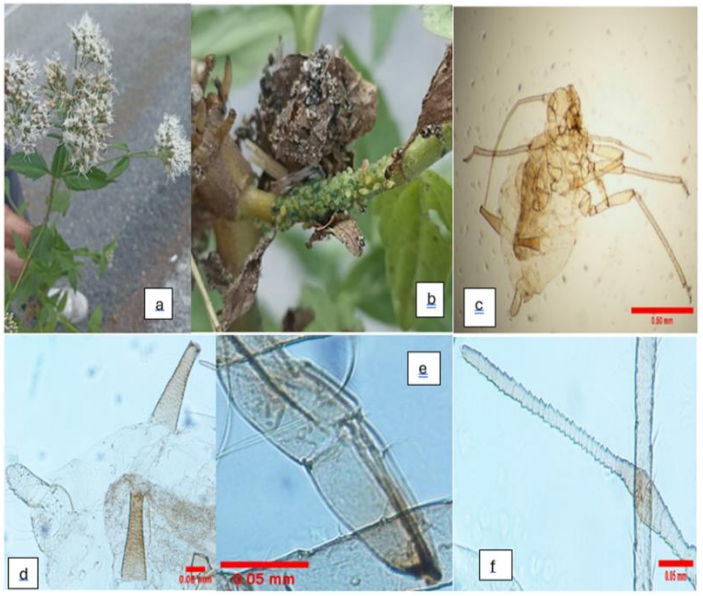

Figure 1.
a) Chromolaena odorata plant, b) Aphis (Aphis) eupatorii on C. odorata, c) General view, d) SIPH and Cauda, e) Rostrum (RIV+V), f) ANT VI (PT+Base).

***Aphis (Aphis) parietariae* Theobald, 1923**

General features: Distributed in Europe, North Africa and Middle East. Dark or pale green aptera individuals were feeding on the stem or underside of leaves of *Parietaria* sp. BL: 0.9-1.7 mm (Blackman & Eastop, 2025; Dransfield, 2025; Holman, 2009).

Material examined: İstanbul/Çatalca, 01.XI.2024. Green 10 apterae individuals (♀) feeding on the underside of leaves of *Paraetaria judaica* L. Morphometric measurements of *Aphis (Aphis) parietariae* are as follows; BL: 1.35 mm. SIPHL: 0.20 mm. RIV+V: 0.11 mm (Figure 2).

Figure 2.
a) Aphis (Aphis) parietariae on Paraetaria judaica, b) General view, c) SIPH and Cauda, d) Rostrum (RIV+V).

***Capitophorus* van der Goot, 1913**

They are widely in the Palearctic and eastern regions. The genus contains about 30 species, and 7 species have been recorded from Türkiye (Blackman & Eastop, 2025; Görür et al., 2025).

***Capitophorus mitegoni* Eastop, 1956**

General features: Palearctic (Africa) originated, distributed in Africa, Afghanistan, India, Bangladesh, Bhutan, Nepal, Hong Kong, Philippines, New Guinea and Australia. Pale green aptera individuals were feeding on the underside of leaves of *Polygonum* sp. and *Persicaria* sp. BL: 1.6-2.2 mm (Blackman & Eastop, 2025; Holman, 2009).

Material examined: Kırklareli/Pınarhisar, 18.VII.2024 and İstanbul/Eyüpsultan-Pirinçci village, 20.VIII.2024. Pale green 15 apterae individuals (♀) were feeding underside of leaves of *Persicaria* sp. and *Persicaria maculosa* Gray Morphometric measurements of *Capitophorus mitegoni* are as follows; BL: 1.62 mm. PT/Base (0.74/0.10): 7.4 mm. SIPHL: 0.55 mm. Cauda length (CaudaL): 0.22 mm (Figure 3).

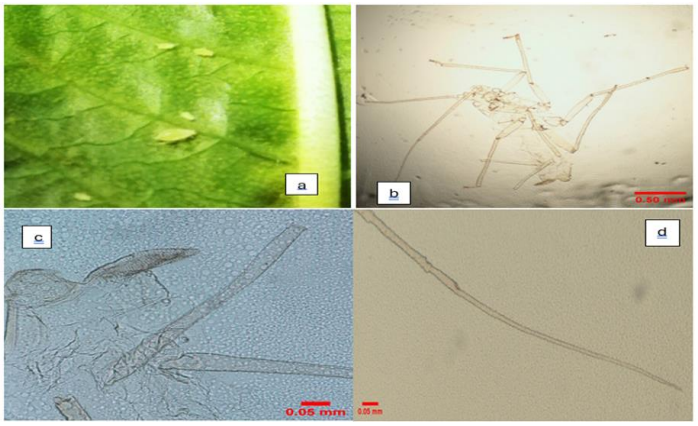

Figure 3.
a) Capitophorus mitegoni on Persicaria maculosa, b) General view, c) SIPH and Cauda, d) ANT VI (PT+Base).

***Dysaphis* Börner, 1931**

It is a Palaearctic genus and consists of about 110 species. About 19 species have been recorded from Türkiye (Blackman & Eastop, 2025; Görür et al., 2025).

***Dysaphis (Dysaphis) ranunculi* (Kaltenbach, 1843)**

General features: Distributed in Europe, Iran and Central Asia. Grey-green with wax, aptera individuals were feeding on *Ranunculus* sp. Also, pale yellowish-green aptera individuals were feeding on curled-leaf galls on *Crataegus* sp. BL: 1.7-2.3 mm (Blackman & Eastop, 2025; Holman, 2009).

Material examined: Kırklareli/Babaeski, 29.X.2024. Pale green 6 apterae individuals (♀) were feeding inside flower of *Ranunculus* sp. Morphometric measurements of *Dysaphis (Dysaphis) ranunculi* are as follows; SIPHL: 0.25 mm (Figure 4).

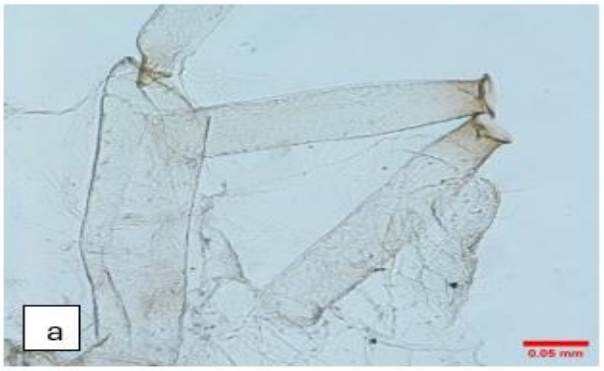

Figure 4.
SIPH and Cauda.

