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Determination of Fruit Characteristics, Nutrients and Biochemical Contents of Transvalia (Prunus persica L.) Peach Variety Grafted on Different Clonal Rootstocks Obtained by Selection and Hybridization

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Abstract

Rootstocks are frequently used in modern orchard practise due to their special characteristics. They not only eliminate the limiting factors in fruit growing, but also have advantages such as increasing productivity, fruit quality, dwarfing and nutrient yield. In addition, rootstocks have a significant impact on plant development, fruit characteristics, nutrients and biochemical content. The study was conducted to investigate the effects of different peach rootstocks on fruit quality, nutrient content and biochemical content. A total of 16 rootstocks of the species *P. persica* were used as test material. The morphological characteristics include fruit weight (297,33 g), fruit width (83.5 mm), fruit length (77.58 mm), seed weight (9.96 g), seed width (28.16 mm) and seed length (43 mm). The rootstock GGF3 has the highest values (0.47 mm). The effect of rootstocks on nutrients (except Al, Ca, Cu, K, P and Fe) in the fruits was statistically significant. The effect of rootstocks on nutrients (except Pb, Na and Cr) in the leaves was found to be statistically significant. The effect of the individual rootstocks on the plant nutrients varied. It has been found that there is a positive relationship between micro and macronutrients. The highest mineral content in peach rootstocks was found in rootstock NGF14 with P (1071,34 mg kg^{-1}) and K (4234,30 mg kg^{-1}), in rootstock NG1 with Ca (539,6 mg kg^{-1}) and in rootstock FG64 with Mg (289.98 mg kg^{-1}). With regard to the analysed characteristics, a large variation between the peach rootstocks was observed. According to the results of biochemical analysis, statistically significant differences were found in total biochemical contents. Among the peach rootstocks, KL38 rootstock had the highest content of total flavonoids with 25.68 mg 100gr-1 the highest anthocyanin content with 7.48 mg kg-1, KL38 rootstock also had the highest phenolic content with 137,19 mg kg-1, and NGF14 rootstock had the highest antioxidant content with 349,46 mg kg-1. According to principal component analysis (PCA), the eigenvalue of 13 PCs was above 1.0 and accounted for 85.08% of the total variation; this effectively showed the variation among peach rootstocks with respect to the traits analysed. These results show that most of the peach rootstocks analysed are rich in minerals, nutritional values and bioactive substances. Therefore, these rootstocks, which have high nutritional value and important health properties, can be used as genetic material in peach breeding programmes and similar studies for the development of new peach varieties. The data obtained show that rootstock varieties have a significant impact on the aforementioned traits and that the selection of rootstock varieties has a very important place, especially in economic breeding.

Introduction

Stone fruits play an important role in human health due to the variety of phenolic compounds and carotenoids they contain. Although they have a lower total antioxidant capacity (TAC) than some other fruits such as peaches, strawberries, kiwis, apples and oranges (Szeto, Tomlinson, & Benzie, 2002), they are economically and nutritionally important as they can form an important part of the diet. In spring and summer, the diet needs to be more substantial as portion sizes are usually larger. Phenolic compounds are the main sources of the antioxidant capacity of peaches (Chang, Tan, Frankel, & Barrett, 2000). Vitamin C and carotenoids also contribute to the antioxidant effect (Gil, Tomas-Barberan, Hess-Pierce, & Kader, 2002).

The peach (*Prunus persica*) is recognised worldwide as one of the most popular types of fruit and is considered an important crop. This fruit, which is used for both fresh consumption and processed foods, is known for its delicious flavour, aroma and high nutritional value. However, the cultivation and productivity of peaches can vary greatly depending on plant health, soil conditions and growing methods. Peach cultivation is an important part of the agricultural sector and is successfully grown in different climatic conditions around the world. Looking at the FAO's production data for 2021, a total of 25 million tonnes of peaches and nectarines were produced worldwide (FAO 2021). The content of phytochemicals in fruit tissue is influenced by numerous pre-harvest factors, such as genotype, rootstock, climatic conditions, agricultural practises and harvest time, as well as post-harvest factors, including storage conditions and processing methods (Cevallos-Casals et al. 2004). The key to the commercial expansion of peach production lies in promoting and maintaining the highest possible quality standards for the fruit. To this end, the responses of genotype and rootstock to growing conditions and management must be accurately evaluated and the best combinations identified (Giorgi et al. 2005). In a recent study, we have shown that peach genotype plays an important role in determining the total antioxidant capacity in peach fruit (Tavarini et al. 2008). In addition, Gil et al. (2002) showed in their study on the antioxidant composition of different peach cultivars that the main source of antioxidants are phenolic compounds. Of course, the rootstock is also a very important factor in determining fruit quality. For example, it is known that dwarfing rootstocks can channel more nutrients to the fruit because there is less competition for nutrients from vegetative growth (Chalmers, Mitchell and Van Heek, 1981). In addition, Giorgi et al. (2005) reported that rootstock plays an important role in determining the nutritional characteristics of peaches. Many different rootstocks have been developed for different purposes in fruit production, depending on the different soil and climatic characteristics, the different cultivation parameters and the different growing conditions

For peach production, it is important to understand the effects of different rootstocks on plant and fruit nutrients, biochemical constituents and fruit characteristics. The effects of rootstocks on the nutrient content of peach fruit are very important. Peach fruits are rich in nutrients such as vitamin C, vitamin A, potassium and fibre and are beneficial to human health. Determining the contribution of different rootstock species to the fruit content of these nutrients has the potential to offer healthier and more delicious fruits to consumers. In addition, rootstocks can also affect fruit quality. The firmness, sugar content, size and flavor profile of peach fruits can vary depending on the type of rootstock grown. For example, some rootstocks may produce larger fruit, while others may produce sweeter or firmer fruit. This is an important factor for both consumers and commercial producers. The study was conducted to examine the effects of different rootstocks on the nutrients, biochemical content and pomological properties of peach plants and fruits. The data obtained shows that rootstocks have significant effects on the mentioned characteristics and that the selection of rootstocks has a very important place, especially in economic breeding.

Material and Methods

Plant Material

The material of the study consisted of a total of 16 rootstocks obtained by selection and hybridization. GN-22 (Garnem) and Myrobolan 29 C rootstocks were used as control rootstocks (Table 1). The Transvalia peach variety was utilized as the variety of choice.

Table 1
The rootstocks used in the research and their origins

Rootstock	Origin	Breeding Method
FG-16	*Prunus amygdalus* X *(Prunus dulcis* X *Prunus persica)*	Hybridization
FG-42	*Prunus amygdalus* X *(Prunus dulcis* X *Prunus persica)*	Hybridization
FG-58	*(Prunus amygdalus* X *(Prunus dulcis* X *Prunus persica)*	Hybridization
FG-64	*(Prunus amygdalus* X *(Prunus dulcis* X *Prunus persica)*	Hybridization
NG-1	*(Prunus davidiana* X *Prunus persica)* X *(Prunus dulcis* X *Prunus persica)*	Hybridization
NG-4	*(Prunus davidiana* X *Prunus persica)* X *(Prunus dulcis* X *Prunus persica)*	Hybridization
NG-5	*(Prunus davidiana* X *Prunus persica)* X *(Prunus dulcis* X *Prunus persica)*	Hybridization
NGF-14	*(Prunus davidiana* X *Prunus persica)* X *Prunus amygdalus*	Hybridization
NGF-6	*(Prunus davidiana* X *Prunus persica)* X *Prunus amygdalus*	Hybridization
GGF-3	*(Prunus dulcis* X *Prunus persica)* X *(Prunus dulcis* X *Prunus persica)*	Hybridization
DO-1	*Prunus domestica*	Selection
DO-2	*Prunus domestica*	Selection
KL-23	*Prunus persica*	Selection
KL-24	*Prunus persica*	Selection
KL-38	*Prunus cerasifera*	Selection
KL-39	*Prunus cerasifera*	Selection
GN-22	*(Prunus dulcis* X *Prunus persica)*	Control
Myrobolan 29C	*(Prunus davidiana* X *Prunus persica)*	Control

The Location of the Study

The work material consists of plants that were planted at the Eastern Mediterranean Transition Zone Agricultural Research Institute Field (37° 32' 11" N- 36° 55' 04" E) in the year 2018. In the study, fruit samples were collected from trees that were 4 and 5 years old. The irrigation system was set up in the form of a drip irrigation system, and irrigation was carried out from June to October. During the years of the study, approximately 50 liters of water were given to the plants every 15 days during the irrigation periods. Before establishing the study, a soil analysis was conducted to ensure proper plant fertilization (Table 2), and the fertilization program was prepared according to the values provided for optimal plant development in Table 3. Fertilization procedures were carried out in February with a composite fertilizer (20 + 20 + 20) + Sulfur + Microelements, and by the end of April, additional ammonium sulfate was applied at a rate of 100 g per tree age calculation. Fertilization was applied to the projection of the tree canopy before irrigation using traditional methods.

