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RESEARCH ARTICLE

Characterization of olive (*Olea europaea* L.) cultivars; colour properties, biochemical contents, antioxidant activity and nutrient contents

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Abstract The olive tree, scientifically known as *Olea europaea* L., is an evergreen xerophytic tree that defines the natural flora, historical background, and cultural essence of the Mediterranean Basin. This study aimed to establish relationships using multivariate analysis methods between the nutrient content of soil conditions in which olive cultivars grown in Türkiye are cultivated and the nutrient element content, phytochemical contents, antioxidant activity, total chlorophyll amount, and leaf colors of these cultivars. All data sets used in the study were analyzed in 2022 and 2023, and average values were used in the research. According to Tukey's comparison result, it was determined that the soil structure of the garden was homogeneous in terms of nutrients it contained. In nutrient analysis conducted on leaves, in the 'Çelebi' cultivar, Al (59.25 mg kg^{-1}), B (6.53 mg kg^{-1}), Cu (48.36 mg kg^{-1}), Fe (69.34 mg kg^{-1}), K (1438.11 mg kg^{-1}), Na (197.12 mg kg^{-1}) nutrients are the highest; in the 'Gemlik-21' cultivar, Ca (5485.03 mg kg^{-1}) nutrient is the highest; in the 'Sarı Haşebi' cultivar, Mg (928.11 mg kg^{-1}), Mn (19.71 mg kg^{-1}), S (632.77 mg kg^{-1}) nutrients are the highest; and in the 'Tavşan Yüreği' cultivar, Ni (1.71 mg kg^{-1}), Zn (9.76 mg kg^{-1}) nutrients are the highest. The L* (49.19), b* (29.43) color values are highest in the 'Sarı Yaprak' cultivar, while the a* (28.84) value is highest in the 'Girit Zeytini' cultivar. The highest leaf chlorophyll content was determined in the 'Girit Zeytini' cultivar (95.57). Total phenolics, total flavonoids, antioxidant capacity were determined to be highest in the 'Manzanilla' (151.49 mg GAE/100 g), 'Edincik Su' (39.01 mg QE/100 g), 'Nizip Yağlık' (91.18%) cultivars, respectively. According to the principal component analysis, the first three principal components accounted for 82% of the total variation. The correlation matrix analysis revealed that high levels of certain minerals in the soil led to an increase in the leaves, resulting in positive correlation, while the opposite was true for negative correlation. According to heat map analysis, mineral elements in the leaf were in the same group, while other data sets were in different groups. The data obtained will shed light on future research on similar topics.

Keywords Olive cultivars · Leaf minerals · Soil minerals · Phytochemical content · Antioxidant activity · Multivariate analysis

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Introduction

Different ecological conditions resulting from the climate change in Türkiye from subtropical to continental cause many plant species to spread throughout the country. These plant species are grown by producers both naturally and economically. Olives are among the species that can be grown economically (Ercisli 2004; Ilhan 2024). The olive tree, belonging to the Oleaceae family, is an evergreen plant species. There are approximately 11 million hectares of olive groves in a total of 47 countries (Rallo et al. 2018). Mediterranean Basin countries alone account for over 97% of this area, and cultivation of olive cultivars, both for table olives and oil production, has been practiced since around 4000 BCE (Navajas-Porras et al. 2020).

Suggesting an alternative method to reduce waste disposal and minimize environmental impact, the cultivation of olive trees can be seen as an option driven by the increasing demand for natural products in various industrial sectors such as food and pharmaceuticals (Jabalbarezi Hukerdi et al. 2018). Among these, olive leaves (OL), traditionally used as a folk remedy, have gained prominence recently mainly due to their documented positive effects on human health (diuretic, antipyretic, bladder infections, hypotensive, headaches (Hutchings et al. 1996) and colon cancer (Zeriouh et al. 2017), attributed to their rich phytochemical content (total phenols, total flavonoids, antioxidant activity, etc.) (Pereira et al. 2007; Talhaoui et al. 2015). Consequently, while olives are primarily grown for the production of olive oil and table olives, OL has witnessed increasing demand in the global market, particularly for the extraction of valuable phytochemicals (Pasković et al. 2020).

Olive trees growth, productivity, fruit, and leaf nutrient content rely on essential nutrients such as Al (Aluminum), C (Carbon), H (Hydrogen), O (Oxygen), N (Nitrogen), P (Phosphorus), K (Potassium), Ca (Calcium), Mg (Magnesium), S (Sulfur), Fe (Iron), Zn (Zinc), Mn (Manganese), Mo (Molybdenum), Cu (Copper), B (Boro), Ni (Nickel), Si (Silicon), Co (Cobalt), Na (Sodium), and Cl (Chlorine) (Zipori et al. 2020). Additionally, all nutrients except for C and O are absorbed through the soil solution while being removed from olive orchards during fruit harvesting and pruning activities (Fernández-Escobar et al. 2015).

One of the other significant components found in olive leaves is chlorophylls (Chls) (Bahloul et al. 2014). Chls are green pigments that play a vital role in photosynthesis. They serve as catalysts during the process, converting solar energy into chemical energy (Kacar et al. 2006). Hence, understanding the chlorophyll content of the leaves is of utmost importance in terms of the region's cultivation.

This study aims to establish relationships using multivariate analysis methods between the nutrient content of the soil conditions in which olive cultivars are grown in Türkiye and the nutrient element content, phytochemical contents, antioxidant activity, total chlorophyll amount, and leaf colors of these cultivars leaves.