***Illinoia* Wilson, 1910**

This genus includes about 45 North American species and one Caucasian species. 2 species have been recorded from Türkiye (Blackman & Eastop, 2025; Görür et al., 2025).

***Illinoia (Illinoia) liriodendri* (Monell, 1879)**

General features: Nearctic (North America) originated, distributed in North America, Japan, France, Italy, UK, Germany, Luxembourg, Slovenia, Poland, Hungary, Serbia, Greece, Egypt and Korea. Pale green with lightly wax, aptera individuals were feeding underside of leaves of *Liriodendron tulipifera* L. Antennae and siphunculi black except at bases. Also, the legs are pale green except for black apices to the tibiae and tarsi. BL: 1.7-2.5 mm (Blackman & Eastop, 2025; Dransfield, 2025; Holman, 2009).

Material examined: Istanbul/Atatürk arboretum, 20.VIII.2024. Pale green or pale yellow 15 apterae individuals (♀) were feeding underside of leaves of *Liriodendron tulipifera* L. Morphometric measurements of *Illinoia (Illinoia) liriodendri* are as follows; PT/Base (1/0.15): 6.6 mm. Siphunculi length/cauda length (SIPHL/CaudaL): (0.72/0.22): 3.27 mm. RIV+V: 0.10 mm (Figure 5).

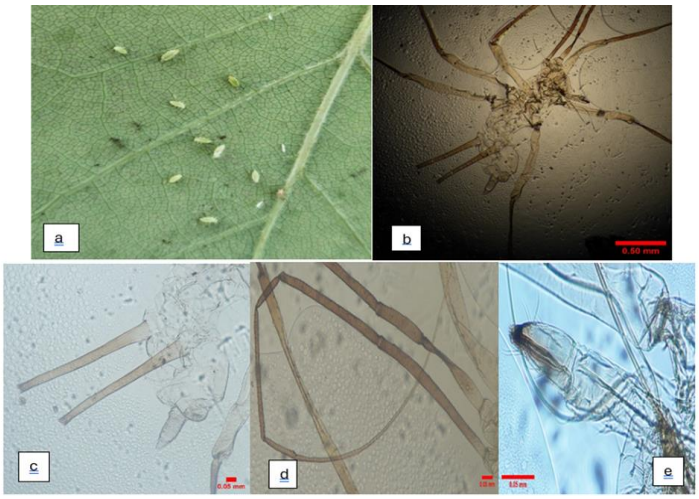

Figure 5.
a) Illinoia (Illinoia) liriodendri on Liriodendron tulipifera, b) General view, c) SIPH and Cauda, d) ANT VI (PT+Base), e) Rostrum (RIV+V).

***Macrosiphoniella* Del Guercio, 1911**

The genus, which is Palearctic and Nearctic, contains about 115 species. About 17 species have been recorded from Türkiye. (Blackman & Eastop, 2025; Görür et al., 2025).

***Macrosiphoniella (Asterobium) asteris* (Walker, 1849)**

General features: Palearctic (Spain) originated, distributed in throughout Europe, Spain and Korea. Reddish brown with little wax, aptera individuals were feeding on the upper parts of the stems and the flowers of *Aster tripolium* L. Also, *Galatella sedifolia* (L.) Greuter has been recorded. BL: 2.3-3.2 mm (Blackman & Eastop, 2025; Dransfield, 2025; Holman, 2009).

Material examined: Kırklareli/Vize/Çüvenli village/ April 10th Police Forest, 30.X.2024. Dark brown 24 apterae individuals (♀) were feeding inside flower of *Galatella linosyris* (L.) Rchb. f. Morphometric measurements of *Macrosiphoniella (Asterobium) asteris* are as follows; BL: 2.65 mm. PT/Base (1.04/0.16): 6.5 mm. SIPHL/CaudaL (1.14/0.55): 2.07 mm. RIV+V: 0.15 mm (Figure 6).

***Protaphis* Börner, 1952**

This genus is closely related to *Aphis* and contains about 50 nominal species. Most nominal species are in Europe and Central Asia. About 5 species have been recorded from Türkiye (Blackman & Eastop, 2025; Görür et al., 2025).

***Protaphis carthami* (Das, 1918)**

General features: Palearctic (North Africa) originated, distributed in North Africa, Lebanon, Iran, Kazakhstan, Pakistan and India. Dark green or reddish-brown with greyish white wax, aptera individuals were feeding on the stems and flowers of *Carthamus tinctorius* L. and *Carthamus* sp. BL: 1.6-2.3 mm (Blackman & Eastop, 2025; Holman, 2009).

Figure 6.
a) Macrosiphoniella (Asterobium) asteris on Galatella linosyris, b) General view, c) Rostrum (RIV+V), d) Cauda, e) ANT VI (PT+Base).

Material examined: Tekirdağ/Muratlı, 20.VII.2024. Dark green with wax, 12 apterae individuals (♀) were feeding on the stems *Carthamus lanatus* L. The populations were ant attended. Morphometric measurements of *Protaphis carthami* are as follows; BL: 1.60 mm. SIPHL: 0.10 mm. RIV+V: 0.14 mm (Figure 7).

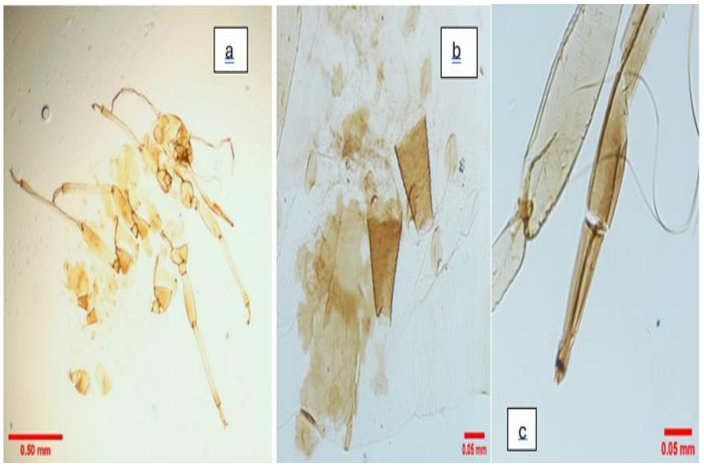

Figure 7.
a) General view, b) SIPH, c) Rostrum (RIV+V).