Table 2. Some physical and chemical properties of the soils of the research area

Soil Properties	Value (0-30 cm)	*Evaluation	Value (30-60 cm)	*Evaluation
Sand (%)	47,4		47,4	
Silty (%)	34,0		34,0	
Clay (%)	18,6		18,6	
Texture		Loamy		Loamy
pH	7.72	Slightly alkaline	7.76	Slightly alkaline
Total salt (%)	0.042	Unsalted	0.041	Unsalted
Organic Matter (%)	3.25	Well	2.67	Medium
Available phosphorous (mg kg^{-1})	8.93	Medium	5.03	Low
Available potassium (mg kg^{-1})	550	Very high	210	Well
Available calcium (mg kg^{-1})	3340	Well	3340	Well
Available magnesium (mg kg^{-1})	290	Very high	260	Very high

The evaluations were conducted according to Bouyoucos (1921) for texture, USDA (1998) for pH, Anonymous (2018) for total salts, Ülgen and Yurtsever (1995) for organic matter, Rehm and colleagues (1996) for available phosphorus and potassium, Loue (1968) for available calcium, and FAO (1990) for available magnesium.

Table 3
The plant nutrient elements required for the growth of most plants and some related characteristics (Çepel, 1996; Jones and Jacobsen, 2001; Epstein and Bloom, 2005; Montanes et al. 1993).

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

Morphologic Analysis

Stone, fruit and leaf analysis

In the study, fruits and leaves were collected from each rootstock plant, with 3 fruits and 3 leaves taken from each. The collected samples were numbered and placed in paper bags. Fruit and leaf samples were brought to the laboratory immediately. In the laboratory, unhealthy and damaged fruits and leaves were removed and placed in numbered papers. Afterward, a preliminary wash was conducted, followed by rinsing with distilled water after 0.1 N HCl solution. Washed samples were dried in a drying cabinet at 65°C until a constant weight was reached, approximately 48 hours. The dried samples were ground, placed in nylon bags, labeled, and stored in a refrigerator until analysis. (Lillehand and Mcollam 1961; Sannoveld and Van Dijk 1982; Kacar and İnal 2008). Fruit weight and seed weight measurements were carried out on a sensitive balance accurate to ± 0.01 g. Digital calipers with a precision of 0.01 mm were used to measure seed parameters such as seed width and seed length, as well as fruit parameters such as fruit width and length. L* (indicating the brightness of the fruit skin color L* = 0 black, L* = 100 white), a* (indicating the change in fruit skin color from green (negative values) to red (positive values)), and b* (indicating the change in fruit skin color from yellow (positive values) to blue (negative values)) color values were obtained using a colorimeter (Minolta CR-400, Minolta, Osaka, Japan).

Analysis of Macro and Micronutrient Elements

The total content of B (Boron), Mg (Magnesium), Mn (Manganese), Na (Sodium), S (Sulfur), Ni (Nickel), Zn (Zinc), Al (Aluminum), Ca (Calcium), Cu (Copper), K (Potassium), P (Phosphorus), and Fe (Iron) in peach fruit and leaves was determined. A microwave-assisted digestion process was used for the decomposition of fruit samples, employing nitric acid (HNO_3) and hydrogen peroxide (H_2O_2). Dried and ground peach samples were decomposed using an HNO_3-H_2O_2 acid mixture (2:3 v/v). Subsequently, the samples were subjected to a microwave oven (Berghof Speedwave, MWS2) at 145°C, 75% relative humidity for 5 minutes; then at 180°C, 90% relative humidity for 10 minutes; and finally at 100°C, 40% relative humidity for 10 minutes in three stages (Mertens, 2005a). The nutrient content of the samples was determined in mg kg-1 using inductively coupled plasma optic emission spectrometry (ICP-OES) (Agilent) (Mertens, 2005b).

Biochemical Analysis

In this study, the bioactive compound content of fruit samples obtained from grafted plants on different peach rootstocks was analyzed. The analyses were conducted to determine total phenolic content, total flavonoid content, and antioxidant and anthocyanin activity using the FRAP and DPPH methods.

Extraction

For the extraction of biochemical analyses, peach fruits were mashed into a puree, and 5 g of fruit sample was weighed. Then, 25 mL of methanol was added, and the mixture was homogenized for 2 minutes. The obtained samples were incubated in the dark at + 4°C (refrigerator) for 16 hours. Subsequently, the samples were centrifuged at 10,000 rpm for 20 minutes, and after centrifugation, supernatants were collected using a micropipette.

Total Phenolic Content

The total phenolic content of peach rootstocks was determined using Folin-Ciocalteu reagents. To each 500 µl of fresh fruit extract from the genotypes, 4,1 ml of distilled water was added, and it was processed with 100 µl of Folin-Ciocalteu reagent and 2% sodium carbonate (Na_2CO_3). The solution was incubated in the dark for 2 hours and then analyzed using a spectrophotometer at a wavelength of 760 nm. The obtained absorbance values were calculated in terms of gallic acid equivalent (GAE) and expressed as mg/100 g (Beyhan et al. 2010).

Total Flavonoid Content

The total flavonoid content of the peach rootstocks was determined following the method described by Demir and colleagues in 2021. For each sample related to the rootstocks, 1000 µL of the sample was mixed with 3,3 ml of methanol, and to this mixture, 0,1 ml of 10% $AlCl_3 \cdot 6H_2O$ and CH_3COOK solution was added. The samples were then measured at a wavelength of 415 nm using a spectrophotometer. The entire flavonoid content was calculated in terms of Quercetin equivalent (QE) and expressed as mg/100 g (Demir et al. 2021).

Total Antioxidant Content

The antioxidant activity of peach rootstocks was determined using a modification of the method developed by Brand-Williams and colleagues in 1995. During the analysis, a 0.26 mM DPPH (1,1-diphenyl-2-picrylhydrazyl) solution was used. For each genotype, 100 µl of fruit extract was mixed with 2900 µl of ethanol and 1 ml of the DPPH solution, and the mixture was vortexed. It was then incubated in the dark for 30 minutes. After incubation, the absorbance values of the genotypes were determined using a spectrophotometer at a wavelength of 517 nm. The total antioxidant activity was expressed in µg of trolox per gram (µg of trolox/g) following the method of Garcia and colleagues in 2012.

Total Anthocyanin Content

The total anthocyanin content of the peach rootstocks was determined using the pH methods described by Giusti and Wrolstad in 2001. During the analysis, the samples were diluted with buffer solutions at two different pH values and incubated for 30 minutes. Subsequently, the samples were analyzed at wavelengths of 527 nm and 700 nm using a spectrophotometer. The results were calculated based on a 26,900 molar absorptivity and expressed as mg cyn-3-glucoside per 100 g (mg cyn-3-gluc /100 g) according to the method by Gil and colleagues in 2000.

Statistical analysis

The study was designed to include three replicates for hardness, water-soluble dry matter content, L, a, b values, titratable acidity, nutrient content in leaves and fruits, phenolic, flavonoid, antioxidant, and anthocyanin values. The obtained data were subjected to variance analysis, and differences between means were determined using the LSD (Least Significant Different) test. The data from the research were evaluated using the Tukey test in the JMP Pro 14 statistical package program (SAS Institute Inc., Cary, NC, USA). Principal components and correlation analyses were performed using the Past 4.13 statistical package program.

Results and Discussion

Morphological Analysis

In the scope of this research, statistically significant differences were found among the rootstocks in terms of fruit and leaf characteristics for all parameters evaluated (Table 4 and Table 5). The lowest and highest fruit weight values among the rootstocks were determined to be between 146,19 g and 297,33 g, respectively. In this parameter, the lowest and highest values were obtained from the KL38 and GGF3 rootstocks, respectively. The fruit width value was taken by the FG16 rootstock with the lowest fruit width value of 53.31 mm, while the GGF3 rootstock obtained the highest fruit width value of 83.50 mm. The lowest fruit length in the research was obtained from the KL38 rootstock, with a length of 74.45 mm. The FG58 rootstock has a higher fruit length of 85.69 mm compared to other rootstocks. However, the analysis results did not show a statistical difference in fruit lengths among the rootstocks. The seed weight value is an important quality parameter for fruits. In the research, seed weight was determined to be between 6.56 g and 9.96 g. The lowest and highest seed weights were obtained from the KL38 and GGF3 rootstocks, respectively. Seed width in the research ranged from 17.18 mm to 28.82 mm. The lowest and highest seed widths were obtained from the KL38 and NG5, FG64, and GGF3 rootstocks at the same significance level. The lowest seed length was obtained from the KL39 rootstock with a length of 33.57 mm. The GGF3 rootstock has a higher seed length of 43.47 mm compared to other rootstocks. Similar morphological values were obtained in other studies. Furthermore, peach fruit weight is a function of the crop load, and statistically higher crop loads may have influenced the similar fruit weight of rootstocks and may have also affected lower fruit weight (Layne, 1994; Day, and DeJong, 1999). De Salvador (2007) conducted a study on several peach rootstocks and showed different sensitivity to alternative crop loads. The rootstocks were more sensitive to increased crop loads, resulting in smaller fruits.