Materials and methods

Plant material and research region

In the scope of the research, a total of 23 olive cultivars were used, including 20 local ('As Topakaşı', 'Ayvalık', 'Çelebi', 'Domat', 'Edincik Su', 'Elmacık', 'Gemlik', 'Gemlik-21', 'Girit Zeytini', 'Halhalı', 'Karamani', 'Kilis Yağlık', 'Memecik', 'Nizip Yağlık', 'Sarı Haşebi', 'Sarı Ulak', 'Sarı Yaprak', 'Saurani', 'Tavşan Yüreği', 'Uslu') and 3 foreign ('Arbequina', 'Frantoio', 'Manzanilla') cultivars. The cultivars used were grown on their own roots without the use of rootstocks.

The olive grove located in the producer garden in Hatay province covers an area of 50 acres (36°42′44"N 36°30′30"E). The cultivars, planted at 4×4 spacing, are 7 years old, and cultural practices such as irrigation, fertilization, pruning, and spraying are regularly carried out. Hatay province is located in the Mediterranean region, therefore, summers are hot and dry, while winters are mild and rainy.

Soil analysis

Before starting the study, soil analysis was performed to ensure appropriate plant fertilization (Table 1), and the fertilization plan was adjusted accordingly.

Table 2 displays the optimal conditions for plant growth. Fertilization procedures persisted using compound fertilizer (20 + 20 + 20) supplemented with sulfur and micronutrients until the conclusion of April.

Table 1 The physical and chemical characteristics of the soils in the study area

Soil characteristics	0–30 cm value	*Evaluation	30–60 cm value	*Evaluation	References
Sand (%)	43.60		43.25		
Silty (%)	29.87		28.99		
Clay (%)	29.78		33.86		
Texture (%)	65	Clay loam	66	Clay loam	Tüzüner (1990)
pH	7.79	Moderately alkaline	7.85	Moderately alkaline	Tüzüner (1990)
Total salt (%)	0.06	Unsalted	0.06	Unsalted	Tüzüner (1990)
Organic Matter (%)	2.00	Medium	1.91	Medium	Richards (1954)
Available phosphorous (mg kg^{-1})	8.52	Medium	8.29	Medium	Cheng and Kurtz (1963)
Available potassium (mg kg^{-1})	385	High	245	Medium	Richards (1954)
Available calcium (mg kg^{-1})	3150	High	2850	Medium	Loue (1968)
Available magnesium (mg kg^{-1})	284	Very high	269	Very high	Loue (1968)

Table 2 The vital nutrients crucial for the development of most plants and specific related characteristics (Epstein and Bloom 2005; Yaman et al. 2024)

Plant nutrient	Content in dry substance	Suitable shape for the plant
Nitrogen (N)	2.0 (2,5–3,0)	NH_4
Phosphorus (P)	0.2 (0,1–0,5)	H_2PO_{4-}, $HPO_{4-}{}^{2}$
Potassium (K)	1.0 (2,0–3,0)	K^+
Calcium (Ca)	0.5 (0,2–1,0)	Ca^{+2}
Magnesium (Mg)	0.2 (0,1–0,4)	Mg^{+2}
Iron (Fe)	100 (50–250)	Fe^{+2}, Fe^{+3}
Copper (Cu)	15 (10–20)	Cu^+, Cu^{+2}
Manganese (Mn)	50 (20–200)	$Mn2^+$
Zinc (Zn)	20 (6–60)	$Zn2^+$
Boron (B)	20 (6–60)	$BO_3{}^{-3}$, $B_4O_7{}^{-2}$

Additionally, an extra 100 g of ammonium sulfate was administered according to the age of the trees. Fertilizer was incorporated into the soil under the tree canopy prior to irrigation.

Soil samples were collected from different regions of the field for use in the study (Gagour et al. 2024). Samples taken from five different regions of the field were dried at 40 °C and ground into powder to pass through a 2 mm sieve. The prepared samples were analyzed for minerals (Cu, K, Mg, Zn, Mn, Fe, and Na). The mineral analysis was conducted utilizing inductively coupled plasma optical emission spectrometry (ICP-OES), following the NF X31-121 and NF X31-108 standards (Afron 2002), and the results were expressed in mg kg^{-1}. Soil analyses were conducted in five different regions of the area in 2022 and 2023, and average values were utilized.

Leaf nutrient analysis

Leaf nutrient analysis were conducted with 3 replicates, each consisting of 150 leaves. Leaf samples were collected when the fruits began to ripen, which occurred between late September, early October in 2022 and 2023 (Yıldız et al. 2023). Samples of leaves were selected from various sections of the tree in a randomized manner. In olive leaves, the total contents of Al, B, Ca, Cu, Fe, K, Mg, Mn, Na, Ni, S and Zn were determined. Microwave-assisted digestion process using nitric acid (HNO_3) and hydrogen peroxide (H_2O_2) was employed for the decomposition of leaf samples. Dried and ground samples of olive leaves underwent decomposition with a mixture of HNO3-H2O2 acid (2:3 v/v). Following this, the samples were treated in a microwave oven (Refsan, RK55, Kütahya,

Türkiye) through three stages: 145 °C with 75% relative humidity for 5 min; then 180 °C with 90% relative humidity for 10 min; and finally 100 °C with 40% relative humidity for 10 min (Mertens 2005a). The concentrations of nutrients in the samples were determined in mg kg^{-1} using inductively coupled plasma optical emission spectrometry (ICP-OES) (Agilent) (Mertens 2005b).

Phytochemical analysis

Sample preparation: Phytochemical analysis were conducted with 3 replicates, each consisting of 40 leaves. Preparation of the samples was carried out according to Hannachi et al. (2020); phytochemical analysis were extracted through a maceration process with agitation for 24 h at 25 °C, utilizing methanol as the extraction solvent. The resulting solution underwent filtration followed by centrifugation (OHAUS FC5718; Parsippany, New Jersey, USA) at 11, 200 × g for 15 min. The methanolic extracts obtained from olive leafs were employed to determine the contents of phytochemical analysis.