***Tiliaphis* Takahashi, 1961**

This genus is very similar to *Eucallipterus* and includes four oriental species. 2 species have been recorded from Türkiye (Blackman & Eastop, 2025; Görür et al., 2025).

***Tiliaphis shinae* (Shinji, 1924)**

General features: Palearctic (Japan) originated, distributed in Japan, China, Korea and eastern Siberia. Pale yellow or greenish-yellow alate individuals were feeding on the underside of leaves of *Tilia* sp. BL: 1.7-2.4 mm (Blackman & Eastop, 2025; Holman, 2009).

Material examined: Kırklareli- Central, 29.X.2024. Yellow 10 alate individuals (♀) feeding on the underside of leaves of *Tilia* sp. Morphometric measurements of *Tiliaphis shinae* are as follows; BL: 2.10 mm. PT/Base (0.19/0.08): 2.37 mm. Hind tarsus I segment length/hind tarsus II segment length (HTI/HTII): (0.05/0.10): 0.5 mm. RIV+V: 0.11 mm. (Figure 8).

Figure 8.
a) General view, b) Rhinaria on ANTIII, c) Rostrum (RIV+V), d) HTI and HTII.

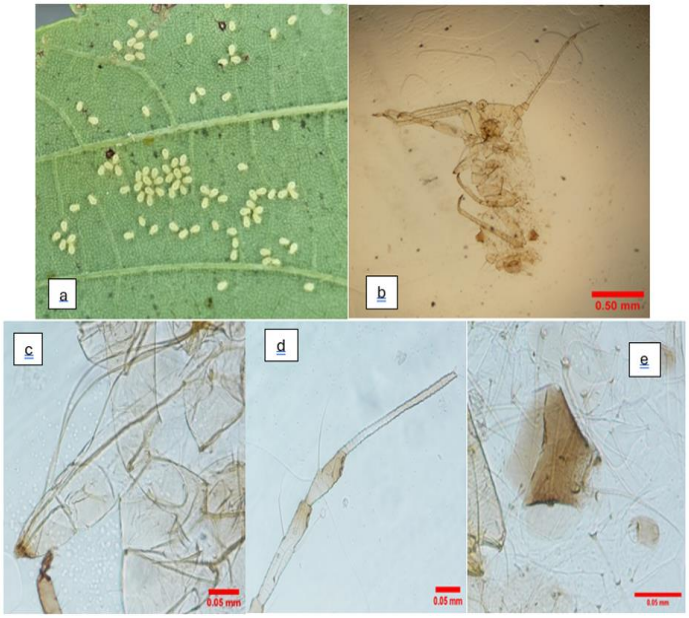

Figure 9.
a) Yamatochaitophorus yichunensis on Acer sp., b) General view, c) Rostrum (RIV+V), d) ANT VI (PT+Base), e) SIPH.

***Yamatochaitophorus* Higuchi, 1972**

This genus includes two east Asian species (Blackman & Eastop, 2025).

***Yamatochaitophorus yichunensis* Jiang, Chen & Qiao, 2016**

General features: Palearctic (China) originated, distributed in China. The records are given on undersides of leaves of *Acer tegmentosum* Maxim. BL: 0.8-1.4 mm (Blackman & Eastop, 2025).

Material examined: Kırklareli/ Değimenköy/ Sarpköy/ Dupnisa cave, 17.VII.2024. Green 35 apterae individuals (♀) aptera individuals were feeding on the underside of leaves and petiole of *Acer* sp. Morphometric measurements of *Yamatochaitophorus yichunensis* are as follows; BL: 1.55 mm. PT/Base (0.25/0.09): 2,77 mm. SIPHL: 0.06 mm. RIV+V: 0.10 mm (Figure 9).

Discussion

Approximately 676 aphid species have been identified in Türkiye so far (Görür et al., 2025; Kök et al., 2024). As a result of various studies, 97 aphid species were identified in Istanbul and approximately 30 species of aphids were recorded from the Thrace region of Istanbul (Çanakçıoğlu, 1967, 1975; Toper Kaygın & Çanakçıoğlu, 2003). Akyıldırım Beğen & Görür (2021), detected 43 aphids in Istanbul (Büyükada) and 2 of these species are new records for the Türkiye aphid fauna. Kök et al. (2016) identified 39 aphid species in Çanakkale and *Aphis sedi* Kaltenbach, 1843 was a new record for the aphid fauna of Türkiye. Kök (2021) described 27 aphid species as a result of their study in Çanakkale (Çardak Lagoon) and stated that *Aphis symphyti* Schrank, 1801 is a new record for the aphid fauna of Türkiye. Tayat & Özder (2024) identified 83 aphid species in their study conducted in Tekirdağ. In another study, 4 species (*Sitobion avenae, Rhapalosiphum padi, Rhapalosihum maidis* and *Schizaphis graminum*) were identified in Edirne (Tayat & Özder, 2016). Considering these studies, it is thought that the aphid diversity in this region is even higher.

Conclusion and Recommendations

With this study, 9 aphid species determined as new records for Türkiye aphid fauna and Türkiye aphid fauna reached to 685 aphid species. In addition, new host plant relation was determined during the conducted study. *Aphis* (*Aphis*) *eupatorii* was detected on the new host plant preference *Chromolaena odorata* (L.) King and Robinson. These studies are very important for determining the aphid fauna of the country. The number of aphid species is expected to increase due to Türkiye geographical characteristics, climatic variability and rich plant diversity. Therefore, further studies are recommended. These findings represent preliminary results of an ongoing project.

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References

Akyıldırım Beğen, H., & Görür, G. (2021). The aphid fauna (Hemiptera: Aphidoidea) and host plants of the Büyükada Island (İstanbul, Turkey). *Journal of Advanced Research in Natural and Applied Sciences*, *7*(1), 1-11. https://doi.org/10.28979/jarnas.890866.

Blackman, R.L. & Eastop, V.F. (2025, Jan 25). Aphids of the world's plants. An online identification and information guide. Retrieved from http://www.aphidsonworldsplants.info.

Çanakçıoğlu, H. (1967). Türkiye'de Orman Ağaçlarına Arz Olan Bitkibitleri (Aphidoidea) Üzerine Araştırmalar. Sıra No 466, Seri No 22. Tarım Bakanlığı, Orman Genel Mudürlüğü Yayınları, Ankara, 151 pp.

