



Evaluation of the diversity among the service tree (*Cormus domestica* L. Spach) accessions grown in the Seben (Bolu, Türkiye) region based on fruit traits and bioactive compounds

Mehmet Fikret Balta · Hüseyin Kırkaya · Fikri Balta · Serkan Uzun · Orhan Karakaya

Received: 2 April 2025 / Accepted: 26 May 2025 / Published online: 11 June 2025
© The Author(s) 2025

Abstract The study was conducted to evaluate the diversity based on fruit traits and biochemical composition of the service tree accessions growing naturally in the Western Black Sea region of Türkiye. A wide variation was determined regarding the traits investigated among service tree accessions. In the service tree accessions, fruit weight varied between 4.90 and 10.33 g, and fruit size ranged from 19.72 to 27.49 mm. Vitamin C was determined between 4.86 and 76.40 mg 100 g⁻¹. Total phenolics,

total flavonoids, and antioxidant activity (according to DPPH and FRAP assays) ranged from 82.4 to 1749.1 mg 100 g⁻¹, 34.8 to 497.1 mg 100 g⁻¹, 1.42 to 20.98 mmol kg⁻¹, and 7.68 to 61.28 mmol kg⁻¹, respectively. Catechin, caffeic, epicatechin, and rutin were determined as major individual phenolics. Principle component analysis revealed that traits investigated could effectively explain the variability among service tree accessions. The first three components explained 56.6% of the total variation. These findings highlight the rich genetic diversity of local service tree accessions and their potential for use in future breeding and conservation programs.

Supplementary Information The online version contains supplementary material available at <https://doi.org/10.1007/s10681-025-03558-9>.

M. F. Balta · F. Balta
Department of Horticulture, Faculty of Agriculture, Ordu University, Ordu, Türkiye

H. Kırkaya
Department of Plant and Animal Production, Seben Vocational School, Bolu Abant İzzet Baysal University, Seben-Bolu, Türkiye

S. Uzun (✉)
Department of Plant and Animal Production, Çilimli Vocational School, Düzce University, Çilimli-Düzce, Türkiye
e-mail: serkan.uzun28@hotmail.com

O. Karakaya (✉)
Department of Horticulture, Faculty of Agriculture, Sakarya University of Applied Sciences, Arifiye-Sakarya, Türkiye
e-mail: orhankarakaya7@gmail.com

Keywords Germplasm · Fruit size · Phenolics · Catechin · Rutin

Introduction

The service tree (*Cormus domestica* L. Spach), formerly classified within the genus *Sorbus*, is a winter deciduous, insect-pollinated, thermophilous tree, recognized as one of the wild fruit species of Europe. Its natural distribution mainly covers the Mediterranean basin, with scattered distribution from Western Europe to Eastern Europe and Asia Minor (Türkiye), from Central Europe and Great Britain to North Africa (Špišek et al. 2022). It has been cultivated since Roman times and has spread spontaneously. Its

original distribution area is therefore still uncertain (George et al. 2015).

Traditionally placed within the genus *Sorbus*, recent phylogenetic studies have led to the reclassification of this species into the genus *Cormus* within the Rosacea family (Zeiner et al. 2017; Ulaszewski et al. 2021; Tang et al. 2022). It is primarily important for its ornamental uses and includes approximately 80 species. In Türkiye, where *C. domestica* is called 'Üvez', 12 species and 17 taxa are found naturally. Among these, *S. domestica*, *S. aucuparia*, *S. umbellata*, and *S. torminalis* are the most significant. This species shows higher prevalence in the Marmara Region, the Central and Western Black Sea Region, and northern Central Anatolia in the Türkiye (Ercisli 2004; Atasever and Erdem 2022).

The fruits of the service tree are edible and have considerable health benefits (Jeran et al. 2021). The fruits are typically categorized as pears and apples and can be used for culinary and medicinal purposes. The fruit, a pome 2–3.5 cm in length, is greenish-yellow and often red on the sun-exposed side. While astringent and firm at full maturity, the fruits become delicious upon softening (Kamm et al. 2009; Brus et al. 2011). They are traditionally processed into marmalades, jams, jellies, juices, fruit wines, and other fermented beverages. In traditional medicine, it is used to treat intestinal disorders, dysentery, diabetes, and cognitive decline (Altuntaş et al. 2015; Enescu et al. 2016). The fruits of the service tree have a high nutritional value. Its high content of phenolic compounds, flavonoids, ascorbic acid, and various organic acids renders it an important source of antioxidants. Its bioactive properties have been demonstrated to play a role in the prevention of numerous diseases (Termentzi et al. 2006; Sagdic et al. 2022; Tas et al. 2023). Although the fruits of this species are rich in both nutritional content and substances that promote human health, they are not sufficiently appreciated by consumers. In this sense, it will need to gain popularity in order to compete with the attractive and tasty fruits available on the market (Poljak et al. 2021).