Total phenolics: TPs were assessed using the Folin-Ciocalteu method. A total of 500 µL of fresh leaf extract was mixed with 4.1 mL of distilled water, followed by the addition of 100 µL of Folin-Ciocalteu reagent and 2% sodium carbonate (Na_2CO_3). After incubating the solution in darkness for 2 h, resulting in a blue coloration, it was analyzed at a wavelength of 760 nm using a spectrophotometer (SOIF UV-5100H Spektrofotometre-UV/VIS 200–1000 nm). The obtained outcomes were presented as milligrams of gallic acid equivalent (GAE) per 100 g (fresh weight) (Eyduran et al. 2015). The total phenolic content (TPs) was determined using the equation provided in Eq. 1 (Tunç et al. 2024).

$$Total\ phenol\ (mg\ gallic\ acid\ equivalent\ (GAE/100g)) = (absorbance - 0.046) / 0.0048 \quad (1)$$

Total flavonoids: TFs were quantified following the procedure outlined by Yaman et al. (2024). Absorbance readings were obtained using a spectrophotometer (SOIF UV-5100H UV/VIS Spectrophotometer, 200–1000 nm) with measurements taken at a wavelength of 415 nm. The outcomes were expressed as mg/100 g in terms of quercetin equivalents (QE).

Total antioxidant activity

TAA was assessed utilizing the DPPH (2,2-diphenyl-1-picryl-hydrazyl) method as described by Liguori et al. (2016). The reduction in DPPH absorbance was measured at 517 nm using a spectrophotometer (SOIF UV-5100H UV/VIS Spectrophotometer, 200–1000 nm) at 25 °C (A_{sample}). A solution devoid of olive lead served as the blank (A_{blank}), and its absorbance was recorded. TAA was calculated using the equation presented in Eq. 2 (Adiletta et al. 2018).

$$\%\ inhibition\ of\ DPPH = \left[\left(A_{blank} - A_{sample}\right) / A_{blank}\right] \times 100 \quad (2)$$

Color measurements and total chlorophyll content

Color measurements and leaf chlorophyll content were performed with 3 replications and 30 leaf in each replication. Color measurements (L*, a*, b*) of olive leafs were made with a colorimeter (3nh ST50) (Yaman 2022). To determine changes in leaf chlorophyll content, readings of chlorophyll amount were taken using a SPAD meter (SPAD 502). Measurements were conducted between 10:00–14:00 on two fully developed leaf pairs at the middle part of the shoot (Yaman 2024).

Statistical analysis

Since the study was conducted in 2022 and 2023, statistical analysis was performed by taking the average of 2 years. Soil and leaf nutrient content, biochemical properties, antioxidant activity, leaf color measurement and leaf chlorophyll content were analyzed using the JMP® Pro 17 (JMP® 2024) package program. The TUKEY multiple comparison test was used to evaluate the results, and the findings were presented at the 5% significance level. Principal component analysis (PCA), heatmap analysis and correlation matrix analysis in comparing soil nutrient content with other data sets were performed with the Origin Pro® 2024 (OriginLab® 2024) statistical program.

Results and discussion

Soil analysis

The mineral content of soil samples taken from five different regions of the research area is presented in detail in Table 3. As a result of the analysis, seven nutrients were identified in five regions. The nutrients Cu (0.77–0.91 mg kg^{-1}), K (223.45–256.74 mg kg^{-1}), Mg (154.13–172.83 mg kg^{-1}), and Zn (1.64–1.74 mg kg^{-1}) were found to be statistically insignificant, while minor differences were observed in the content of Fe (3.14–3.62 mg kg^{-1}), Mn (1.25–1.67 mg kg^{-1}), and Na (33.71–39.17 mg kg^{-1}). The samples taken from five different regions demonstrate the homogeneity of the research area in terms of nutrients (Damak et al. 2021). Our findings are parallel to those obtained by Gagour et al. (2024) in their study conducted in Morocco.

Leaf nutrient analysis

Mineral contents of olive leaves across the examined cultivars are given in detail in Table 4. Accordingly, Al ranged from 1.11 ('Nizip Yağlık') to 59.25 mg kg^{-1} ('Çelebi'); B changed between 1.79 ('Nizip Yağlık') and 6.53 mg kg^{-1} ('Çelebi'); Ca varied between 65.26 ('Nizip Yağlık') and 5485.03 mg kg^{-1} ('Gemlik-21'); Cu changed between 0.08 ('Nizip Yağlık') and 48.36 mg kg^{-1} ('Çelebi'); Fe varied between 6.95 ('Nizip Yağlık') and 69.34 mg kg^{-1} ('Çelebi'); K ranged from 0.64 ('Nizip Yağlık') to 1438.11 mg kg^{-1} ('Çelebi'); Mg changed between 17.00 ('Nizip Yağlık') and 928.11 mg kg^{-1} ('Sarı Haşebi'); Mn varied between 0.02 ('Nizip Yağlık') and 19.71 mg kg^{-1} ('Sarı Haşebi'); Na ranged from 25.74 ('Edincik Su') to 197.12 mg kg^{-1} ('Çelebi'); Ni changed between 0.03 ('Elmacık') and 1.71 mg kg^{-1} ('Tavşan Yüreği'); S varied between 24.42 ('Nizip Yağlık') and 525.14 mg kg^{-1} ('Gemlik-21'), and Zn ranged from 0.12 ('Nizip Yağlık') to 9.76 mg kg^{-1} ('Tavşan Yüreği'). Our findings differ from previous research conducted on similar topics in Greece (Dimassi et al. 1999), Portugal (Jordao et al. 1999), and Croatia (Pasković et al. 2013). Toplu et al. (2009) reported that leaf nutrient content varies according to nutrient uptake, ecological conditions, plant species, and cultivars.