Table 4
Morphological characteristics analyzed in peach rootstock

Rootstock	Fruit weight	Fruit width	Fruit length	Stone weight	Stone width	Stone length
DO1	249,06 a-d	77,71 abc	79,47 a	7,50 bcd	25,34 ab	37,46 bc
DO2	254,50 a-d	78,46 abc	81,29 a	7,10 cd	25,41 ab	38,68 ab
FG16	225,05 cd	53,31 d	72,84 a	8,90 abc	26,96 a	37,98 bc
FG42	198,00 d	73,23 c	79,13 a	8,20 a-d	25,99 ab	40,20 ab
FG58	255,39 a-d	83,03 ab	85,69 a	9,36 abc	27,69 a	42,23 ab
FG64	216,36 cd	74,83 bc	77,03 a	8,76 a-d	28,76 a	38,49 abc
GGF3	297,33 a	83,50 a	77,58 a	9,96 a	28,16 a	43,47 a
KL23	283,01 ab	82,89 ab	79,18 a	7,80 a-d	26,52 ab	41,05 ab
KL24	228,70 bcd	73,84 c	75,10 a	8,76 a-d	26,89 a	37,95 bc
KL38	146,19 e	59,72 d	74,45 a	6,56 d	17,18 c	38,48 abc
KL39	229,10 bcd	79,20 abc	82,98 a	8,90 abc	22,09 b	33,57 c
NG1	224,06 cd	74,09 c	76,66 a	8,03 a-d	27,23 a	39,32 ab
NG4	259,86 abc	81,30 abc	81,25 a	9,16 abc	26,63 ab	41,07 ab
NG5	227,53 bcd	76,69 abc	74,67 a	8,95 abc	28,82 a	40,55 ab
NGF14	211,38 cd	75,01 bc	77,62 a	9,20 abc	27,29 a	38,78 ab
NGF6	197,56 d	76,95 abc	77,25 a	9,60 ab	26,82 a	37,21 bc

Hardness is a critical factor for fruit texture and durability. Hardness data indicates significant differences in the hardness levels of fruits from different rootstocks. The FG16 rootstock has the highest hardness value at 6,4, while the DO1 rootstock has the lowest hardness value at 1.83. Total Soluble Solids (TSS), often referred to as Brix, is important for fruit sweetness and influences consumer preferences. The highest TSS value of 15.63 was observed in the DO1 rootstock, indicating that its fruits have a higher sugar content. The NGF6 rootstock has the lowest TSS value at 9.33, suggesting that its fruits have a lower sugar content. Some authors have reported that soluble solid content is not affected by rootstocks (Caruso et al. 1997; Giorgi et al. 2005). Luminance (L value) is an indicator of fruit brightness. The FG42 rootstock has the highest L value at 50.03, while the KL23 rootstock has the lowest L value at 27.63. This suggests that fruits from the FG42 rootstock have a brighter color. The color values obtained from the analysis indicate that peaches have fruit skin colors ranging from yellow to dark red, and even close to black. Titratable acidity reflects the acid levels in plant fruits, which can affect taste and use. The FG16 rootstock has the highest titratable acidity at 0.46, while the DO1 and KL24 rootstocks have the lowest titratable acidity at 0.12. A high SSC: TA ratio, which combines soluble solid concentration and acid levels, can make the fruit more suitable for consumers (Crisosto, 2001; Crisosto, 2005). The a and b values reflect the color properties of plant fruits. The KL39 rootstock has the highest b value at 196,5, indicating a more distinct fruit color. Higher b values may suggest a more vivid fruit color. The FG16 rootstock has lower a and b values at 21.77 and 17.63, respectively, indicating paler-colored fruits. Many studies have indicated that some peach rootstocks can enhance the yield, size, and quality of commercial peaches (Minas, 2023; Anthony, 2022; Remorini, 2008). While the findings regarding fruit characteristics in this research are similar to previous studies, there are differences among the results. These differences may primarily be due to genetic and environmental influences.

Table 5
Morphological characteristics analyzed in peach rootstock

Rootstock	Fruit flesh firmness	Total soluble solids (TSS)	Fruit skin colour L	Fruit skin colour a	Fruit skin colour b	Titratable acid (TA)
DO1	1,83 c	15,63 a	32,37 ab	31,8 ab	25,53 b	0,12 e
DO2	4,53 ab	12,27 b	44,1 ab	27,5 ab	23,53 b	0,17 cde
FG16	6,4 a	11,07 bc	39,57 ab	21,77 ab	17,63 b	0,46 a
FG42	5,17 ab	12,2 bc	50,03 a	26,23 ab	31,87 b	0,25 a-e
FG58	3,1 bc	11,1 bc	39,87 ab	22,8 ab	18,27 b	0,35 a-e
FG64	4,93 ab	11,73 bc	40,5 ab	28,93 ab	23,9 b	0,34 a-e
GGF3	4 abc	11,87 bc	40,3 ab	29,2 ab	21,5 b	0,36 a-d
KL23	3,17 bc	12 bc	27,63 b	38,4 a	32,17 b	0,27 a-e
KL24	5,33 ab	12,3 b	37,13 ab	26,13 ab	17,67 b	0,12 e
KL38	4,4 abc	11,03 bc	36,43 ab	33,3 ab	26,83 b	0,27 a-e
KL39	4,83 ab	12 bc	40,6 ab	30,13 ab	196,5 a	0,19 b-e
NG1	5,23 ab	11,9 bc	36,07 ab	29,23 ab	19,7 b	0,39 abc
NG4	4,17 abc	12,03 bc	41,6 ab	25,53 ab	23,1 b	0,3 a-e
NG5	4,5 ab	10,67 bc	34,93 ab	16,6 b	14,13 b	0,15 de
NGF14	3,2 bc	11,6 bc	40,37 ab	28,67 ab	23,4 b	0,19 b-e
NGF6	3 bc	9,33 c	29,81 ab	26,27 ab	13,07 b	0,41 b

Nutritional Content Analysis

The mineral content directly affects fruit quality. The study examined the effects of different peach rootstocks on the macro and micro mineral content of fruits (Table 6). The effects of different rootstocks on the fruit content of B, Mg, Mn, Na, S, Ni, and Zn were found to be statistically significant, while other element contents were insignificant. The fruit content of Al, Fe, B, Zn, Cu, Mn, Zn, and Ni was found to be low compared to other elements. In peach fruits, 13 mineral elements were identified, with potassium (K) being dominant. Potassium was followed by minerals such as P, Ca, Na, Mg, and S. Among the rootstocks, NGF14 had the highest K content (4234,3 mg kg^{-1}). It was followed by NG4, NGF6, and KL23 (with 4227,07 mg kg-1, 4165,92 mg kg-1, and 4128,15 mg kg-1, respectively). NGF14 also had the highest P content (1071,34 mg kg-1), while the lowest P content was observed in NG1 (754,11 mg kg-1). NGF14 was followed by NGF6, NG5, and NG4 (with 1062,76 mg kg-1, 1038,54 mg kg-1, and 1002,45 mg kg-1, respectively). NG1 had the highest Ca content (539,66 mg kg-1), while FG16 had the lowest Ca content (170,77 mg kg-1). NG1 was followed by FG64, DO2, and KL38 (with 241,04 mg kg-1, 238,74 mg kg-1, and 236,53 mg kg-1, respectively). DO1 had the highest Na content (346,3 mg kg-1), while DO2 had the lowest Na content (187,86 mg kg-1). DO1 was followed by NGF6, KL39, and NG1 (with 321,28 mg kg-1, 295,84 mg kg-1, and 293,34 mg kg-1, respectively). The highest Mg level was found in FG64 (289,98 mg kg-1), while the lowest Mg level was found in DO1 (158,12 mg kg-1). FG64 was followed by NG4, NG1, and NGF14 (with 271,28 mg kg-1, 268,15 mg kg-1, and 268,03 mg kg-1, respectively). NGF14 had the highest S content (254,57 mg kg-1), while DO1 had the lowest S content (78,9 mg kg-1). NGF6 had the highest Al content (32,49 mg kg-1), while FG42 had the lowest Al content (9,42 mg kg-1). NGF6 was followed by GGF3, FG58, and NG4 (with 17,32 mg kg-1, 17,28 mg kg-1, and 16,61 mg kg-1, respectively). NGF6 had the highest Fe content (24,07 mg kg-1), while KL23 had the lowest Fe content (12,5 mg kg-1). The highest B content was found in NG5 (23,42 mg kg-1), while the lowest B content was found in FG42 (10,48 mg kg-1). FG64 had the highest Zn content (12,76 mg kg-1), while FG16 had the lowest Zn content (7,8 mg kg-1). FG64 was followed by DO2, GGF3, and KL39 (with 10,53 mg kg-1, 10,45 mg kg-1, and 9,61 mg kg-1, respectively). Cu content was highest in FG64 (7,86 mg kg-1) and lowest in KL24 (5,09 mg kg-1). KL23 had the highest Mn content (4,81 mg kg-1), followed by FG6, FG64, and KL39 (with 4,66 mg kg-1, 4,65 mg kg-1, and 4,64 mg kg-1, respectively). FG42 had the highest Ni content (2,24 mg kg-1), while NGF6 had the lowest Ni content. FG42 was followed by DO2, KL39, and KL38 (with 2,13 mg kg-1, 1,27 mg kg-1, and 1,11 mg kg-1, respectively). Statistically significant differences were found in B, Zn, Mn, and Ni content among different peach rootstocks, but not in Fe, Al, and Cu content. Many researchers have emphasized the key role of rootstocks in determining fruit quality and mineral content (Giorgi, 2005; Remorini, 2008). Other studies have also shown that peach rootstocks can improve the nutrient content and quality of commercial peaches (Mestre, 2017; Gullo, 2014).