Çanakçıoğlu, H. (1975). *The Aphidoidea of Turkey*. Istanbul University Faculty of Forestry Publications, Istanbul, 309 pp.

Dransfield, B. (2025). Biology, images, analysis, design. Retrieved from https://influentialpoints.com/Gallery/Aphid_genera.htm (Accessed: 21.01.2025).

Favret, C. (2025). Aphid Species File. Retrieved from http://Aphid.SpeciesFile.org. (Accessed: 25.01.2025).

Görür, G., Başer, G., Akyıldırım Beğen, H., Şenol, Ö. & Akyürek, B. (2023). Effects of temperature fluctuations on aphids life cycle: Four case species. *Osmaniye Korkut Ata Üniversitesi Fen Bilimleri Enstitüsü Dergisi*, 6(1), 68-77. https://doi.org/10.47495/okufbed.1085692.

Görür, G., Şenol, Ö., Akyıldırım Beğen, H. & Akyürek, B. (2025). Turkish aphid. Retrieved from www.turkishaphid.com. (Accessed: 10.02.2025).

Güner, A., Aslan, S., Ekim, T., Vural, M. & Babaç, M.T. (2012). Türkiye Bitkileri Listesi (Damarlı Bitkiler). ANG Vakfı, İstanbul, Türkiye 1290 pp.

Hullé, M., d'Acier, A. C., Bankhead-Dronnet, S. & Harrington, R. (2010). Aphids in the face of global changes. *Comptes Rendus. Biologies*, *333*(6-7), 497-503.

Holman. J. (2009). Host plant catalog of aphids, Palearctic Region, Springer, Branisovska. Check Republic, 1216 pp.

Kök, Ş. (2021). Diversity and plant interactions of aphids (Hemiptera: Aphidomorpha) adjacent to Çardak Lagoon with new aphid and host records for Turkey. *Turkish Journal of Entomology, 45*(4), 425-439. https://doi.org/10.16970/entoted.995280.

Kök, Ş., Karabacak, E., Yaşar, İ., Kasap, İ. & Barjadze, S. (2024). A new species of Aphis Linnaeus, 1758 (Hemiptera: Aphididae) from the northwestern Türkiye with a key to the species of the subgenus Bursaphis Baker, 1934. *Zootaxa, 5551*(3), 569-579. https://doi.org/10.11646/zootaxa.5551.3.7.

Kök, Ş., Kasap, İ. & Özdemir, İ. (2016). Aphid (Hemiptera: Aphididae) species determined in Çanakkale Province with a new record for the aphid fauna of Turkey. *Turkish Journal of Entomology, 40*(4), 397-412.

Martin, J. H. (1983). The identification of common aphid pests of tropical agriculture. *International journal of pest management, 29*(4), 395-411.

Ruberson, J.R. (1999). Handbook of Pest Management. Marcel Dekkar Inc., New York, USA.

Tayat, E. & Özder, N. (2016). Edirne ilinde buğday tarlalarında görülen yaprakbiti türleri (Hemiptera: Aphididae) üzerine araştırmalar. *Türkiye Entomoloji Bülteni, 6*(1), 53-60. https://doi.org/10.16969/teb.35786.

Tayat, E. & Özder, N. (2024). Aphid (Hemiptera: Aphididae) species on the herbaceous host plants in the Tekirdağ Province (Türkiye). *Turkish Journal of Entomology*, *48*(1), 15-33. https://doi.org/10.16970/entoted.1284917.

Toper Kaygın, A. & Çanakçıoğlu, H. (2003). Contributions to the knowledge of conifer aphid fauna in Turkey and their zoogeographical distribution. *Journal of Pest Science*, *76*(2), 50-56.

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The Utilization of Plant Growth Regulators (PGRs) in Agricultural Application and The Effecting Mechanisms

Tarımsal Uygulamalarda Bitki Büyüme Düzenleyicilerinin (BBD) Kullanımı ve Etki Mekanizmaları

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ABSTRACT

Plants, which lack a sophisticated endocrine system, utilize growth regulators (phytohormones) naturally produced within their bodies to grow, develop, and respond to environmental factors. Many physiological processes in plants occur under the control of hormones that are continuously interacting with each other in a balance. Plant growth regulators are classified into two main categories: growth simulators (e.g auxin, gibberellic acid, cytokinin.) and growth inhibitors (e.g. absisic acid ethylene). They play a role in various processes such as plant elongation, branching, germination, fruit growth, flowering, cell division, root development, and stress responses. This article provides a detailed examination of how plant growth regulators are used in agriculture and their effects on physiological processes. Research on these regulators is of great importance for agricultural productivity and sustainability. They enhance plant growth, improve stress resistance, leading to higher yields and increase product quality. Additionally, they offer opportunities for multiple harvests with shorter growth periods and optimize resource use. Thus, while the economic benefits are provided, environmental impacts are also minimized. Such research contributes to the development of innovative agricultural techniques, playing a critical role for increasing global food demand, ensuring food security.

Keywords: Agriculture, Growth inhibitors, Growth simulators, Plant growth regulators

ÖZ

Gelişmiş bir endokrin sistemi olmayan bitkiler, büyümek, gelişmek ve çevresel faktörlere yanıt oluşturmak için vücutlarında doğal olarak ürettikleri büyüme düzenleyicilerini (fitohormon) kullanmaktadırlar. Bitkide meydana gelen fizyolojik süreçlerin birçoğu bir denge içerisinde birbirileriyle sürekli etkileşim halinde olan hormonların kontrolünde gerçekleşmektedir. Bitki büyüme düzenleyicileri büyümeyi teşvik edenler (örn; oksin, giberellin, sitokinin, …) ve büyümeyi baskılayanlar (örn; absisik asit, etilen) olmak üzere iki ana kategoriye ayrılır. Bitki uzaması, dallanma, çimlenme, meyve büyümesi, çiçeklenme, hücre bölünmesi, kök gelişimi ve stres yanıtları gibi süreçlerde etkilidirler. Bu yazı, bitki büyüme düzenleyicilerinin tarımda nasıl kullanıldığını ve fizyolojik süreçlerde nasıl etki gösterdiğini detaylı bir şekilde ele almaktadır. Bu bağlamda, bitki büyüme düzenleyicileri üzerine yapılan araştırmalar, tarımsal verimlilik ve sürdürülebilirlik açısından büyük önem taşımaktadır. Bu düzenleyiciler, bitkilerin daha hızlı ve sağlıklı büyümesini sağlayarak verimi artırır, stres faktörlerine karşı direnci güçlendirir ve ürün kalitesini iyileştirir. Ayrıca, daha kısa yetişme süreleriyle birden fazla hasat imkanı sunar ve kaynak kullanımını optimize eder. Bu sayede, ekonomik kazanç sağlanırken, çevresel etkiler de minimize edilir. Yenilikçi tarım tekniklerinin geliştirilmesine katkı sunan bu araştırmalar, gıda güvenliğini artırarak, dünya nüfusunun artan gıda talebini karşılamada kritik bir rol oynar.