Leaf color and chlorophyll content analysis

Color and chlorophyll values of olive cultivars are given in detail in Table 5. The color properties of fruits and leafs significantly influence various parameters, including phytochemical structures (Šamec et al. 2016; Yaman 2022). The L* value ranged from 31.79 ('Domat') to 49.19 ('Sarı Yaprak'). The a* value varied between 6.58 ('As Topakaşı') and 28.84 ('Girit Zeytini'). The b* value ranged from 9.94 ('Frantoio') to 29.43 ('Sarı Yaprak'). Tunç and Nikpeyma (2023) reported L*, a*, b* values in olive cultivars varied between 17.66 and 42.74; -0.44 and 7.47; -2.88 and 20.62, respectively. Leaf chlorophyll content varied between 64.67 ('As Topakaşı') and 95.57 ('Girit Zeytini'). Pouyafard et al. (2016) found that this value ranged between 71.21 and 97.08. Although the L* color value and chlorophyll content we obtained in the study are similar to the findings of researchers, the a* and b* color values do not show similarity. These differences are thought to stem from ecological, nutritional, and cultivar differences (Yaman 2022).

Phytochemical and antioxidant activity analysis

The phytochemical and antioxidant activity contents of olive cultivars given in detail in Table 6. Total phenolics, total flavonoids, antioxidant activity values

Table 3 Mineral content of soil samples from five different regions of the research area (The average of 2022 and 2023 years)

Differences between the means shown with the different letters in the same column are significant at the $p < 0.05$ level

Regions	Cu	Fe	K	Mn	Mg	Na	Zn
Region 1	0.77	3.15 b	237.15	1.67 a	162.2	33.71 b	1.66
Region 2	0.91	3.54 a	231.36	1.59 a	172.83	37.51 a	1.68
Region 3	0.85	3.45 a	223.45	1.25 b	157.99	33.85 b	1.71
Region 4	0.76	3.14 b	256.74	1.28 b	168.36	39.17 a	1.74
Region 5	0.84	3.62 a	246.13	1.63 a	154.13	36.64 a	1.64
Mean	*0.81*	*3.38*	*238.97*	*1.48*	*163.10*	*36.18*	*1.69*

Table 4 Mineral content of olive leaves across the examined cultivars (The average of 2022 and 2023 years)

Cultivars	Al	B	Ca	Cu	Fe	K	Mg	Mn	Na	Ni	S	Zn
'Arbequina'	16.43 fg	5.00 a-e	4799.33 b	2.17 h-j	38.38 e	826.50 h	292.39 j	17.96 ab	108.94 d	0.4 bc	323.11 g	5.65 bc
'As Topakaşı'	17.13 f	3.56 a-f	2968.47 g	1.24 ij	31.18 fg	352.17 n	336.80 i	4.20 g-i	75.57 i	0.47 bc	235.16 k	1.83 fg
'Ayvalık'	15.27 fg	3.83 a-f	1865.87 j	2.04 h-j	28.16 gh	481.75 j	183.60 o	11.43 bc	74.52 ij	0.42 bc	240.32 j	2.84 c-g
'Çelebi'	59.25 a	6.53 a	2573.08 h	48.36 a	69.34 a	1438.11 a	407.32 h	7.84 d-f	197.12 a	1.26 ab	404.79 e	5.69 bc
'Domat'	5.78 jk	2.71 d-f	845.62 o	0.83 ij	12.66 lm	200.12 u	79.85 t	5.46 f-i	26.91 n	0.12 c	126.05 s	1.3 fg
'Edincik Su'	8.58 h-j	3.07 c-f	2081.02 i	5.58 fg	17.64 i	249.16 r	222.31 m	3.75 hi	25.74 n	0.62 bc	149.29 q	2.21 e–g
'Elmacık'	2.75 kl	2.87 c-f	1243.17 l	5.86 fg	9.71 mn	237.18 s	266.49 l	2.93 ij	34.93 m	0.03 c	142.72 r	0.94 fg
'Frantoio'	34.93 d	4.19 a-f	4897.68 b	2.41 h-j	51.71 d	392.11 m	485.07 e	10.77 b-d	84.47 g	0.32 bc	298.31 h	2.86 c-g
'Gemlik'	7.66 ij	2.86 c-f	1701.7 k	1.4 ij	17.2 ij	278.03 q	190.94 n	6.81 e–h	27.09 n	0.1 c	207.5 m	1.58 fg
'Gemlik-21'	38.62 c	5.69 a-d	5485.03 a	7.34 ef	62.09 b	1385.39 b	521.04 d	17.99 ab	133.63 b	0.92 a-c	525.14 b	7.28 ab
'Girit Zeytini'	7.05 ij	3.99 a-f	1131.5 m	1.84 h-j	16.13 jk	403.95 l	152.78 r	5.28 f-i	32.18 m	0.17 c	191.86 o	5.05 b-e
'Halhalı'	6.93 ij	3.67 a-f	1909.65 j	13.41 d	16.07 jk	666.65 i	276.18 k	5.62 f-i	41.95 l	0.13 c	279.65 i	2.68 d-g
'Karamani'	9.68 hi	3.12 b-f	2153.11 i	6.7 ef	19.75 i	311.44 p	275.15 k	3.78 hi	71.95 j	0.18 c	211.76 l	1.55 fg
'Kilis Yağlık'	2.80 kl	2.56 ef	1160.35 lm	4.76 f–h	9.03 kn	157.18 v	174.63 q	2.76 ij	42.81 l	0.12 c	126.54 s	0.78 fg
'Manzanilla'	14.01 g	4.46 a-f	2167.86 l	3.44 g-i	32.07 f	335.12 o	221.93 m	6.87 e–g	95.57 f	0.21 c	196.93 n	3.24 c-f
'Memecik'	34.87 d	5.63 a-d	4534.75 c	7.52 ef	55.15 c	1115.91 e	413.76 g	13.38 b	103.59 e	0.98 a-c	430.04 d	5.53 b-d
'Nizip Yağlık'	1.11 l	1.79 f	65.26 p	0.08 j	6.95 n	0.64 y	17.00 u	0.02 j	26.98 n	0.28 c	24.42 t	0.12 g
'Sarı Haşebi'	16.99 fg	5.78 a-c	4173.94 d	27.38 c	50.05 d	1124.15 f	928.11 a	19.71 a	84.03 gh	0.5 bc	632.77 a	6.92 ab
'Sarı Ulak'	43.26 b	6.1 ab	3508.84 f	45.57 a	53.13 cd	1169.95 c	458.91 f	9.31 c-e	87.09 g	0.32 bc	431.34 d	5.3 b-d
'Sarı Yaprak'	10.99 h	3.96 a-f	1109.72 m	24.5 c	20.23 i	422.8 k	180.40 p	2.7 ij	50.07 k	0.09 c	180.09 p	2.35 e–g
'Saurani'	9.45 hi	5.35 a-e	3760.93 e	26.57 c	25.13 h	950.63 f	894.38 b	10.62 b-d	93.89 f	0.4 bc	488.29 c	6.21 b
'Tavşan Yüreği'	31.8 e	5.57 a-e	4495.22 c	32.09 b	55.56 c	903.32 g	682.97 c	11.88 bc	117.71 c	1.71 a	377.51 e	9.76 a
'Uslu'	5.87 j	2.78 c-f	976.26 n	9.52 e	13.46 kl	233.84 t	136.72 s	2.67 ij	81.28 h	0.08 c	150.44 q	1.56 fg
Mean	*17.44*	*4.13*	*2591.69*	*12.20*	*30.9*	*592.87*	*339.08*	*7.99*	*74.70*	*0.43*	*277.13*	*3.62*