The presence of *C. domestica* has declined in some areas due to habitat loss, deforestation, and a lack of interest in its fruits compared to commercial fruit species. It is endangered in some European countries (Austria, Germany, and Spain) (Cáceres Escudero 2020; Moskalets et al. 2023). It is valuable

for maintaining both biodiversity and ecological sustainability (del Río et al. 2009). Therefore, further research on this species is warranted. In Türkiye, studies concerning *C. domestica* are limited (Atasever and Gerçekcioğlu 2013; Atasever and Erdem 2022; Tas et al. 2023). The study aims to evaluate the diversity of naturally growing service tree accessions in the Seben (Bolu, Türkiye) region based on fruit traits and biochemical composition, and to determine their potential use in future breeding studies.

Materials and methods

The plant material of the study consisted of 35 accessions within the service tree (*C. domestica* L.) population in the Seben district (Bolu, Türkiye). The accessions investigated are naturally growing in the population. Fruit samples were taken to represent the tree at harvest maturity in the identified accessions. The physical properties of the collected fruits were determined, and biochemical analyses were carried out. Physical measurements were made on 30 fruits of each service tree accession.

The province of Bolu is constituted of 18% agricultural and 55% forested areas, with the Karadere, Seben, and Aladağ Forests being of particular importance to the country. The regions outside these forested areas are significant in terms of fruit cultivation, with suitable conditions for the production of pears, apples, and citrus fruits. The province is subject to the climatic influences of the Black Sea Region. However, due to its location, it is also affected by the climate characteristics of Marmara and Central Anatolia in different periods, thereby resulting in a climate diversity that influences various agricultural areas, new plant species, and natural vegetation. The climate structure influenced by different regions leads to cool summers, mild winters, and evenly distributed rainfall over the seasons. The prevailing lodos winds in Bolu province and its surroundings, coupled with the abundant moisture brought by air masses moving from the sea towards the land and the moderate temperatures, contribute to a high moisture content (Yayla 2019).

Fruit physical traits

The service tree fruits were weighed using a digital balance (± 0.01 g) (AS 220/C/2, Radwag, Poland),

and their diameters (fruit width, fruit size, and fruit length) were measured using a digital caliper (± 0.01 mm) (CD-15CP, Mitutoyo, Japan). Fruit firmness was measured using a digital penetrometer (Agrosta 100 field, Agrotechnologie, France) and the measurements were expressed as percent (%).

pH, soluble solids content, titratable acidity, and vitamin C

The pH value of the fruit juice of the service tree accession was determined using a digital pH meter (Hanna, HI4221, ABD), and the soluble solids content (SSC) was determined using a digital refractometer (PAL-1, Atago, Japan). For titratable acidity (TA), 10 mL of extract was taken from each sample, 10 mL of distilled water was added, and sodium hydroxide (NaOH) was titrated to increase the pH of the samples to 8.1. Vitamin C was determined in fruit juice using a Vitamin C test kit (Catalog no: 116981, Merck, Germany) with a reflectometer (Merck RQflex plus 10, Germany). The data obtained are expressed in $\text{mg } 100 \text{ g}^{-1}$ (Ozturk et al. 2024).

Sample preparation for bioactive compounds

Initially, 50 fruits from each genotype were selected for total phenolics, total flavonoids, and antioxidant activity. The fruit pulp were homogenized in a blender. The resulting homogenates were then stored in the 50 mL falcon tubes at -20°C until analysis. The frozen homogenates were thawed at room temperature ($\sim 21^\circ\text{C}$) and re-homogenized using a blender. 1 g of fruit sample was weighed, and 10 mL of methanol was added. The prepared extract was separated from the pulp by centrifuging at $12,000 \times g$ for 30 min at $+4^\circ\text{C}$. The resulting extract was used for phenolic, flavonoid, and antioxidant analyses.

Total phenolics, total flavonoids, and antioxidant activity

The total phenolic content (Tp) was determined using Folin-Ciocalteu's reagent, in accordance with the method used by Beyhan et al. (2010). The prepared solution was measured at a wavelength of 760 nm in a spectrophotometer, and the results were expressed as mg kg^{-1} .

Total flavonoid content (Tf) was determined according to the method of Zhishen et al. (1999). Accordingly, the prepared solution was measured at a wavelength of 510 nm in a spectrophotometer, and the results were expressed as mg kg^{-1} .

The Ferric Ions (Fe^{+3}) Reducing Antioxidant Power Assay (FRAP) was carried out according to the method used by Benzie and Strain (1996). The prepared solution was measured at a wavelength of 593 nm in a spectrophotometer, and the values obtained were presented as mmol kg^{-1} . The 1,1-diphenyl-2-picryl-hydrazil assay (DPPH) was performed by modifying Blois (1958)'s method. The prepared solution was measured at 517 nm in a spectrophotometer (Shimadzu UV 1280, Tokyo, Japan), and the results were calculated as mmol kg^{-1} .