Anahtar Kelimeler: Tarım, Büyüme engelleyicileri, Büyüme uyarıcıları, Bitki büyüme düzenleyicileri

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Introduction

In the physiological processes of plants, numerous chemical compounds that act as stimulators or inhibitors of growth have been identified, with their chemical structures varying. These compounds, referred to as phytohormones when naturally produced by plants, are produced in low concentrations as signaling molecules within plants. They play crucial roles in plant development and growth (Binici et al., 2022; Çakir et al., 2021; Köksal, 2012; Mundiyara et al., 2020). Understanding these regulators and their mechanisms of action is essential for obtaining higher quality, more productive, and stress-tolerant crops. This article aims to provide informative insights into plant growth regulators, their applications in agriculture with advancing technologies, and their effects on physiological processes.

Growth Regulators

External factors such as light, air, water, and various nutrients significantly influence plant growth and development. In addition to these, internal chemical factors also play a role. Plant growth regulators (PGRs) that regulate plant growth are known as plant growth substances. These regulators can be effective in the tissues where they are produced and can be transported to different parts or tissues of the plant, maintaining their effectiveness in other tissues as well. PGRs influence plant development from germination through to harvest and even post-harvest stages (Kumlay & Eryiğit, 2011). They play important roles in germination, organ development, seed maturation, storage, stress response, and other functional processes (Figure 1) (Amoanimaa-Dede et al., 2022). Auxins, gibberellin (GA), cytokinin (CK), abscisic acid (ABA), and ethylene are among the most important regulators known to influence plant growth, yield, and various physiological responses. Jasmonic acid, salicylic acid, brassinosteroids, strigolactones, and polyamines are also considered plant regulators (Amoanimaa-Dede et al., 2022). Growth regulators can be classified into two main categories: those that promote growth and those that inhibit it (Figure 1) (Kumlay & Eryiğit, 2011). They can also be categorized based on their origin as endogenous (produced with in plants) and exogenous (applied externally) regulators.

Growth Simulators

Growth-promoting regulators primarily include auxins (IAA), gibberellins (GAs), and cytokinins (CKs), which regulate key vegetative processes such as elongation, branching, and organogenesis. The concentrations of these three regulators increase during early fruit development and pollination/fertilization. Strigolactones and brassinosteroids are also included in this group (Srivastava & Handa, 2005; Sezgin & Kahya, 2018).

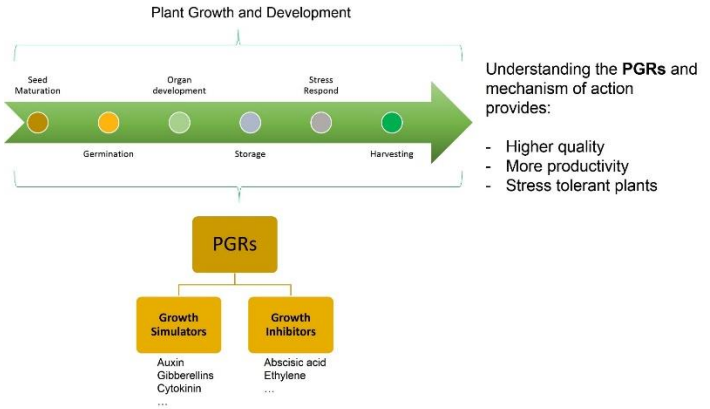

Figure 1.
Classification and function of plant growth regulators (PGRs)

Auxin, first discovered and identified chemically in rice, is one of the most effective hormones in plant growth and development and has been extensively studied. Active forms of auxins include Indole-3-acetic acid (IAA), 4-chloroindole-3-acetic acid (4-Cl-IAA), and phenylacetic acid (PAA), while inactive precursors include Indole-3-pyruvic acid (IPyA), Indoleacetamide (IAM), Indole-3-acetaldoxime (IAOx), Indole-3-acetonitrile (IAN), and Indole-3-acetaldehyde (IAAld). Auxins conjugated with amino acids and sugars, such as Indole-3-butyrate (IBA) and Methyl-IAA (MeIAA), are known as storage forms. Both natural and synthetic forms of auxins are available. Synthetic auxins such as 2,4-dichlorophenoxyacetic acid (2,4-D), 1-naphthaleneacetic acid (NAA), and 4-amino-3,5,6-trichloropicolinic acid (picloram) stimulate the auxin response (Köksal, 2012; Korasick et al., 2013). Auxins are synthesized in high amounts in the apical meristems of plant tissues and are transported to lower tissues, significantly influencing cell elongation and proliferation. They play crucial roles in growth, phototropism, gravitropism, branching, and embryonic pattern formation (Çatak & Atalay, 2020; Liu & Li, 2023; Sezgin & Kahya, 2018). Auxins produced in the apical bud inhibit the growth of lateral buds, allowing the plant to grow with a single main stem. This inhibition mechanism is known as apical dominance. When auxin production stops or the apical bud is removed, the number of branches increases (Çetin, 2002; Rademacher, 2015). Auxins also interact with other compounds to alleviate stress conditions during many abiotic stress processes (Sabagh et al., 2021). When auxin levels are low, plant growth slows, and the number of leaves increases (Çatak & Atalay, 2020).

Gibberellins (GAs), named after the fungus *Giberella fujikuroi* that causes disease in rice, have been extensively studied since 1956, leading to in the isolation of over 50 GAs (Köksal, 2012). According to Sezgin and Kahya (2018), more than 126 forms of GAs exist. GAs, which are predominantly tetrasubstituted diterpenoid compounds, play roles in various physiological

processes including photosynthesis, flowering, leaf development, germination, seed dormancy, and cell division. Gibberellic acid (GA_3) is one of the most produced and used GAs associated with these processes (Amoanimaa-Dede et al., 2022; Kaynak & İmamgiller 1997). Typically synthesized in roots, young leaves, and embryos, GAs affect fruit growth and seedless fruit formation. Excessive application of GAs can cause increased plant height, while insufficient application results in dwarf plants (Çatak & Atalay, 2020).