The study examined the content of macro and micro minerals in the leaves of grafted plants on different peach rootstocks, and the results are presented in Table 7. The effects of different peach rootstocks on elements other than Cr, Na, and Pb in the leaves were found to be statistically significant. In peach plant leaves, 14 mineral elements were identified, with calcium (Ca) being dominant. Ca was followed by minerals such as K, Mg, P, S, Na, Fe, and Al. Among the rootstocks, FG64 had the highest Ca content (15981,81 mg kg-1), while FG42 had the lowest Ca content (8797,96 mg kg-1). Calcium is important for cell wall formation and essential for plant growth. DO2 had the highest K content (6647,05 mg kg-1), while DO1 had the lowest K content (3289,28 mg kg-1). Potassium is important for plant growth and water balance. The Mg content was highest in GGF3 (3330,84 mg kg-1), and other rootstocks showed a similar

level of magnesium content. Magnesium is essential for plants as a macro nutrient and is required for chlorophyll production. P content was highest in NGF6 (978,12 mg kg-1), with other rootstocks showing a similar level of P content. Phosphorus is essential for plant growth and energy transfer. S content was highest in DO1 (442,22 mg kg-1), and other rootstocks showed a similar level of S content. Sulfur is essential for plant protein synthesis and metabolic processes. NGF6 had the highest Na content (347,46 mg kg-1), while KL39 had the lowest Na content (249,59 mg kg-1). DO2 had the highest Fe content (181,64 mg kg-1), and DO2 also had the highest Al content (166,62 mg kg-1). KL23 had the lowest Al content (109,18 mg kg-1). There were no statistically significant differences in Na content among different peach rootstocks, but statistically significant differences were found in Ca, K, Mg, P, S, Cu, Fe, and Al mineral contents. The B, Mn, Zn, Ni, Cu, Cr, and Pb minerals in the fruits of different peach rootstocks were found to be present in low amounts. KL39 had the highest B content (25.12 mg kg-1), with other rootstocks showing a similar level of B content. Boron plays an important role in plant development and fruit quality. DO2 had the highest Mn content (25.82 mg kg-1), with other rootstocks showing a similar level of Mn content. Manganese is important for plant metabolism and enzyme activity. KL39 had the highest Zn content (15,58 mg kg-1), while KL23 had the lowest Zn content (10,05 mg kg-1). KL39 had the highest Ni content (5,33 mg kg-1), with other rootstocks showing a similar level of Ni content. Nickel is important as a micronutrient for plants and is essential for some plant species. KL38 had the highest Cu content (7,04 mg kg-1). Among the rootstocks, FG64 had the highest Cr content (1,36 mg kg-1). The highest Pb content was found in NGF6 (0,36 mg kg-1), and the lowest Pb content was found in KL39 (0,19 mg kg-1). Some studies have highlighted the importance of rootstocks in leaf mineral content values (Gil, 2002; Drogoudi, 2007).

Table 6
Effects of Rootstocks on Nutrients in Fruit

Rootstock	B	Mg	Mn	Na	S	Ni	Zn	Al	Ca	Cu	K	P	Fe
DO1	16,13 ab	158,12 c	3,85 ab	346,3 a	78,9 c	0,93 bcd	7,65 b	16,44 a	232,59 a	6,38 a	3168,97 a	960,43 a	18,16 a
DO2	18,88 ab	182,93 bc	4,22 ab	187,86 b	100,94 bc	2,13 a	10,53 ab	14,05 a	238,74 a	5,96 a	3064,06 a	894,41 a	15,99 a
FG16	19,1 ab	246,65 abc	4,5 ab	286,69 ab	207,3 abc	0,89 bcd	7,8 b	12,29 a	170,77 a	6,24 a	4063,68 a	997,59 a	13,82 a
FG42	10,48 b	207,27 abc	3,77 ab	282,17 ab	160,95 abc	2,24 a	9,26 ab	9,42 a	172,81 a	6,73 a	3116,34 a	855,75 a	15,59 a
FG58	19,41 ab	241,49 abc	4,66 ab	272,36 ab	169,12 abc	0,85 bcd	8,22 b	17,28 a	211,15 a	7,3 a	3676,95 a	947,5 a	19,95 a
FG64	20,55 ab	289,98 a	4,65 ab	288,37 ab	202,32 abc	0,96 bcd	12,76 a	13,5 a	241,04 a	7,86 a	3837,02 a	998,14 a	17,8 a
GGF3	20,3 ab	242,06 abc	4,53 ab	255,78 ab	163,03 abc	1,03 bcd	10,45 ab	17,32 a	235,02 a	7,04 a	3886,77 a	985,58 a	17,32 a
KL23	22,87 a	242,46 abc	4,81 a	263,55 ab	171,21 abc	0,68 cd	9,52 ab	11,23 a	206,87 a	6,54 a	4128,15 a	823,47 a	12,5 a
KL24	18,77 ab	263,76 abc	4,56 ab	212,48 ab	152,99 abc	0,77 bcd	8,18 b	14,75 a	212,07 a	5,09 a	4023,47 a	977,09 a	15,9 a
KL38	17,11 ab	204,09 abc	3,64 b	253,35 ab	147,96 abc	1,11 bc	8,87 ab	14,89 a	236,53 a	6,24 a	3876,29 a	975,57 a	12,84 a
KL39	19,19 ab	248,01 abc	4,64 ab	295,84 ab	157,8 abc	1,27 b	9,61 ab	10,04 a	215,49 a	5,86 a	3790,96 a	914,41 a	15,03 a
NG1	18,02 ab	268,15 ab	4,43 ab	293,34 ab	149,46 abc	0,73 cd	8,57 ab	13,18 a	539,66 a	6,6 a	3618,77 a	754,11 a	15,65 a
NG4	18,14 ab	271,28 ab	4,56 ab	288,7 ab	184,13 abc	0,72 cd	8,85 ab	16,61 a	203,99 a	6,61 a	4227,07 a	1002,45 a	17,76 a
NG5	23,42 a	219,94 abc	4,36 ab	240,84 ab	110,35 bc	1,01 bcd	7,87 b	15,92 a	189,99 a	6,41 a	3753,34 a	1038,54 a	17,1 a
NGF14	14,78 ab	268,03 ab	4,89 a	244,96 ab	254,57 a	0,79 bcd	9,37 ab	20,27 a	221,35 a	7,34 a	4234,3 a	1071,34 a	20,54 a
NGF6	12,11 b	256,91 abc	4,48 ab	321,28 ab	235,47 ab	0,57 d	8,83 ab	32,49 a	218,8 a	6,94 a	4165,92 a	1062,76 a	24,07 a