Individual phenolics

1 g of fruit sample was extracted with 10 mL methanol. The extraction was centrifuged at 6000 rpm for 30 min at $+4^\circ\text{C}$. The supernatant was passed through a $0.45 \mu\text{m}$ filter and transferred to vials. Individual phenolics in the prepared samples were analyzed by high-performance liquid chromatography (HPLC) (Thermo Scientific, Ultimate 3000, USA) using a modified method of Ates (2023). Hypersil GD phenyl clone (Thermo Scientific, Waltham, MA) was used, and measurements were performed at 280 nm with a UV detector (DAD-3000). Mobile phase A was methanol with a flow rate of 1 mL min^{-1} and mobile phase B consisted of 2.5% formic acid prepared in distilled water. The injection volume was $20 \mu\text{L}$. 4-aminobenzoic acid, protocatechuic acid, 4-hydroxybenzoic acid, catechin, chlorogenic acid, caffeic acid, epicatechin, *p*-coumaric acid, rutin and kaempferol as individual phenolics were determined. The results obtained were expressed as mg kg^{-1} .

Statistical analysis

Data was analyzed using the JMP 16.0 (Trial) statistical package. The Kolmogorov–Smirnov test was used to control the normal distribution of the data obtained from the study, and the Levene test was used to control the homogeneity of the variances. Descriptive statistics [minimum (min), maximum (max), mean, standard deviation (SD), and coefficient of variance (CV)] were calculated. Differences between means

were determined using the LSD multiple comparison method at the 5% significance level. Principal component, biplot, and heatmap analyses were performed using physical and biochemical traits of service tree accessions. Correlation analyses were also carried out between the traits examined. Pearson's correlations were used to determine the relationships among traits.

Results and discussion

The descriptive statistics of the physical traits (fruit weight, fruit width, fruit length, and fruit firmness) and biochemical traits (pH, soluble solids content, titratable acidity, vitamin C, total phenolic content, total flavonoid content, and antioxidant activity) of the service tree accessions examined during the research are presented in Table 1.

The highest CV value was calculated for *p*-coumaric acid (1.39). It was followed by kaempferol

(1.16), 4-hydroxybenzoic acid (0.88), chlorogenic acid (0.86), and 4-Aminobenzoic acid (0.80). The lowest CV value was calculated for pH (0.03). Many traits had CV values of 0.39 and above. The high CV of these traits is an indicator of dissimilarity. Individual phenolics and bioactive compounds had higher CV values than physical traits. Using these traits as separators is considered appropriate in the differentiation of the investigated accessions (Table 1).

Variations within individuals belonging to populations of species or genus are defined as genetic diversity. This diversity is very valuable for the production of quality products. Genetic diversity in fruit species can be seen as fruit size or a different trait (Ahmad et al. 2021). Fruit size is one of the traits that has a significant impact on consumer preferences. This trait is mainly expressed by the weight and dimensional traits of the fruit (Balta et al. 2022; Kurnaz et al. 2024). Variation in genetic resources in terms of fruit size is important for

Table 1 Descriptive statistics of service tree accessions investigated

Traits	Abbreviation	Unit	Min	Max	Mean	SD	CV	Sig	LSD (0.05)
Fruit weight	Fw	g	4.90	10.33	7.39	1.53	0.21	***	1.18
Fruit length	Fl	mm	18.54	32.05	22.39	2.51	0.11	*	5.38
Fruit width	Fwi	mm	20.28	30.37	23.44	2.10	0.09	***	3.49
Fruit size	Fs	mm	19.72	27.49	22.91	1.81	0.08	***	2.50
Fruit firmness	Ff	%	59.07	92.07	79.21	5.27	0.07	***	6.0
pH	pH	-	3.91	4.41	4.11	0.14	0.03	***	0.07
Soluble solids content	SSC	%	8.27	39.17	19.70	5.01	0.25	***	0.33
Titratable acidity	TA	%	0.02	0.05	0.03	0.01	0.18	***	0.00
Vitamin C	VC	mg 100 g ⁻¹	4.86	76.40	38.79	14.96	0.39	***	1.47
Total phenolics	Tp	mg 100 g ⁻¹	82.4	1749.1	577.9	358.4	0.62	***	13.2
Total flavonoids	Tf	mg 100 g ⁻¹	34.8	497.1	186.1	93.1	0.50	***	17.6
DPPH	DPPH	mmol kg ⁻¹	1.42	20.98	11.46	5.43	0.47	***	0.40
FRAP	FRAP	mmol kg ⁻¹	7.68	61.28	17.49	9.88	0.57	***	0.15
4-Aminobenzoic	Aa	mg kg ⁻¹	0.06	6.93	2.13	1.71	0.80	***	0.22
Protocatechuic	Pa	mg kg ⁻¹	0.00	1.35	0.34	0.25	0.75	***	0.03
4-Hydroxybenzoic	Ha	mg kg ⁻¹	0.00	1.38	0.37	0.32	0.88	***	0.04
(+)-catechin	Cat	mg kg ⁻¹	18.23	143.54	56.58	33.57	0.59	***	5.40
Chlorogenic	Cha	mg kg ⁻¹	0.90	31.92	7.40	6.36	0.86	***	0.78
Caffeic	Ca	mg kg ⁻¹	5.98	79.34	27.69	16.30	0.59	***	2.62
(-)-epicatechin	Ep	mg kg ⁻¹	6.14	73.02	29.35	15.38	0.52	***	2.72
<i>p</i> -coumaric	Pc	mg kg ⁻¹	0.00	13.78	1.95	2.71	1.39	***	0.27
Rutin	Ru	mg kg ⁻¹	8.01	199.29	60.07	42.18	0.70	***	5.96
Kaempferol	Ka	mg kg ⁻¹	0.06	74.28	14.66	17.04	1.16	***	1.81