Differences between the means shown with the different letters in the same column are significant at the $p < 0.05$ level

Table 5 Color and chlorophyll values of olive cultivars (The average of 2022 and 2023 years)

Cultivars	Leaf colour L*	Leaf colour a*	Leaf colour b*	Chl (SPAD)
'Arbequina'	33.72 bc	28.84 a	15.33 ab	89.9 ab
'As Topakaşı'	39.55 a-c	21.73 ab	29.43 a	93.03 ab
'Ayvalık'	34.15 bc	18.26 ab	26.87 ab	74.80 ab
'Çelebi'	43.84 a-c	16.75 ab	19.34 ab	95.57 a
'Domat'	31.79 c	15.30 ab	11.79 b	77.93 ab
'Edincik Su'	38.7 a-c	14.68 ab	12.54 ab	85.37 ab
'Elmacık'	45.26 ab	14.15 ab	10.61 b	82.77 ab
'Frantoio'	32.8 bc	14.11 ab	20.72 ab	87.00 ab
'Gemlik'	32.9 bc	13.95 ab	11.30 b	76.70 ab
'Gemlik-21'	35.42 bc	13.00 ab	9.94 b	91.17 ab
'Girit Zeytini'	37.28 a-c	12.72 ab	13.64 ab	89.7 ab
'Halhalı'	40.47 a-c	12.69 ab	26.67 ab	82.90 ab
'Karamani'	37.8 a-c	12.15 ab	20.15 ab	82.20 ab
'Kilis Yağlık'	33.94 bc	11.81 ab	14.66 ab	86.63 ab
'Manzanilla'	33.27 bc	11.46 ab	14.61 ab	83.27 ab
'Memecik'	35.4 bc	11.37 ab	14.75 ab	64.67 b
'Nizip Yağlık'	44.03 a-c	10.77 b	14.89 ab	89.17 ab
'Sarı Haşebi'	40.34 a-c	9.92 b	14.46 ab	89.00 ab
'Sarı Ulak'	35.89 bc	9.11 b	22.21 ab	79.13 ab
'Sarı Yaprak'	49.19 a	9.10 b	13.43 ab	91.33 ab
'Saurani'	35.35 bc	8.68 b	18.15 ab	88.77 ab
'Tavşan Yüreği'	36.58 a-c	6.76 b	18.74 ab	87.07 ab
'Uslu'	40.49 a-c	6.58 b	19.10 ab	87.00 ab
Mean	*37.75*	*13.21*	*17.10*	*85.00*

Differences between the means shown with the different letters in the same column are significant at the $p < 0.05$ level

varied between 51.43 ('Nizip Yağlık) and 151.49 mg GAE/100 g ('Manzanilla'), 14.49 ('Sarı Ulak') and 39.01 mg QE/100 g ('Edincik Su'), 52.94 ('Saurani') and 91.18% ('Nizip Yağlık'), respectively. In a similar study conducted in Iran, they found that total phenolics varied between 42.35 and 190.98 mg GAE/100 g, antioxidant activity ranged from 20.66 to 95.39% (Ghasemi et al. 2018). Our findings are in agreement with the findings of the researchers. In a study conducted in Tunisia, the total amount of flavonoids in olive leaves was found to be between 14.02–24.39 mg QE/100 g (Hannachi et al. 2020). Our total flavonoid findings are higher than the researchers findings. It is estimated that this difference is due to the nutritional status of the tree, the use of different cultivars and the different ecological conditions.