Table 7
Effects of Rootstocks on Nutrient Elements in the Leaf

ROOTSTOCK	Al	B	Ca	Cu	Mg	Mn	Ni	P	K	S	Zn	Cr	Fe	Na	Pb
DO1	143,46 abc	19,63 ab	11198,87 ab	6,85 ab	3270,79 a	22,36 ab	2,91 b	931,93 ab	3289,28 b	442,22 a	14,23 ab	0,58 a	144,95 ab	310,92 a	0,3 a
DO2	166,62 a	22,9 ab	11408,33 ab	6,76 ab	2700,47 ab	25,82 a	2,68 b	945,47 ab	6647,05 a	335,85 ab	12,09 bc	0,89 a	181,64 a	339,64 a	0,3 a
FG16	114,48 cd	24,04 ab	11953,94 ab	6,33 ab	3145,98 a	21,52 ab	3,04 b	892,63 ab	6192,19 a	291,74 b	10,81 c	0,45 a	123,23 b	257,61 a	0,3 a
FG42	113 cd	20,41 ab	8797,96 b	5,94 ab	1934,05 b	18,09 ab	1,81 b	780,72 ab	5160,25 ab	246,49 b	12,02 bc	0,38 a	118,12 b	282,01 a	0,2 a
FG58	129,71 bcd	19,65 ab	12418,42 ab	6,23 ab	2685,85 ab	18,71 ab	2,24 b	878,94 ab	5438,67 ab	309,15 b	10,79 c	0,52 a	136,23 b	269,42 a	0,2 a
FG64	129,26 bcd	21,15 ab	15981,81 a	6,77 ab	3189,75 a	19,65 ab	2,63 b	852,07 ab	5715,29 a	319,24 b	11,78 bc	1,36 a	153,02 ab	314,92 a	0,3 a
GGF3	126,16 bcd	24,21 ab	12097,4 ab	6,16 ab	3330,84 a	21,08 ab	3,12 b	916,71 ab	5727,02 a	298,77 b	10,81 c	0,48 a	134,82 b	259,55 a	0,2 a
KL23	109,18 d	18,45 b	10629,56 ab	6,15 ab	2556,53 ab	16,95 b	2,66 b	724,48 b	4887,38 ab	289,77 b	10,05 c	0,6 a	120,48 b	265,94 a	0,2 a
KL24	127,06 bcd	21,08 ab	11819,28 ab	6,06 ab	3024,86 a	18,89 ab	2,7 b	845,06 ab	5328,31 ab	299,09 b	10,97 c	0,66 a	133,81 b	288,42 a	0,1 a
KL38	142,41 a-d	24,94 a	15962,91 a	7,04 a	3401,68 a	22,6 ab	2,56 b	933,18 ab	5689,02 a	350,95 ab	12,03 bc	0,66 a	147,66 ab	253,2 a	0,2 a
KL39	124 bcd	25,12 a	11763,59 ab	6,97 a	3091,48 a	22,87 ab	5,33 a	872,18 ab	6219,26 a	334,29 ab	15,58 a	0,47 a	133,1 b	249,59 a	0,1 a
NG1	139,21 a-d	22,55 ab	12397,33 ab	6,78 ab	2796,69 ab	21,92 ab	2,9 b	916,03 ab	5701,1 a	340,56 ab	12,37 bc	0,56 a	144,82 ab	299,08 a	0,3 a
NG4	116,66 cd	21,72 ab	10245,47 b	6,13 ab	2527,2 ab	18,62 ab	2,46 b	812,99 ab	5036,78 ab	279,14 b	10,72 c	0,48 a	130,05 b	270,96 a	0,2 a
NG5	141,2 a-d	22,06 ab	12811,94 ab	6,73 ab	3145,79 a	18,69 ab	2,44 b	960,86 ab	5261,77 ab	271,62 b	10,77 c	0,55 a	148,84 ab	253,15 a	0,3 a
NGF14	135,52 a-d	21,67 ab	12077,21 ab	6,24 ab	3061,37 a	19,39 ab	2,5 b	907,82 ab	5814,8 a	322,06 b	11,8 bc	0,73 a	143,07 ab	271,64 a	0,2 a
NGF6	150,69 ab	19,48 ab	13803,73 ab	6,92 ab	3032,45 a	21,17 ab	2,45 b	978,12 a	6074,1 a	338,58 ab	11,4 c	1,24 a	155,24 ab	347,46 a	0,3 a

Biochemical Analysis

Significant differences were found in the total phenolic content, total flavonoid content, and total anthocyanin content of the fruits obtained from grafted plants on peach rootstocks, and these differences were found to be statistically significant. However, there was no statistically significant difference in the total antioxidant content (Table 8). The evaluated rootstocks were found to have no significant effect on the antioxidant contents of the fruits. The total phenolic content ranged from 30,97 mg 100gr-1 (NG1) to 137,19 mg 100gr-1 (KL38), with KL38 rootstock having the highest phenolic content at 137.19. NG1 rootstock had the lowest phenolic content at 30.97. The significant influence of the rootstocks on phenolic compounds was consistent with a previous study on total phenolics (Orazem, 2011). The values of total flavonoid content ranged from 6,10 mg 100gr-1 (FG58) to 25,68 mg 100gr-1 (KL38), with KL38 rootstock having the highest flavonoid content at 25.68. FG58 rootstock had the lowest flavonoid content at 6.10. In this study, the total anthocyanin content was found to be the lowest in NG4 rootstock at 2,55 mg 100gr-1 and the highest in KL38 rootstock at 7,48 mg 100gr-1. In a study by Gil et al. (2002) on the antioxidant composition in various peach varieties, it was shown that phenolic compounds were the main source of antioxidants. Another study indicated that the antioxidant capacity resulting from the presence of phenolic compounds in peach fruit was strongly influenced by the rootstocks (Petruccell, 2023).

Table 8
Total biochemical analysis results

Rootstock	Phenolic	Flavonoid	Antioxidant	Anthocyanin
DO1	83,85 d	14,72 d	348,11 a	5,12 d
DO2	44,13 fg	8,33 ef	309,14 a	2,60 e
FG16	33,95 jk	7,00 ef	341,39 a	2,62 e
FG42	36,56 hjk	7,75 ef	331,99 a	2,90 e
FG58	40,43 ghj	6,10 f	301,07 a	2,57 e
FG64	40,25 ghj	8,34 ef	309,14 a	2,64 e
GGF3	35,30 jk	8,34 ef	336,02 a	2,82 e
KL38	137,19 a	25,68 a	315,86 a	7,48 a
KL39	120,52 b	23,29 b	321,23 a	6,82 b
KL23	47,82 ef	8,55 ef	348,12 a	2,70 e
KL24	95,39 c	20,42 c	303,76 a	6,15 c
NG1	30,97 k	9,03 e	349,46 a	2,62 e
NG4	32,15 k	14,93 d	309,14 a	2,55 e
NG5	43,05 fgh	8,39 ef	311,82 a	2,89 e
NGF14	37,64 g-k	8,23 ef	349,46 a	2,64 e
NGF6	53,23 e	13,87 d	305,10 a	2,76 e

Principle component and correlation analysis

The Principal Component Analysis (PCA) values based on the fruit quality, nutritional content, and biochemical data of the peach rootstocks are provided in Table 9 and Fig. 1. In the Principal Component Analysis, components with eigenvalues greater than 1 were considered. The first 13 components explain 85.08% of the total variance. The first component explains 16.94% of the total variance and is primarily influenced by minerals (Cu and Zn values) and biochemical properties (total phenolics and total anthocyanins). The second component explains 13.53% of the total variance and is mainly influenced by minerals (Ca, K2, and P2). The third component explains 9.29% of the total variance and is primarily influenced by minerals (Fe, Ni, K2, and Mg2) and anthocyanins, phenolics, and flavonoids. The fourth component explains 7.31% of the total variance and is primarily influenced by fruit weight, fruit width, and fruit length. When comparing the results with previous studies, similar findings were obtained (Usenik et al., 2010; Primoz et al., 2011). This suggests that the PCA results are consistent with previous research, and the components identified provide valuable insights into the relationships between different variables related to peach rootstock fruit quality and nutritional content.

Table 9
Principal component analysis (PCA) and contribution rate based on fruit quality, nutritional content and biochemical data of peach rootstocks