* significant at $p < 0.05$; *** significant at $p < 0.001$

selection studies and breeding programs. The consumer demands a high-quality visual presentation, optimal firmness, and an ideal texture for service tree fruits (Altuntaş et al. 2015). It was observed that the service tree accessions examined in this study exhibited considerable variation in terms of fruit weight and fruit dimensional traits. In consideration of these traits, it was determined that the fruit weight exhibited a range of 4.90–10.33 g, the fruit width a range of 20.28–30.37 mm, the fruit size a range of 19.72–27.49 mm, and the fruit length a range of 18.54–32.05 mm. Also, fruit firmness was determined in the range of 59.07–92.07% during the study period (Table 1, Table S1). Statistically significant differences ($p < 0.05$) were found between the findings obtained from the fruit physical properties of the examined service tree accessions. In related studies, Drvodelić et al. (2009) reported fruit weights in between 8.75 and 11.23 g, fruit length 22.05–25.66 mm, fruit width 24.55–27.30 mm in the Tounj (Croatia) district; Miletic and Paunovic (2012) reported fruit weight 14.2–25.6 g, fruit length 26.3–36.2 mm, and fruit thickness 25.7–34.8 mm under Serbian conditions; Šebek (2020) reported fruit weight 15.65–29.06 g, fruit length 25.89–37.16 mm, fruit width 19.23–31.35 mm in the Donja Morača conditions; Kepenek Şahin (2018) reported fruit weight 5.58–12.28 g, fruit length 19.15–26.17 mm, fruit width 20.94–28.95 mm, and firmness 5.20–13.78 N of selected genotypes in the Tokat province conditions; Drvodelić et al. (2018) reported fruit weight 7.67–18.83 g, fruit length 23.19–29.93 mm, and fruit width 23.81–32.67 mm in the Zagreb (Croatia) conditions. The study revealed that the fruit weight of the service tree accessions was relatively lower than the values reported by Miletic and Paunovic (2012) and Šebek (2020). However, it was compatible with the values reported by Kepenek Şahin (2018), and Drvodelić et al. (2009; 2018). It is thought that these differences may be due to genetic traits. Indeed, Šebek (2020) reported that fruit mass is an inherited genetic trait. These traits can also be affected by ecological conditions, especially temperature and precipitation. Many researchers have reported that ecological conditions significantly affect the quality traits of different fruit species (Milošević et al. 2012; Mditshwa et al. 2019). The U-1 and U-23 could be used in developing large

fruit size cultivars thanks to their large fruit size (27.49 mm and 27.01, respectively).