Principal component analysis (PCA)

The 3D principal component analysis of the data sets consisting of three principal components is presented in detail in Fig. 1. PCA is a statistical method used in many branches of science to reduce the complexity in data sets (El Bakali et al. 2022). The 1st, 2nd and 3rd principal components account for 41.3%, 21.2% and 19.5% of the variation, respectively. Thus, the first three principal components account for 82% of the total variation. In the principal component analysis scatter plot, the values of AA, a*, L*, Fe (S), Zn (S), TFs, SPAD, Ca (L), Mg (L), S (L), Zn (L), region 1 and region 2 are located in the positive direction, while the other values are located in the negative direction. In the study conducted by Uslu Aksu et al. (2023), the first three principal components accounted for 62.05% of the total variation. Yaman et al. (2024) determined the variation accounted for by the first three principal components as 40.55%. Our findings regarding the variation captured by the first three principal components are higher than those reported by the researchers. The elevated variance values signify the effectiveness of the classification in the conducted study (Tunç et al. 2024).

Table 6 Phytochemical and antioxidant activity content of olive cultivars (The average of 2022 and 2023 years)

Cultivars	Total phenolics (mg GAE/100 g)	Total flavonoids (mg QE/100 g)	DPPH antioxidant activity (% inhibition)
'Arbequina'	133.28 d	25.09 f-i	75.49 ef
'As Topakaşı'	131.33 d-f	32.50 cd	78.43 de
'Ayvalık'	110.88 i	23.76 g-i	61.76 k
'Çelebi'	108.02 i	26.58 fg	60.78 kl
'Domat'	145.42 b	22.72 i	69.61 hi
'Edincik Su'	140.22 c	39.01 a	59.8 kl
'Elmacık'	124.08 g	26.38 f–h	66.67 ij
'Frantoio'	116.37 h	23.32 hi	80.39 cd
'Gemlik'	128.71 f	30.45 de	82.35 bc
'Gemlik-21'	102.04 j	36.41 ab	84.31 b
'Girit Zeytini'	129.81 ef	27.24 f	58.82 kl
'Halhalı'	116.07 h	25.06 f-i	73.53 fg
'Karamani'	88.88 k	24.65 f-i	80.39 cd
'Kilis Yağlık'	129.96 ef	32.22 cd	58.82 kl
'Manzanilla'	151.49 a	37.81 a	71.57 gh
'Memecik'	140.3 c	31.93 cd	57.84 l
'Nizip Yağlık'	51.43 l	24.68 f-i	91.18 a
'Sarı Haşebi'	141.38 c	26.41 f–h	58.82 kl
'Sarı Ulak'	104.59 j	14.79 j	70.59 gh
'Sarı Yaprak'	130.65 d-f	30.77 d	78.43 de
'Saurani'	147.32 b	27.55 ef	52.94 m
'Tavşan Yüreği'	132.14 de	33.96 bc	58.82 kl
'Uslu'	132.24 de	36.11 ab	65.69 j
Mean	*123.33*	*28.67*	*69.44*

Differences between the means shown with the different letters in the same column are significant at the $p < 0.05$ level

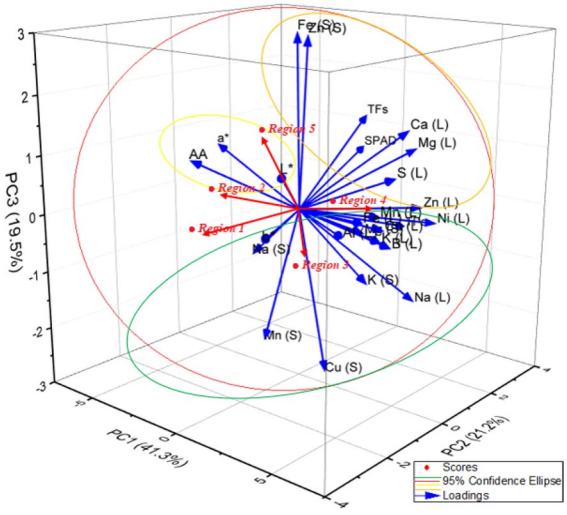


Fig. 1 3D principal component analysis of data sets consisting of three principal components (The average of 2022 and 2023 years)

Correlation matrix analysis

The correlation matrix of soil and leaf nutrient contents is presented in detail in Fig. 2. There is both a positive correlation and statistical significance between Al (L) and Fe (L) ($r = 0.97$**); Mn (L) ($r = 0.96$**); K (S) ($r = 0.89$*). There is a positive correlation between B (L) and Cu (L) ($r = 0.89$*); K (L) ($r = 0.99$***); S (L) ($r = 0.93$*). There is both a positive correlation and statistical significance between Cu (L) and S (L) ($r = 0.89$**); Zn (L) ($r = 0.88$*). There is a positive correlation between Fe (L) and K (L) ($r = 0.88$*); Mn (L) ($r = 0.98$**). There is both a positive correlation and statistical significance between K (L) and S (L) ($r = 0.92$*); Mg and Zn (L) ($r = 0.94$*); Mn (L) and K (S) ($r = 0.88$*); Na (L) and Ni (L) ($r = 0.88$*); Fe (S) and Zn (S) ($r = 0.99$**). Despite the negative correlation between Cu (S) and Fe (S) ($r = -0.93$*);