Properties	PCA1	PCA2	PCA3	PCA4	PCA5	PCA6	PCA7	PCA8	PCA9	PCA10	PCA11	PCA12	PCA13
Al	0,22	0,20	-0,23	0,05	0,01	-0,05	-0,05	-0,08	0,04	0,14	-0,08	0,04	0,14
B	0,19	0,01	0,09	-0,14	0,28	-0,06	0,13	0,20	-0,12	0,04	-0,14	0,11	-0,09
Ca	0,11	0,25	0,09	-0,09	-0,01	-0,15	-0,08	0,17	0,23	-0,05	-0,06	0,04	0,23
Cr	0,09	0,14	-0,18	-0,05	-0,06	-0,15	0,20	-0,16	0,15	-0,03	0,37	-0,09	-0,28
Cu	0,29	0,15	-0,06	-0,04	-0,03	0,12	0,14	0,02	0,03	0,06	0,01	0,15	-0,08
Fe	0,20	0,20	-0,25	0,05	0,06	-0,12	0,06	-0,10	0,06	0,16	0,04	-0,06	0,01
K	0,08	0,19	0,01	-0,14	0,33	-0,15	0,08	-0,13	0,04	0,03	-0,22	-0,08	-0,17
Mg	0,14	0,24	0,16	0,03	-0,10	-0,13	-0,10	0,23	-0,18	0,03	-0,05	-0,06	0,18
Mn	0,21	0,11	-0,03	0,11	0,11	-0,08	0,17	-0,18	-0,20	0,00	-0,15	-0,16	0,32
Na	0,04	0,20	-0,14	0,11	0,06	0,05	0,02	-0,05	0,23	-0,21	0,39	-0,06	-0,02
Ni	0,14	0,03	0,25	0,16	0,06	-0,04	0,25	-0,14	-0,24	0,14	0,10	-0,19	-0,19
P	0,21	0,17	-0,15	-0,08	0,03	0,01	0,04	0,15	-0,09	0,01	-0,15	0,31	-0,01
Pb	0,08	0,20	-0,24	-0,10	-0,13	0,07	0,14	0,06	-0,11	0,04	-0,12	-0,14	0,07
S	0,24	0,10	-0,06	0,17	-0,17	0,20	0,08	0,06	-0,09	-0,10	0,04	0,04	0,02
Zn	0,26	-0,01	0,05	0,22	0,03	0,12	0,17	-0,16	-0,07	-0,13	-0,02	0,12	-0,05
Al 2	-0,02	0,18	-0,04	-0,07	-0,22	0,09	-0,30	-0,23	-0,15	0,11	-0,24	-0,04	-0,14
B 2	-0,06	0,13	0,15	0,10	0,09	-0,01	-0,04	0,38	0,00	0,41	0,16	0,03	0,08
Ca 2	-0,04	-0,10	0,00	-0,15	-0,14	0,26	0,27	-0,09	0,07	0,38	-0,07	0,04	0,27
Cu 2	-0,06	0,23	0,00	-0,05	0,06	0,37	-0,04	0,17	0,08	-0,17	0,02	0,01	-0,06
Fe 2	-0,05	0,20	-0,04	-0,01	-0,17	0,21	-0,31	-0,27	-0,18	0,06	-0,16	-0,03	-0,13
K 2	-0,11	0,25	0,28	0,02	-0,03	-0,07	-0,01	0,04	0,04	-0,05	-0,02	0,06	0,07
Mg 2	-0,16	0,21	0,26	-0,12	0,00	0,15	0,05	-0,07	0,09	0,15	0,06	-0,03	-0,01
Mn 2	-0,13	0,24	0,19	0,07	0,07	0,16	0,11	0,06	0,02	0,18	0,12	-0,07	-0,19
Na 2	-0,02	0,01	0,11	0,03	-0,21	0,23	0,31	-0,18	-0,12	-0,20	0,09	0,10	0,32
Ni 2	0,06	-0,10	-0,11	0,07	0,37	0,16	-0,16	-0,16	0,12	-0,10	-0,02	-0,14	0,16
P 2	0,04	0,30	0,08	0,09	0,08	-0,10	-0,25	0,07	-0,13	-0,29	0,09	0,00	-0,03
S 2	-0,16	0,21	0,20	-0,09	-0,02	-0,01	0,06	-0,15	0,14	-0,28	-0,09	-0,07	0,03
Zn 2	-0,02	0,16	0,08	-0,01	0,17	0,29	0,03	0,02	0,33	0,08	-0,15	-0,31	0,16
Anthocyanin	0,25	-0,11	0,27	0,05	-0,09	-0,07	-0,15	-0,01	0,03	0,01	0,07	0,03	0,09
Phenolic	0,26	-0,09	0,25	0,03	-0,11	-0,06	-0,15	-0,02	0,10	0,01	0,05	0,04	0,06
Flavonoid	0,23	-0,08	0,28	0,00	-0,13	-0,10	-0,12	-0,10	0,11	0,01	0,03	0,06	0,05
Antioxidant	0,00	-0,08	-0,02	0,04	0,04	0,20	0,09	0,34	-0,16	-0,22	-0,30	-0,06	-0,27
F. Hardness	0,00	-0,05	0,09	-0,18	0,37	-0,10	0,08	-0,05	-0,15	0,01	0,16	-0,05	0,04
SSC	0,09	-0,09	-0,03	0,30	-0,02	0,21	-0,05	0,24	-0,17	-0,14	0,15	-0,23	0,12
L	-0,06	-0,06	0,03	0,01	0,38	0,15	-0,13	-0,18	-0,08	-0,10	-0,06	0,10	0,25
a	0,06	-0,07	0,03	0,17	-0,18	-0,19	0,12	0,08	0,32	-0,14	-0,28	-0,43	-0,04
b	0,11	-0,07	0,25	0,17	0,11	0,05	0,13	-0,14	0,01	0,04	-0,19	0,01	-0,32
TA	-0,13	0,06	0,06	-0,23	-0,12	-0,12	0,37	0,05	0,00	-0,25	-0,13	0,16	0,06
F. Weight	-0,19	0,03	-0,02	0,40	0,04	-0,11	0,11	0,08	-0,09	0,12	-0,14	-0,01	0,12
F. Width	-0,13	0,05	-0,06	0,42	-0,04	0,00	0,00	-0,10	0,20	0,17	-0,11	0,12	-0,07

(2*: fruit minerals)

Properties	PCA1	PCA2	PCA3	PCA4	PCA5	PCA6	PCA7	PCA8	PCA9	PCA10	PCA11	PCA12	PCA13
F. Length	-0,04	0,04	-0,01	0,30	0,11	0,02	0,03	-0,02	0,30	-0,06	-0,11	0,53	-0,03
S. Weight	-0,20	0,15	0,14	0,15	-0,02	-0,20	0,02	-0,20	-0,24	-0,07	0,00	0,05	0,06
S. Width	-0,24	0,14	-0,12	0,16	0,04	-0,08	0,07	0,01	-0,20	0,03	0,17	0,04	0,01
S. Length	-0,18	0,02	-0,16	0,08	-0,01	-0,30	0,03	0,05	0,00	-0,04	-0,16	-0,06	0,13
Eigenvalue	7,45	5,95	4,09	3,22	3,02	2,72	2,19	2,03	1,64	1,49	1,34	1,19	1,11
Variation (%)	16,94	13,53	9,29	7,31	6,87	6,19	4,98	4,61	3,73	3,38	3,04	2,72	2,51
Total Variation (%)	16,94	30,47	39,75	47,06	53,93	60,12	65,10	69,71	73,44	76,82	79,85	82,57	85,08
(2*: fruit minerals)													

The heatmap analysis in the study reveals that the peach rootstocks can be divided into two main groups. The first group includes DO1, DO2, KL38, and KL39 rootstocks, while the second group consists of FG58, FG64, GGF3, KL38, KL39, KL23, KL24, NG1, NG4, NG5, NGF14, and NGF6 rootstocks. Furthermore, each of these two main groups is further subdivided into two subgroups. In the study, the identified characteristics were divided into two main groups, and within these two main groups, further subdivisions were made. Pomological data are primarily associated with leaf nutrients in the first group, while in the other group, nutrients in the fruit are more prominent (Fig. 2). When comparing these results with previous studies, similar findings were obtained (Marios et al., 2017; Sayan et al., 2018). This suggests that the results are in parallel with previous research and provide insights into the clustering and relationships of different rootstock characteristics.

In the research, correlation analyses of different peach rootstocks related to fruit quality, nutrient content, and biochemical data are presented in Figs. 3–5. In the correlation analysis of rootstock nutrient content, the following correlations were observed: Aluminum (Al) content showed a strong positive correlation with Iron (Fe) content (r = 0.90***). Aluminum (Al) content showed moderate correlations with Phosphorus (P) (r = 0.71***), Copper (Cu) (r = 0.63***), Manganese (Mn) (r = 0.63***), and Sulfur (S) (r = 0.50*). Calcium (Ca) and Magnesium (Mg) content showed a strong positive correlation with Copper (Cu) and Phosphorus (P) content (r = 0.71***). Iron (Fe) showed strong positive correlations with Manganese (Mn) (r = 0.51***) and Zinc (Zn) content (r = 0.61***). Copper (Cu) content showed a strong positive correlation with Phosphorus (P) (r = 0.70***) and a moderate correlation with Copper (Cu) content (r = 0.63***). A strong positive correlation was found between Aluminum (Al2) and Iron (Fe2) content (r = 0.85***). Weak correlations were observed among other mineral element compositions (Fig. 3). In the analysis of correlations between different characteristics, weak correlations were found among morphological characteristics (Fig. 4). For biochemical characteristics, strong correlations were observed. Antocyanin content showed a strong positive correlation with phenolic content (r = 0.97***) and flavonoid content (r = 0.90***), while it showed a weak and negative correlation with antioxidant content (r = 0.09*) (Fig. 5). These findings suggest that different rootstock characteristics exhibit important correlations, indicating that rootstocks have significant effects on various traits, and that some characteristics are strongly interrelated. The results align with data from previous studies, providing consistent findings (Forcada et al., 2019; Iglesias et al., 2019; Butkeviciute et al., 2022).

Conclusions

When we look at the data obtained in our study, it has been determined that different rootstocks have varying effects on the quality of peach fruits. The results obtained in the study have shown that different rootstocks have significant effects on the nutrient content of leaves and fruits, as well as fruit quality characteristics. Data obtained parallel to previous studies increase the validity of the study. This study is of a nature that will pave the way for future research, and it indicates the need for more detailed biochemical analyses and the consideration of factors such as tree growth.

Declarations

Author Contribution

All authors contributed equally.

Consent to Participate and Publish

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

Compliance with Ethical Standards

Not applicable

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No funding was received to conduct this study.

Data availability

All data needed to conduct this study is provided within the manuscript.

Conflict of Interest

The authors confirm that this article content has no conflict of interest.