In the study, pH was found to be between 3.91 and 4.41, SSC 8.27–39.17%, and TA 0.02–0.05% in service tree accessions. In addition, the Vitamin C content was determined to be 4.86–76.40 mg 100 g⁻¹ (Table 1, Table S2). Previously in the literature, Brindza et al. (2009) reported vitamin C in between 0.089 and 0.098 mg 100 g⁻¹; Egea et al. (2010) reported TA as 0.85%, SSC 24.03%, and vitamin C 22.65 mg 100 g⁻¹; Miletic and Paunovic (2012) reported SSC in between 17.7 and 24.8%; Altuntaş et al. (2015) reported pH value in between 4.637–4.683, SSC 11.75–13.07%, and TA 0.215–0.241%; Kepenek Şahin (2018) reported pH value in between 4.06 and 4.29, SSC 18.50–26.40%, and TA 0.67–1.41%; Ľorbová et al. (2023) reported vitamin C in between 111.46 mg 100 g⁻¹; Tas et al. (2023) reported pH value in between 3.98 and 4.32, SSC 11.17–20.58, TA 0.71–1.55%, and vitamin C content 42.37–95.83 mg 100 g⁻¹; Raigón Jiménez et al. (2024) reported pH value in between 3.56 and 3.98, SSC 16.29–16.57%, and TA 0.79–1.17%. The pH, SSC, and TA are indicative of the degree of ripeness of the fruit. As reported by Gunness et al. (2009), an examination of these traits is an effective method for predicting the flavor, sourness, and sweetness of fruits. Accordingly, the data obtained from the study were found to be generally compatible with the literature. Vitamin C is an important component for human health. It is an essential antioxidant required by the human body (Elgailani et al. 2017). It has been demonstrated to reduce blood pressure and cholesterol levels. Furthermore, it has been demonstrated that adequate intake of vitamin C can effectively reduce the risk of developing various types of cancer in humans (Rahman et al. 2007). In this respect, it can be said that the examined service tree accessions have an important vitamin C source potential in general. Especially, the U-17, U-6, and U-7 (76.40, 66.15, and 64.72 mg 100 g⁻¹, respectively) could be utilized in developing cultivars with high vitamin C in service tree breeding programs.

In service tree accessions, the highest Tp was 1749.1 mg 100 g⁻¹ (U-7), followed by 1291.3 mg 100 g⁻¹ (U-26), 1167.7 mg 100 g⁻¹ (U-25), and 1111.2 mg 100 g⁻¹ (U-13), respectively. The lowest Tp was found to be 82.4 mg 100 g⁻¹ (U-27) (Table 1, Table S3). The study revealed a wide

range of values for Tp in the service tree accessions examined, with statistically significant differences between the accessions ($p < 0.05$). In related studies, the Tp was reported as 8.99 mg 100 g⁻¹ (Egea et al. 2010), 2485.7–6180.6 mg 100 g⁻¹ (Piagnani et al. 2012), 50.0–10560 mg 100 g⁻¹ (Majić et al. 2015), 350–1210 mg 100 g⁻¹ (Poljak et al. 2021), 3.574 mg 100 g⁻¹ (Ognyanov et al. 2022), 153–2570 mg 100 g⁻¹ (Camadan et al. 2023). The highest Tf was found to be 497.1 mg 100 g⁻¹ (U-7), followed by 332.4 mg 100 g⁻¹ (U-8), 278.7 mg 100 g⁻¹ (U-13) and 272.0 mg 100 g⁻¹ (U-25), respectively. The lowest Tf was found to be 34.8 mg 100 g⁻¹ (U-31) (Table 1, Table S3). In related studies, the Tf was reported in between 1031.3 and 4322.6 mg 100 g⁻¹ (Piagnani et al. 2012), 680–3700 mg 100 g⁻¹ (Majić et al. 2015), 76.1 mg 100 g⁻¹ (Ognyanov et al. 2022), 39.4–714.7 mg 100 g⁻¹ (Camadan et al. 2023). Regarding total phenolic and total flavonoid contents, the results of this study are consistent with the range of values reported in previous studies. It was reported that those constituents are mostly affected by growing conditions and climate (Piagnani et al. 2012), and stage of maturity (Figuerola-Pérez et al. 2018). In addition, different researchers reported that genetic factors were also effective on these traits (Balta et al. 2022; Yaman et al. 2023). Among the accessions investigated, U-7 and U-21 gave remarkable results in terms of total phenolics (1749.0 and 5694.47 mg 100 g⁻¹, respectively) and total flavonoids (497.1 and 223.2 mg 100 g⁻¹, respectively). These accessions could contribute to service tree breeding studies as a source of phenolics and flavonoids. Fruits with a high phenolic content protect against the harmful effects of cancer and oxidative stress and promote human health (Di Nunzio 2019).

The antioxidant capacity of fruits cannot be fully characterized by a single method, as it is susceptible to influence from a range of factors, including the specific assay applied. As natural antioxidants frequently possess multifunctional properties, it is beneficial to employ an evaluation protocol encompassing diverse antioxidant activities to account for the various mechanisms of action (Fu et al. 2011). In this study, the antioxidant activity of the service tree accessions examined in the study was determined using FRAP and DPPH assays. Antioxidant activity showed a wide variation in the service tree accessions analyzed in the study. The variation between