Cytokinins (CKs), distinct from auxins and GAs, were first identified in coconut milk and later isolated from fish sperm in 1995. CKs promote cell division in tissue cultures and have similar chemical structures to kinetin, which was isolated in 1964 from corn kernels and named Zeatin (Köksal, 2012). CKs are involved in processes such as germination, increasing root and shoot biomass, bud development, enhancing antioxidant capacity, stimulating root and shoot development, leaf expansion, delaying senescence, and promoting chlorophyll synthesis. Unlike auxins, they primarily stimulate root formation rather than shoot development (Çatak & Atalay, 2020; Çetin, 2002; Sabagh et al., 2021). CKs also play a role in plant defense mechanisms (Martineau et al., 1994). Their most effective function is known to be in cell division. Natural and synthetic derivatives of CKs include Zeatin, Dihydrozeatin, Isopentyladenine, Dimethyladenine, Kinetin, Benzyladenine, and Benzimidazole (Çetin, 2002). CKs are closely related to nitrogen metabolism, performing their functions mainly in roots (Sakikabara et al., 2016).

Growth Inhibitors

Growth inhibitors are substances that play inhibitory roles in physiological and biochemical processes related to growth and development. ABA and ethylene are well-known growth inhibitors (Çetin, 2002).

ABA is one of the most recognized growth inhibitors, synthesized in almost all plant tissues, with its quantity varying according to environmental conditions. It is produced in fresh leaves, root tips, buds, and seed embryos. ABA is involved in seed and bud dormancy, preventing seed germination, and promoting stomatal closure under extreme weather conditions, thus preventing leaf, flower, and fruit drop. By regulating stomatal closure, ABA helps conserve water during drought conditions (Çatak & Atalay, 2020; Kaynak & Ersoy, 1997).

Ethylene, despite having a more complex chemical structure compared to other regulators, has a simpler structure and is in a gaseous form at normal temperatures. It is synthesized in ripe fruits, aged leaf tissues, and flowers. Ethylene influences various processes such as seed germination, leaf and fruit abscission, and fruit ripening. It is also activated under biotic and abiotic stress conditions. Its gaseous form allows it to spread easily in the environment and affect other plants. For example, ethylene released by one plant can induce flowering in another or cause nearby fruits to ripen (Çatak & Atalay, 2020; Keskin, 2012).

Utilization Areas of Growth Regulators

The primary applications of plant growth regulators include accelerating ripening, enhancing germination capacity, stimulating or delaying flowering, increasing seed production, improving fruit size, enhancing disease resistance, extending fruit shelf life, preventing fruit drop, breaking dormancy, controlling weeds, and promoting organ development in tissue culture studies (Algül et al., 2016). Similar synthetic derivatives of the growth regulators mentioned above are available. These regulators can be used in agricultural production either by direct application or through natural plant enhancement. For example, synthetic auxin derivatives are known to be effective in weed control (Çatak & Atalay, 2020). Synthetic growth stimulants like NAA, used as a substitute for IAA, have been utilized to thin fruit sets and thus produce larger and higher-quality fruits. They are also known to be used in promoting rooting in cuttings (Kaynak & Ersoy, 1997).

GA_3 is employed in viticulture and some pear varieties for seedless production, in artichokes to promote early maturation, and in strawberries to increase fruit size (Kaynak & İmamgiller, 1997). Many plants enter a period of dormancy after completing their bud growth phases. Various chemicals are used to shorten or eliminate this period. In a study on potatoes, GA application was shown to break dormancy, emphasizing that the hormone should primarily act on the buds of the tubers. Additionally, the effectiveness of GA on potato tubers was found to depend more on the treatment duration than on the GA concentration (Alexopoulos et al., 2008). Despite being an important food source, chestnut trees may exhibit low productivity due to producing fewer female flowers and more male flowers. Consequently, a study investigating flower buds before and after winter indicated that high GA concentrations break bud dormancy and promote male flower bud development, while low GA levels combined with high jasmonic acid concentrations affect female flower bud formation (Cheng et al., 2022).

Short internodal distances are caused by a mutation in a gene that inhibits GA activity or effectiveness. This genetic dwarfism can be completely resolved with GA application. Additionally, plants rich in GA have longer internodes (Feucht & Watson, 1958). For tea quality, which is significantly affected by leaf integrity, obtaining varieties suitable for mechanical harvesting is crucial. A study with seven tea varieties showed a positive correlation between internode length and bud and leaf

integrity, with a strong relationship between GA_3 levels and internode length (Luo et al., 2023).

In a study, external applications of IAA, ABA, and GA_3 to *Nitraria tangutorum* shrubs at doses of 10 mg L^{-1}, 150 mg L^{-1}, and 200 mg L^{-1}, respectively, resulted in increased osmotic regulatory compounds and antioxidant enzyme activities in the plants. This aimed to enhance tolerance to stress factors and improve environmental adaptation (Didi et al., 2022).

Plant tissue culture studies are among the most common areas for using plant hormones. CKs are frequently used in tissue and meristem cultures. In tissue cultures, CKs and auxins are typically used together. When auxins are used in higher amounts than CKs, root formation is stimulated, while excess CKs over auxins result in shoot and leaf formation in callus tissues. When used in similar ratios, they promote the formation of callus tissues (Çatak & Atalay, 2020; Köksal, 2012).

Ethylene, used as a ripening hormone, is also employed in post-harvest technologies to preserve many garden products and as a stress hormone. Ethylene exhibits physiological effects when present in concentrations above 10 ppm in the air. Ethylene production accelerates under stress conditions, with the highest levels detected near plant death (Çatak & Atalay, 2020). On the other hand, during drought conditions, synthesis of another hormone, ABA, increases, and external application of low amounts of ABA is known to reduce plant transpiration (Aslam et al., 2022).

Dosages of external applications of plant growth regulators are crucial. For instance, it has been shown that horizontal gene transfer of antibiotic resistance genes in bacteria is stimulated by IAA and GA_3. The study reported that reactive oxygen species (ROS) formation was induced, changes occurred in cell membrane permeability, and these regulators increased the frequency of gene transfer at specific concentrations (Zhao et al., 2023). This situation leads to an increase in resistant pathogens. It indicates the need for controlled and careful use of PGRs.