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Figures

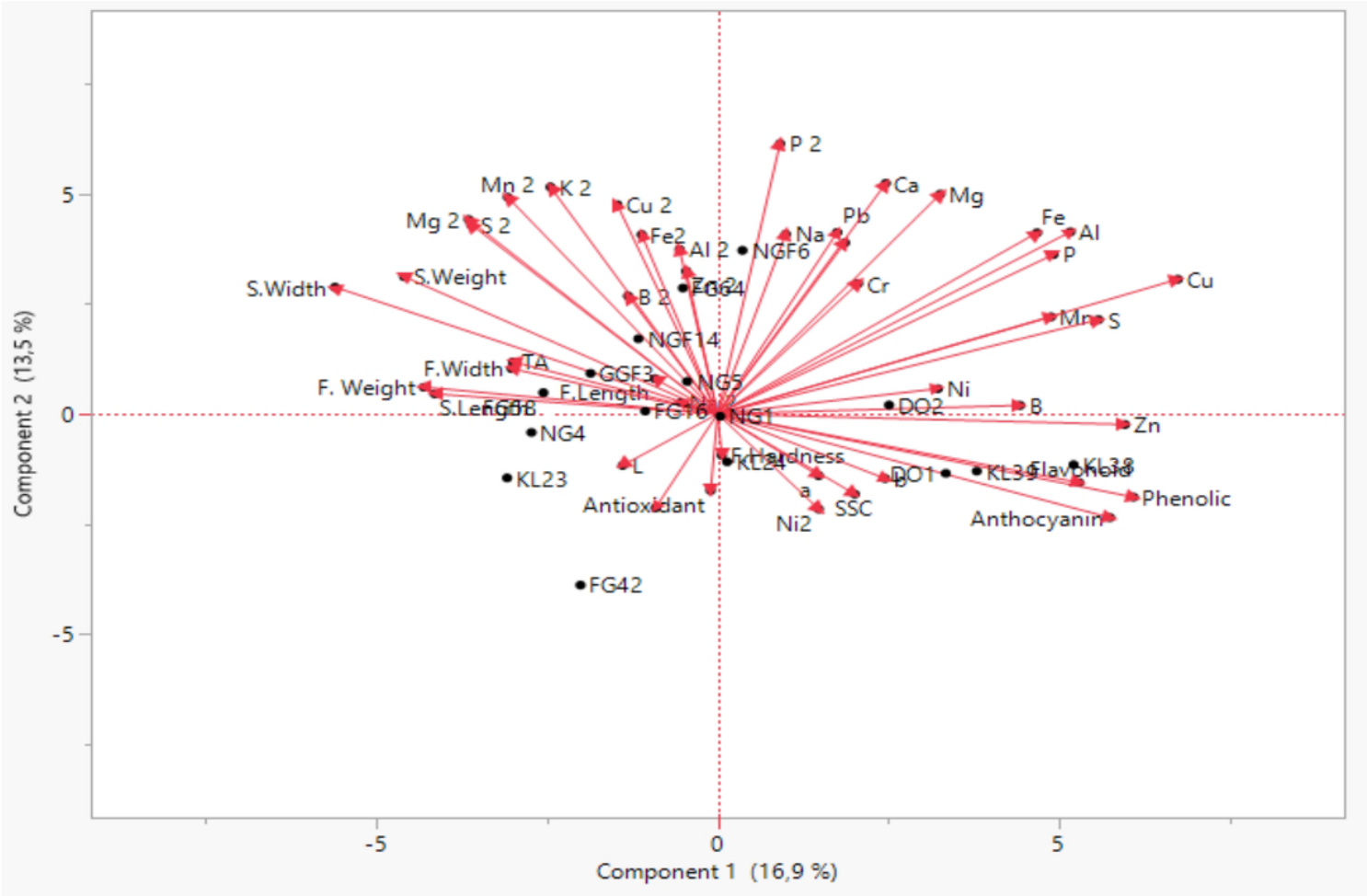


Figure 1

Biplot graph of the first two principal components in the peach rootstock

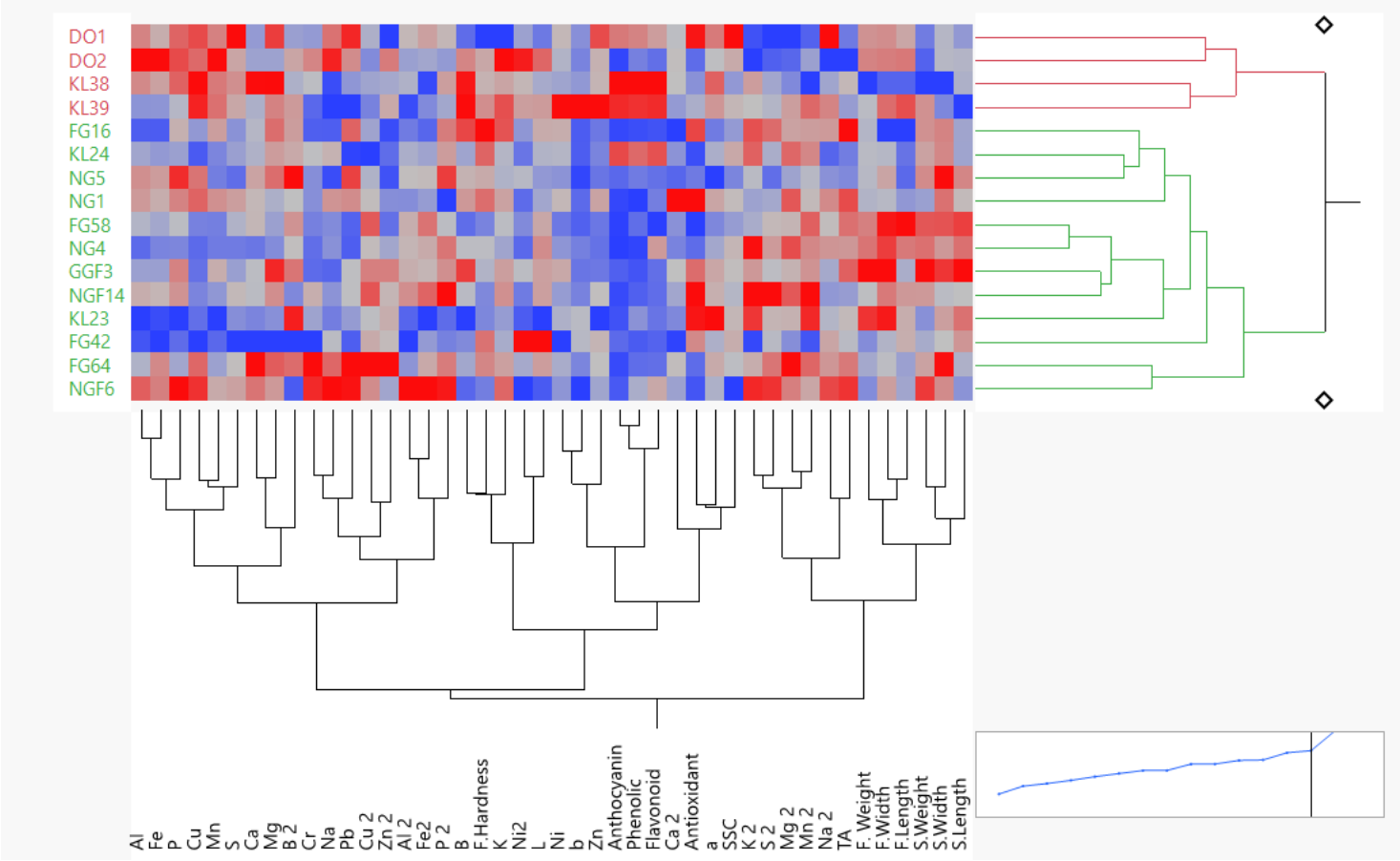


Figure 2

Heatmap analysis morphological characteristics, nutritional content and biochemical contents of peach rootstocks