the accessions was found to be statistically significant according to both assays applied ($p < 0.05$). The FRAP assay revealed that the highest antioxidant activity was 61.28 mmol kg⁻¹. This was followed by 34.43 mmol kg⁻¹, 29.89 mmol kg⁻¹, and 26.09 mmol kg⁻¹. The lowest antioxidant activity was 7.68 mmol kg⁻¹. The DPPH assay revealed that the highest antioxidant activity was 20.98 mmol kg⁻¹. This was followed by 20.72 mmol kg⁻¹, 19.69 mmol kg⁻¹, and 19.57 mmol kg⁻¹. The lowest antioxidant activity was 1.42 mmol kg⁻¹ (Table 1, Table S3). It is thought that the antioxidant activity in fruits is influenced by the assay (Fu et al. 2011) and the ripeness of the fruit, and the differences may be due to genetic characteristics (Moulehi et al. 2012). Antioxidant activity can also be affected by biotic (diseases, pests, and pathogen attacks) and abiotic factors (especially high temperature, drought, and light) (Güler 2023; Karakaya et al. 2024). Lim (2012) reported that service tree fruits are an important natural source of antioxidants. The present study, the FRAP test revealed that accessions U-7, U-8, U-19, and U-6 exhibited relatively higher antioxidant activity, while the DPPH test indicated that accessions U-32, U-34, U-35, and U-25 demonstrated similarly elevated antioxidant activity. These accessions could be used in developing cultivars with high antioxidant activity in service tree breeding programs.

C. domestica fruits are rich in phenolic compounds such as flavanols (aglycones, glycosides, and esters), especially quercetin and kaempferol derivatives, hydroxybenzoic acids (vanillic and protocatechuic acid), chlorogenic acid, and hydrocinnamic acids (Macit et al. 2022). Gazdik et al. (2008) reported that total phenolic content could not be fully revealed by the Folin-Ciocalteu method, therefore, phenolic levels in *Sorbus* species could be confirmed by more detailed analyses. In the 35 accessions analyzed in this study, the following were determined between: 4-aminobenzoic acid 0.06–6.93 mg kg⁻¹; protocatechuic acid 0.00–1.35 mg kg⁻¹; 4-hydroxybenzoic acid 0.00–1.38 mg kg⁻¹; catechin 18.23–143.54 mg kg⁻¹; chlorogenic acid 0.90–31.92 mg kg⁻¹; caffeic acid 5.98–79.34 mg kg⁻¹; epicatechin 6.14–73.02 mg kg⁻¹; *p*-coumaric acid 0.00–13.78 mg kg⁻¹; rutin 8.01–199.29 mg kg⁻¹; and kaempferol 0.06–74.28 mg kg⁻¹ (Table 1, Table S4). The variation between the accessions

was found to be statistically significant ($p < 0.05$). In studies on *Sorbus* species, Kim et al. (2010) reported protocatechuic acid in between 19.10 mg 100 g⁻¹, *p*-coumaric acid 2.00 mg 100 g⁻¹, caffeic acid 90.30 mg 100 g⁻¹ in the Jeju (Korea) conditions; Işık (2017), recorded chlorogenic acid in between 1.99 and 8.75 mg kg⁻¹, caffeic acid 1.98–10.96 mg kg⁻¹, *p*-coumaric acid 1.00–5.86 mg kg⁻¹, rutin 2.18–77.92 mg kg⁻¹, kaempferol 0.10–13.33 mg kg⁻¹ in the Bursa (Türkiye) district; Tas et al. (2023) reported catechin in between 1.61 and 12.68 mg 100 g⁻¹, chlorogenic acid 29.50–48.49 mg 100 g⁻¹, caffeic acid 2.15–15.33 mg 100 g⁻¹, *p*-coumaric acid 1.53–17.89 mg 100 g⁻¹, rutin 7.90–36.98 mg 100 g⁻¹ in the Bolu (Türkiye) conditions. Accordingly, it can be stated that the findings obtained

from this study are generally compatible with the literature. It is thought that the differences observed may be due to genetic factors, ecological conditions, and extraction methods. In the present study, the accessions with the highest values stood out; U-6, U-26, U-25, U-7 for 4-aminobenzoic acid; U-22, U-6, U-7, U-20, U-10 for protocatechuic acid; U-32, U-6, U-28, U-30, U-29 for 4-hydroxybenzoic acid; U-6, U-19, U-18, U-7, U-8 for catechin; U-6, U-1, U-4, U-21, U-19 for chlorogenic acid; U-6, U-2, U-21, U-29, U-26 for caffeic acid; U-19, U-6, U-20, U-21, U-24 for epicatechin; U-6, U-8, U-7, U-13, U-12 for *p*-coumaric acid; U-4, U-22, U-21, U-6, U-8 for rutin; U-7, U-26, U-25, U-8, U-13 for kaempferol. Especially, the U-6 could contribute to service tree breeding studies as a source of individual phenolics (Fig. 1).