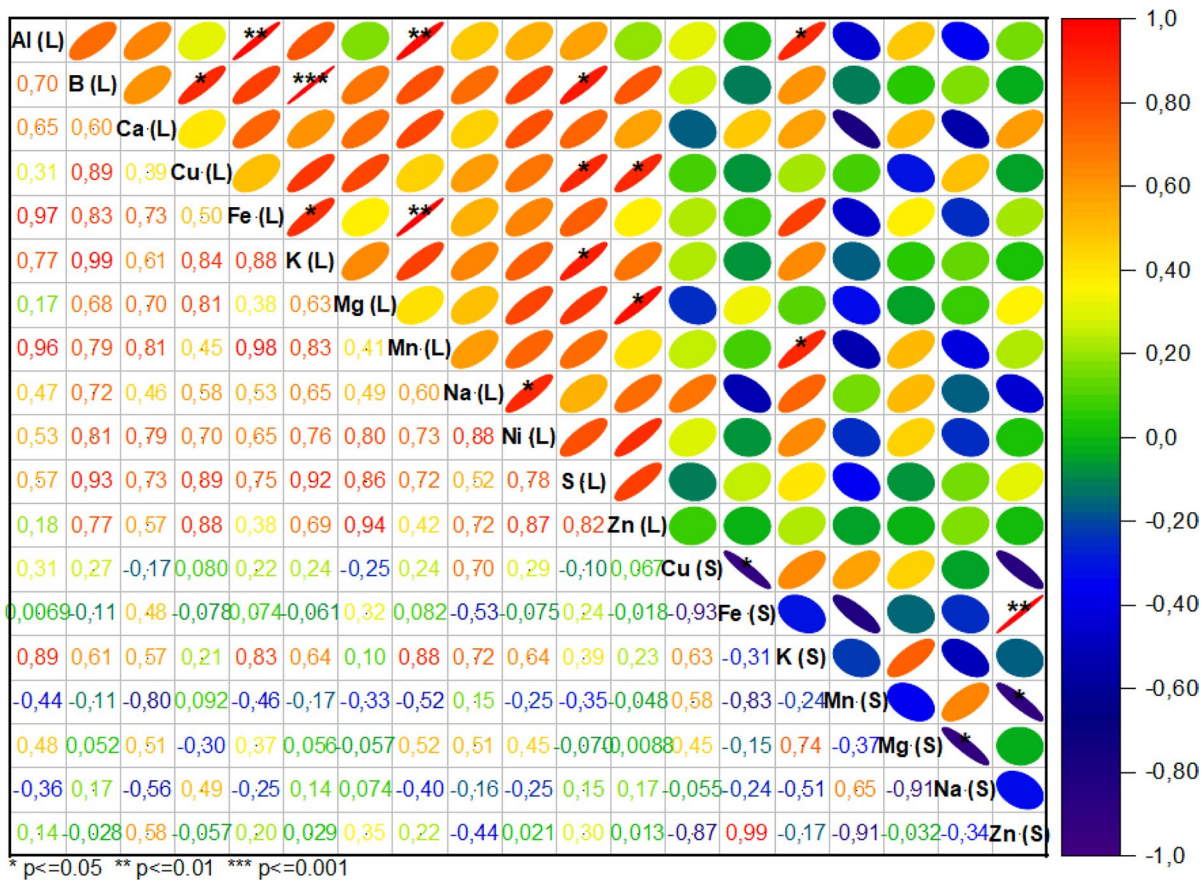


Fig. 2 Correlation matrix of soil and leaf nutrient contents (The average of 2022 and 2023 years). ***(L)*** Leaf, ***(S)*** Soil. *Pearson correlation type was used in the correlation matrix analysis*

Mn (S) and Zn (S) ($r = -0.91$*); Mg (S) and Na (S) ($r = -0.91$*), it is statistically significant.

The correlation matrix consisting of leaf colors, chlorophyll contents, phytochemicals and antioxidant activities is presented in detail in Fig. 3. There is both a positive correlation and statistical significance between L* and b* ($r = 0.94$*); SPAD and TPs ($r = 0.78$***); SPAD and TFs ($r = 0.96$**); TPs and TFs ($r = 0.70$***).

Our findings differ from the research results conducted in Morocco (Gagour et al. 2024) and Türkiye (Gurel et al. 2014). Elevated levels of certain minerals in the soil lead to corresponding increases in the leaves due to absorption, thus elucidating the positive associations among these minerals. Conversely, negative correlations between certain minerals in the soil and leaves may stem from their interchange during absorption or their limited uptake by plant roots (Gagour et al. 2024).

Heatmap analysis

Heatmap analysis of all data sets is presented in detail in Fig. 4. The soil and leaf nutrient contents, leaf color, chlorophyll, phytochemicals, and antioxidant activity were divided into two groups (A and B). Each group was further subdivided into two subgroups (A1, A2 and B1, B2). TPs, TFs, SPAD were included in subgroup A1, while a*, Na (S), Mn (S) were in subgroup A2. AA and Zn (S) were in subgroup B1, while all other datasets were in subgroup B2. The regions were divided into two groups (C and D). Only D was further subdivided into two subgroups (D1 and



Fig. 3 Correlation matrix consisting of leaf colors, chlorophyll contents, phytochemicals, antioxidant activities (The average of 2022 and 2023 years). ***L* a* b**** Leaf colors, ***SPAD*** Leaf chlorophyll content, ***TPs*** Total phenolics (mg GAE/100 g), ***TFs*** Total flavonoids (mg QE/100 g), ***AA*** DPPH antioxidant activity (% inhibition). *Pearson correlation type was used in the correlation matrix analysis*

D2). Region 1 was in group C. While Region 5 was in subgroup D1, the other regions were in subgroup D2.