The Effect Mechanism of Growth Regulators

The growth and development processes of plants involve complex mechanisms. Therefore, it is challenging to explain which vital functions are affected by chemical stimulators or inhibitors. Understanding how hormones function requires examining the expression of genes in relevant signaling pathways. Cells have specific binding sites, and the presence of these sites is crucial for a hormone's recognition by the cell (Bruinsma, 1985; Keskin, 2012). Each hormone or group of hormones has distinct formation, transport, and effects. Hormones that have similar or opposing effects always maintain a balance (Aydoğdu & Boyraz, 2005). Growth regulators have the ability to activate and block genes and their compounds (Köksal, 2012). The perception of hormones occurs through various ligands and receptors (Sabagh et al., 2021). For example, ethylene binds to receptors in the ER (endoplasmic reticulum) via diffusion across the cell membrane, activating the *EIN3 (ethylene-insensitive 3*) transcription factor. The expression of genes involved in the constitutive triple response, characterized by thick, short stems, and horizontal growth, is stimulated by this TF. *EIN3* directly activates *Ethylene Response Factor (ERF)* genes, aiding in the plant's survival under mechanical stress and other extreme conditions (Keskin, 2012; Tipu & Sherif, 2024). Another example is that ABA interacts with receptors associated with G-proteins in the plasma membrane of plant cells. The activation of G-proteins initiates the synthesis of secondary messengers such as Ca^{+2} ions and ROS (reactive oxygen species), which in turn trigger protein phosphorylation and result in changes in gene expression. Effective responses to various stress conditions arise from these changes in gene expression. ABA application alters cytosolic Ca^{+2} concentrations, leading to the closure of stomata (Keskin, 2012).

Genes like *Aux/IAA* and *DR12* encode proteins with nuclear localization signals and constitute a gene family involved in auxin responses (Srivastava and Handa, 2005). Mutations in the *DR12* gene cause changes in seed and seedling development, fruit cell division, and result in phenotypes such as upward curling leaves, high chlorophyll content, unripe fruit conditions, and irregular fruit formation. These conditions are thought to be due to auxin and CK responses, indicating that *DR12* affects hormonal responses (Martineau et al., 1994; Srivastava & Handa, 2005).

Starch stored in the endosperm is reduced to simple sugars via enzymatic pathways during germination and is transported to the embryo as an energy source. In the germination environment, the seed swells with water, and GA is synthesized in the embryo. GA is transported to the layer surrounding the endosperm, where it facilitates the movement of starch by inducing the formation of amylase and protease enzymes (Karakurt et al., 2010). The role of GA in this enzymatic effect is controlled by genes. Genes responsible for enzyme synthesis become active in the presence of GA (Boyraz et al., 2019).

An increase in auxin levels in plants stimulates ethylene production, which then inhibits the effects of auxin, thereby slowing down plant growth (Çatak & Atalay, 2020). Ethylene, the primary regulator of fruit ripening, causes the breakdown of cell walls, leading to reduced fruit firmness and changes in color, thereby facilitating ripening (Tipu & Sherif, 2024).

Growth regulators also respond under stress conditions. For example, auxins interact with stress response signaling components such as Ca^{+2} and ROS. During nutrient deprivation, they play a role in stimulating root

development to enhance the uptake of essential nutrients like N, P, and K from the soil. For instance, the nitrate transporter gene *NRT1-1* stimulates the downward movement of auxins, reducing their accumulation in lateral roots (Sabagh et al., 2021).

Hormonal changes induced by pathogen-host interactions or other stress factors in plants can be controlled through the application of external growth regulators. This approach can also enhance the host's activity against pathogens. For example, the destruction of the host cell wall by enzymes such as pectinase, hemicellulose, and protease from pathogens facilitates pathogen development within the plant. By altering the solubility of pectin with auxins, the damage to pectin structures by pathogen enzymes is prevented, leading to the development of resistant plants (Aydoğdu & Boyraz, 2005). Auxins are also thought to influence phenol metabolism, thereby contributing to disease resistance.

Under stress conditions, growth regulators play regulatory roles in processes such as ROS scavenging, effective photosynthesis, stress protein accumulation, and other crucial metabolic processes. PGRs manage defense responses through synergistic and antagonistic activities known as crosstalk. They balance the negative effects of stress conditions by interacting with various compounds such as nitrates, H_2O_2, ROS, and NO^- (Sabagh et al., 2021).

Conclusion

PGRs play a critical role in plant growth and development processes. Particularly, growth regulators such as auxins, GAs, and CKs promote plant growth and enhance productivity. Additionally, the potential of plant growth regulators to increase plant resilience under environmental stress conditions is of great significance. However, effective use of these regulators requires determining the correct dosages and careful application. Future research should continue to improve the understanding of these regulators' mechanisms and their more effective use in agricultural practices. Studies like these are essential for supporting sustainable agriculture, enhancing agricultural productivity, and promoting environmental sustainability.

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References

Alexopoulos, A. A., Aivalakis, G., Akoumianakisa, K. A., & Passam, H. C. (2008). Effect of gibberellic acid on the duration of dormancy of potato tubers produced by plants derived from true potato seed. *Postharvest Biology and Technology*, *49*(1), 424-430.

Algül, B. E., Tekintaş, F. E., & Dalkılıç, G. G. (2016). The Usage of Plant Growth Regulators and Hormone Biosynthesis Booster Applications. *Journal of Adnan Menderes University Agricultural Faculty*, *13*(2), 87-95.

Amoanimaa-Dede, H., Su, C., Yeboah, A., Zhou, H., Zheng, D., & Zhu, H. (2022). Growth regulators promote soybean productivity: a review. *PeerJ*, 10:e12556.

Aslam, M. M., Waseem, M., Jakada, B. H., Okal, E. J., Lei, Z., Saqib, H.S.A., Yuan, W., Xu, W., & Zhang, Q. (2022). Mechanisms of abscisic acid-mediated drought stress responses in plants. *International Journal of Molecular Sciences*, 23, 1084.

Aydoğdu, M., & Boyraz, N. (2005). Plant growth regulators (hormone) and resistance to diseases (A review). *Bitkisel Araştırma Dergisi*, 1, 35-40.