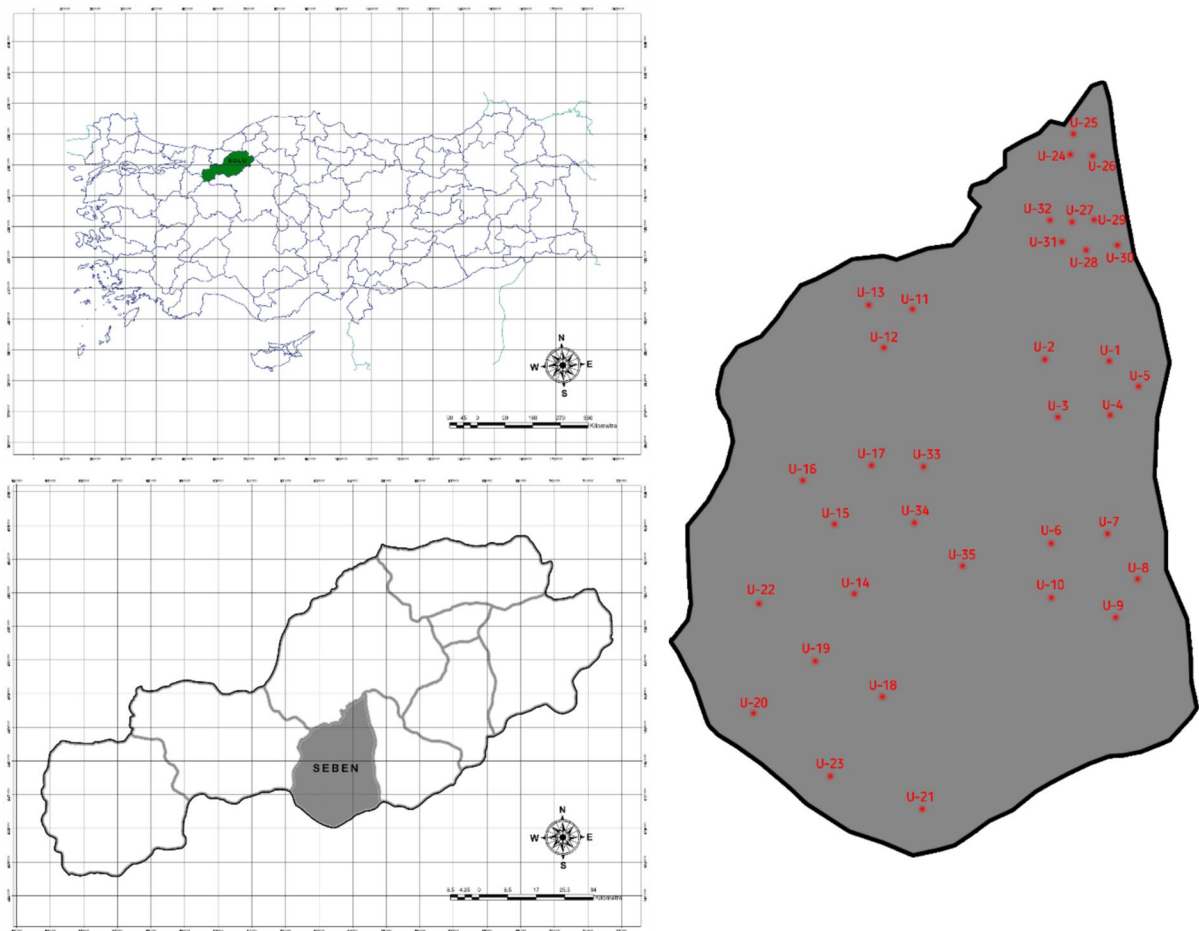


Fig. 1 Map of the study area (Seben, Bolu, Türkiye) and location of the accessions

Principal component and correlation analysis

The 23 traits were used for PCA and 7 PCs had eigenvalue higher than 1.0. These components explained 79.9% of the total variation. PC1, which explained 30.6% of the total variability, was mainly related to pH, titratable acidity, vitamin C, total phenolic, total flavonoids, DPPH, FRAP, 4-aminobenzoic acid, (+)-catechin, chlorogenic, caffeic, *p*-coumaric, rutin, and kaempferol. The most important trait that affected PC1 was total phenolics (0.83). Explaining 16.1% of the variability, PC2 was related to fruit weight, fruit length, fruit width, and fruit size. Fruit size had the most effect on PC2 (0.93). PC3 was related to fruit firmness, total phenolics, and kaempferol by explaining 9.9% of the variability. Kaempferol had the most effect on PC3 (0.60) (Fig. 2, Table 2). Similarly, Poljak et al. (2021) reported that the first two components formed by PCA analysis explained 50.2% of the total variation between service tree genotypes

selected from different regions. They were also found to be an important relationship between physical traits. Similar results were recorded between total phenolics and FRAP. Taş et al. (2023) reported that physical traits explained 60.6% and individual phenolics explained 54.3% of the variation among service tree genotypes. They reported a robust relationship between fruit weight and fruit size. They also noted a similar relationship between caffeic acid and catechin, rutin, and *p*-coumaric acid.