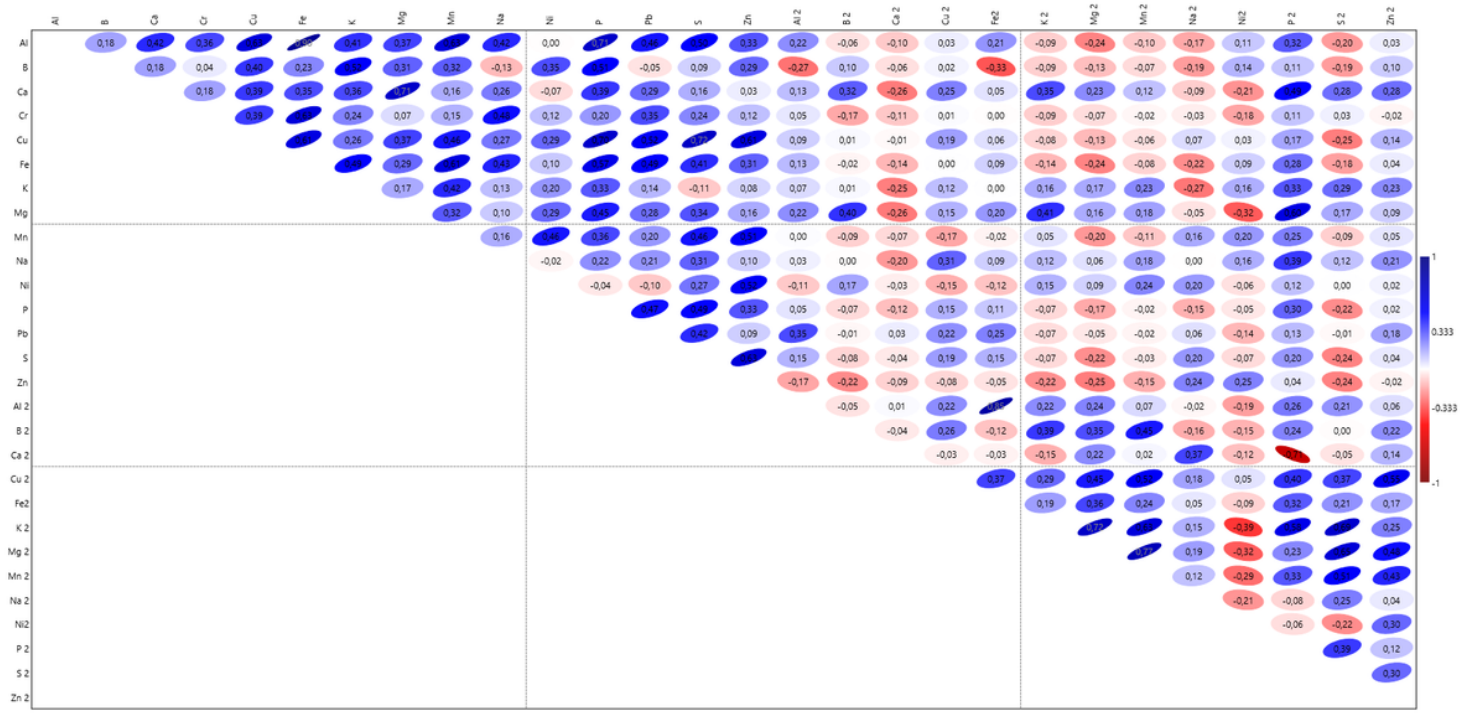


Figure 3

Correlation the among nutritional content of peach rootstocks (2: meyve)

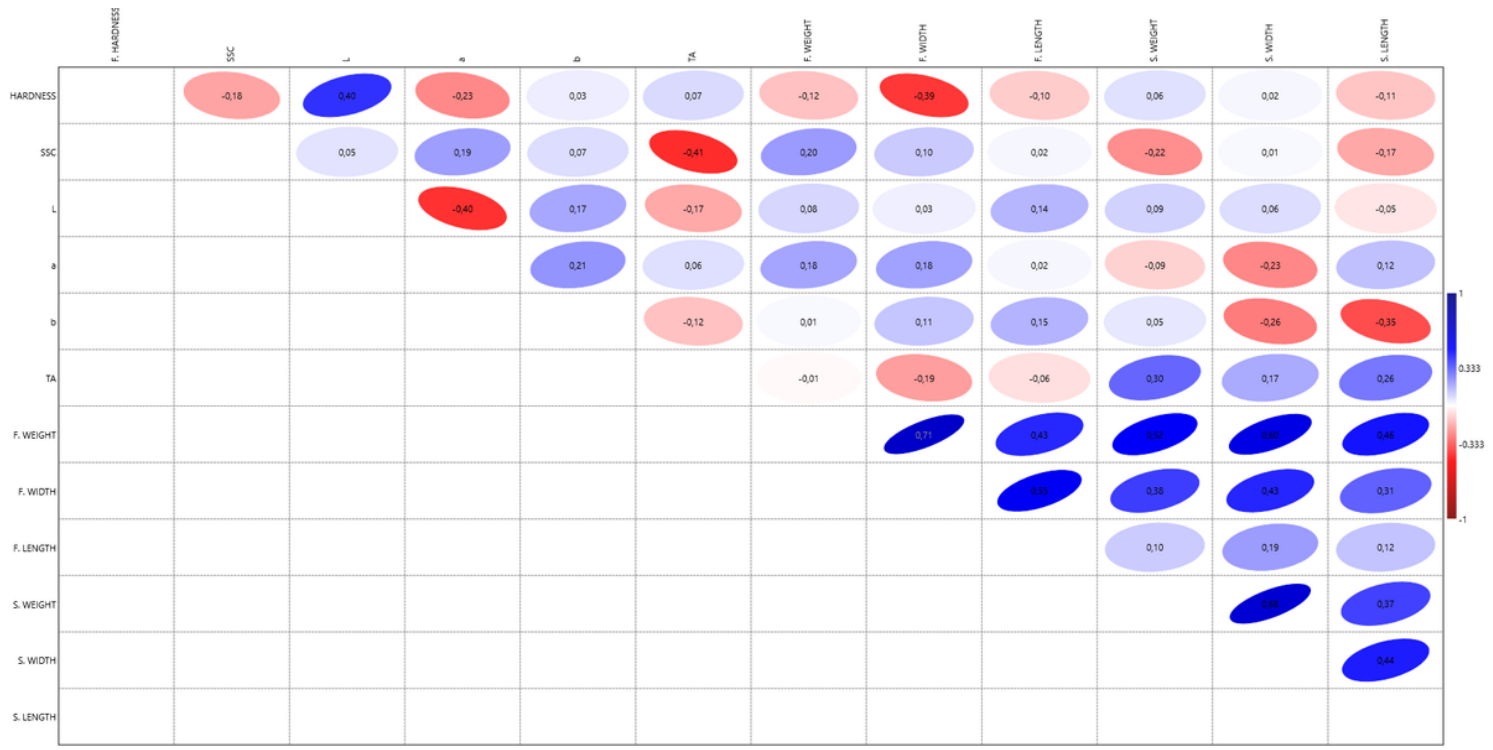


Figure 4

Correlation the among morphological characteristics of peach rootstocks

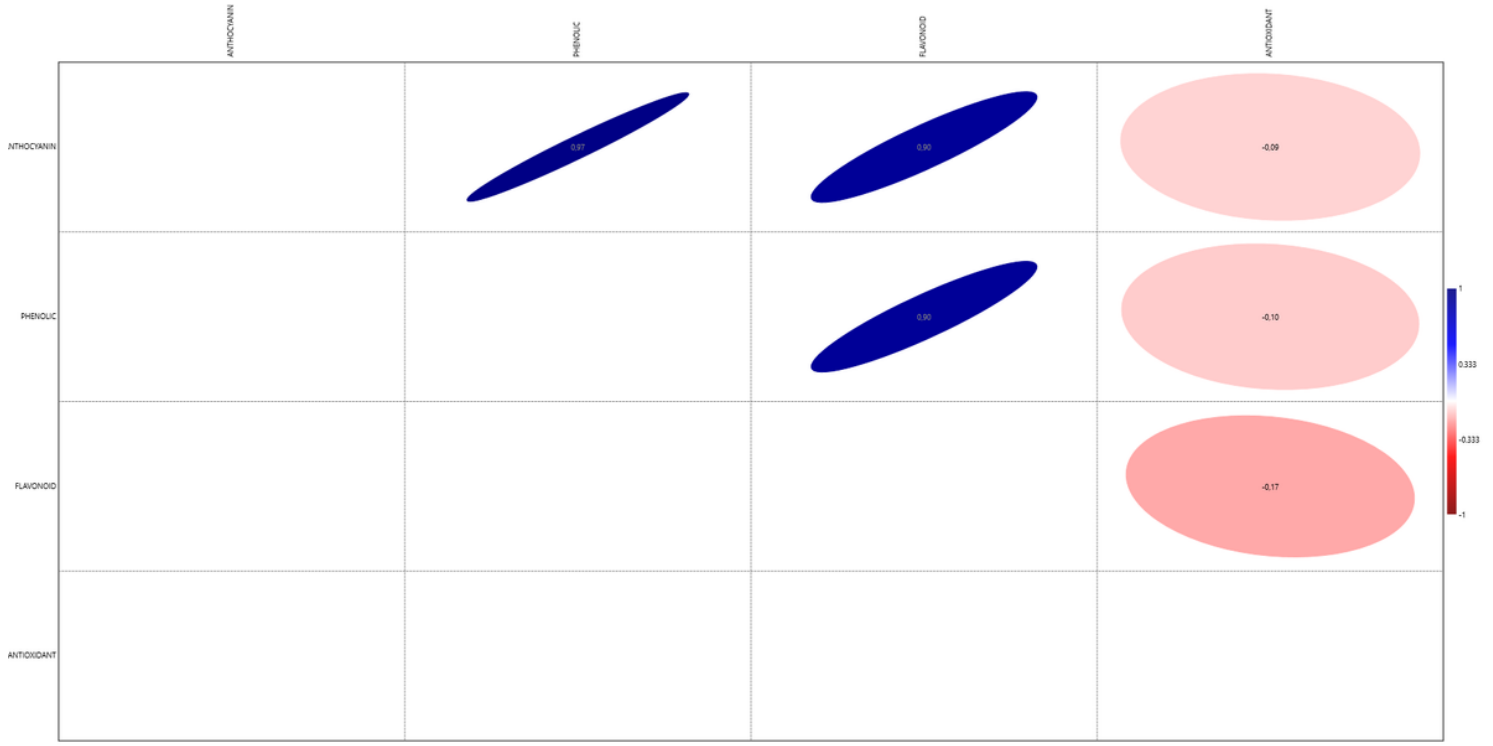


Figure 5

Correlation the among biochemical contents of peach rootstocks