Binici, S., Çelik, C., Yıldırım, F., & Yıldırım, A. (2022). Determination of the effect of harpin protein on nacl salt stress in pistachio (*Pistacia vera* L.) seeds. *Turkish Journal of Nature and Science, 11*(2), 141-150.

Boyraz, M., Korkmaz, H., & Durmaz, A. (2019). Dormancy and Germination on Seeds. *Black Sea Journal of Engineering and Science*, *2*(3), 92-105.

Bruinsma, J. (1985). Growth regulators in horticulture. *Scientific Horticulture*, *36*: 1-11.

Cheng, H., Zha, S., Luo, Y., Li, L., Wang, S., Wu, S., Cheng, S., & Li, L. (2022). JAZ1-3 and MYC2-1 synergistically regulate the transformation from completely mixed flower buds to female flower buds in *Castanea mollisima*. *International Journal of Molecular Sciences*, *23*, 6452.

Çakir, M., Yildirim, A. N., Çelik, C., & Esen, M. (2021). The effect of different plant growth regulators on the

quality and biochemical content of jeromine apple cultivar. *Anadolu Journal of Agricultural Sciences, 36* (3), 478 – 487.

Çatak, E., & Atalay, A. (2020). Plant hormone types and effects on plant growth. *Euroasia Journal of Mathematics, Engineering, Natural & Medical Sciences*. *7*(11), 1-6.

Çetin, V. (2002). Plant Growth Regulators in Used Fruits and Vegetables. *Gıda ve Yem Bilimi-Teknolojisi*, *2*, 40–50.

Didi, D. A., Su, S., Sam, F. E., Tiika, R. J., & Zhang, X. (2022). Effect of plant growth regulators on osmotic regulatory substances and antioxidant enzyme activity of *Nitraria tangutorum. Plants*, *11*, 2559.

Feucht, J. R., & Watson, D. P. (1958). The Effect of gibberellins on ınternodal tissues of *Phaseolus vulgaris* L. *American Journal of Botany*, *45*(7), 520-522.

Karakurt, H., Aslantaş, R., & Eşitken, A. (2010). The Environmental Factors and Some Pre-treatments Affecting On Seed Germination and Plant Growth. *Journal of Agricultural Faculty of Uludag University, 24*(2), 115-128.

Kaynak, L., & Ersoy, N. (1997). General Proporties and Usage of Plant Growth Regulators. *Akd. Üniv. Zir. Fak. Dergisi*, *10*, 223-236.

Kaynak, L., & İmamgiller, B. (1997). Role of the Plant Growth Regulators on Physiological Activities. *Akd. Üniv. Zir. Fak. Dergisi*, *10*, 289-299.

Keskin, B. C. (2012). Signaling in Plants. *Türk Bilimsel Derlemeler Dergisi*, *5*(1), 53–73.

Korasick, D. A., Enders, T. A., & Strader, L. C. (2013). Auxin biosynthesis and storage forms. *Journal of Experimental Botany*, *64*(9), 2541–2555.

Köksal, İ. (Ed.). (2012). Bahçe bitkileri tarımında büyümeyi düzenleyicilerden yararlanma. Genel bahçe bitkileri 3rd edn., Ankara Üniversitesi Yayınları, No: 1579, Ankara.

Kumlay, A. M., & Eryiğit, T. (2011). Growth And Development Regulators in Plants: Plant Hormones. *Iğdır Univ. J. Inst. Sci. & Tech*., *1*(2), 47-56.

Liu, J., & Li, X. (2023). Recent advances in application and progress of advanced materials as adsorbents in sample preparation for plant growth regulators. *Journal of Separation Science*, *46*, 2300066.

Luo, Y., Yu, Q., Xie, Y., Xu, C., Cheng, L., Shi, Q., Li, Y., Zhang, X., & Shen, Z. (2023). Internode length is correlated with GA_3 content and is crucial to the harvesting performance of tea-picking machines. *Plants*, *12*, 2508.

Martineau, B., Houck, C. M., Sheehy, R. E., & Hiatt, W. R. (1994). Fruit-specific expression of the *A. tumefaciens* isopentenyl transferase gene in tomato: effects on fruit ripening and defense-related gene expression in leaves. *The Plant Journal*, *5*(1), 11–19.

Mundiyara, R., Sodani, R., & Bhati, S. S. (2020). Role of plant growth regulators in crop production. *Agriculture and Food*, *2*(6), 822–825.

Rademacher, W. (2015). Plant growth regulators: backgrounds and uses in plant production. *Journal of Plant Growth Regulation*, *34*(4), 845–872.

Sabagh, A. E., Mbarki, S., Hossain, A., Iqbal, M. A., Islam, M. S., Raza, A., Llanes, A., Reginato, M., Rahman, M. A., Mahboob, W., Singhal, R. K., Kumari, A., Rajendran, K., Wasaya, A., Javed, T., Shabbir, R., Rahim, J., Barutçular, C., Rahman, M. H. U., Raza, M. A., Ratnasekera, D., Konuskan, O., Hossain, M. A., Meena, V. S., Ahmed, S., Ahmad, Z., Mubeen, M., Singh, K., Skalicky, M., Brestic, M., Sytar, O., Karademir, E., Karademir, C., Erman, M., & Farooq, M. (2021). Potential role of plant growth regulators in administering crucial processes against abiotic stresses. *Front. Agron*. *3*, 648694.

Sakikabara, H., Takei, K., & Hirose, N. (2006). Interactions between nitrogen and cytokinin in the regulation of metabolism and development. *TRENDS in Plant Science*, *11*(9), 440-448.

Sezgin, M., & Kahya, M. (2018). Phytohormones. *Bitlis Eren University Journal of Science and Technology*, *8*(1), 35–39.

Srivastava, A., & Handa, A. K. (2005). Hormonal regulation of tomato fruit development: A molecular perspective. *Journal of Plant Growth Regulation*, *24*(2), 67–82.

Tipu, M. M. H. & Sherif, S. M. (2024). Ethylene and its crosstalk with hormonal pathways in fruit ripening: mechanisms, modulation, and commercial exploitation. *Front Plant Sci*, 15:1475496.

Zhao, H., Liu, X., Sun, Y., Liu, J., & Waigi, M. G. (2023). Effects and mechanisms of plant growth regulators on horizontal transfer of antibiotic resistance genes through plasmid-mediated conjugation. *Chemosphere*, *318*, 137997.