Conclusion

As a result of the research, very small differences were found in the nutrient contents of soil samples taken from five different regions. Therefore, it was determined that the field soil is generally homogeneous. Despite the general homogeneity of the field soil, significant differences were determined in the leaf nutrient content of the examined olive cultivars. In nutrient analysis conducted on leaves, in the 'Çelebi' cultivar, Al (59.25 mg kg^{-1}), B (6.53 mg kg^{-1}), Cu (48.36 mg kg^{-1}), Fe (69.34 mg kg^{-1}), K (1438.11 mg kg^{-1}), Na (197.12 mg kg^{-1}) nutrients are the highest; in the 'Gemlik-21' cultivar, Ca (5485.03 mg kg^{-1}) nutrient is the highest; in the 'Sarı Haşebi' cultivar, Mg (928.11 mg kg^{-1}), Mn (19.71 mg kg^{-1}), S (632.77 mg kg^{-1}) nutrients are the highest; and in the 'Tavşan Yüreği' cultivar, Ni (1.71 mg kg^{-1}), Zn (9.76 mg kg^{-1}) nutrients are the highest. Additionally, significant differences have been detected in leaf color values (L*, a*, b*), chlorophyll content, phytochemical properties, and antioxidant capacity. The L* (49.19), b* (29.43) color values are highest in the 'Sarı Yaprak' cultivar, while the a* (28.84) value is highest in the 'Girit Zeytini' cultivar. The highest leaf chlorophyll content was determined in the 'Girit Zeytini' cultivar (95.57). Total phenolics, total flavonoids, antioxidant capacity were determined to be highest in the 'Manzanilla' (151.49 mg GAE/100 g), 'Edincik Su' (39.01 mg QE/100 g), 'Nizip Yağlık' (91.18%) cultivars, respectively. These differences are directly associated with the nutritional status of the cultivars, as confirmed by principal component analysis, correlation matrix analysis, and heatmap analysis. This study is indicative of guiding future research and highlights the necessity of its application on different olive cultivars and different fruit types.

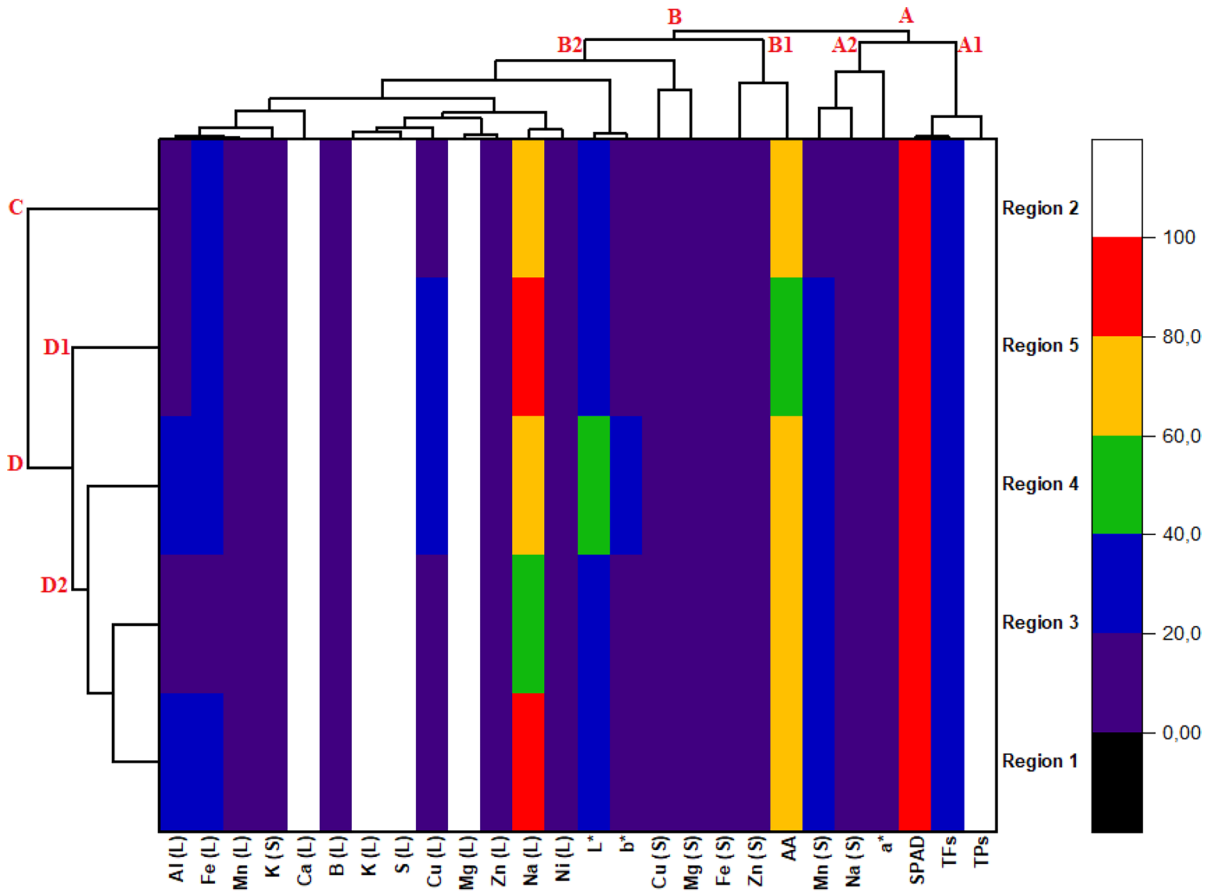


Fig. 4 Heatmap analysis of all data sets (The average of 2022 and 2023 years)

Author contributions Yazgan TUNÇ: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. Mehmet YAMAN: Data curation, formal analysis, methodology, writing – original draft. Yusuf Murat KEÇE: Methodology. Kadir Uğurtan YILMAZ: Methodology, Conceptualization. Ercan YILDIZ: Project administration, Methodology. Adem GÜNEŞ: Formal analysis, Conceptualization.

Consent to Participate and Publish Authors read the manuscript and showed their willingness to publish this study.

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Data availability No datasets were generated or analysed during the current study.

Declarations

Competing interests The authors declare no competing interests.

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