According to PCA results, service accessions investigated were divided into two groups (A and B). The first group (A) consisted of seven service accessions (U-6, U-7, U-8, U-13, U-19, U-25 and U-26). The means of bioactive compounds and individual phenolics in the service tree accessions in this group were higher than the other groups' mean. The second group (B) included twenty-eight service accessions and was divided into two subclusters (B-1 and B-2). The first subcluster (B-1) consisted of thirteen

Fig. 2 Biplot graph of the first two principal components in the service tree accessions investigated

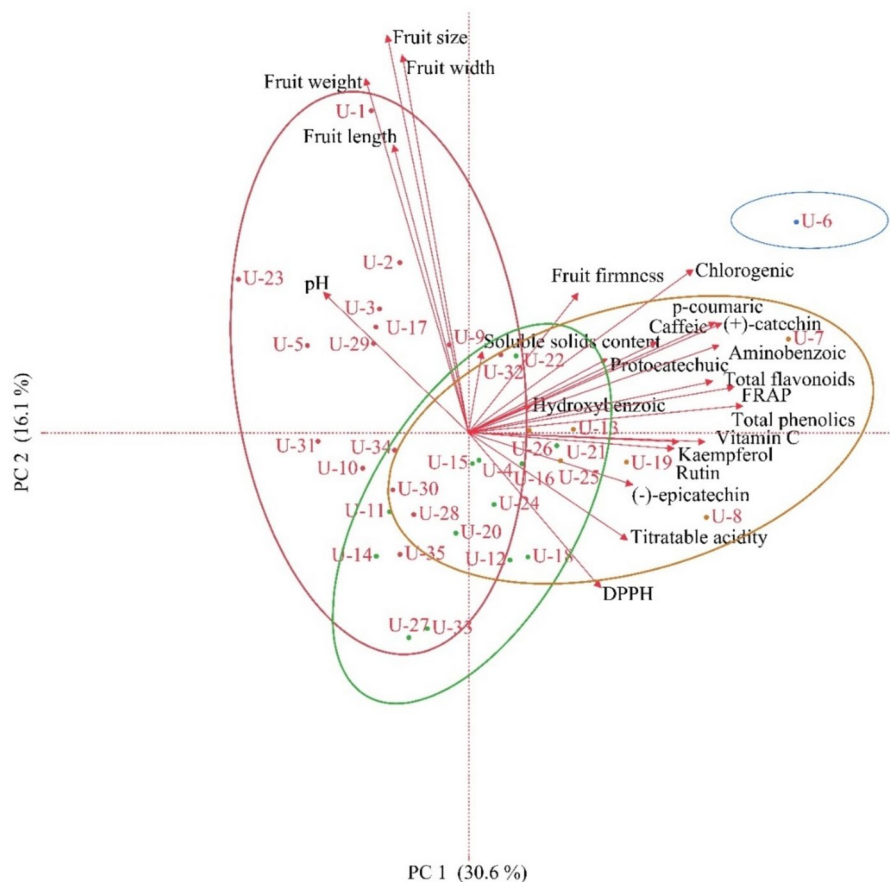


Table 2 The principal component of service tree accessions investigated

Traits	PC1	PC2	PC3	PC4	PC5	PC6	PC7
Fruit weight	−0.31172	0.83341	0.25916	0.02622	−0.10338	0.08860	−0.08248
Fruit length	−0.22646	0.67492	0.24013	−0.23912	0.23666	−0.28333	0.20305
Fruit width	−0.20009	0.88905	0.10060	0.22582	−0.11395	0.14602	−0.03010
Fruit size	−0.24567	0.93459	0.18794	0.04053	−0.00395	−0.00019	0.04750
Fruit firmness	0.32959	0.32487	−0.43989	−0.29418	−0.18807	0.51933	−0.24497
pH	−0.43598	0.32701	−0.31994	0.25640	0.27210	0.15207	0.34913
Soluble solids content	0.04097	0.18433	0.15785	0.73192	0.23877	0.15211	−0.13509
Titrateable acidity	0.47929	−0.25100	0.30913	0.23264	0.36149	−0.21033	−0.33680
Vitamin C	0.71353	−0.02173	−0.11778	0.26215	0.07473	0.11381	−0.12781
Total phenolics	0.82718	0.06322	0.43079	−0.16558	−0.08554	0.06772	−0.00049
Total flavonoids	0.73418	0.11918	0.39061	0.04938	0.25873	0.13647	0.08893
DPPH	0.39692	−0.36351	0.36954	0.33387	−0.29374	0.25335	0.30847
FRAP	0.80070	0.10596	0.27636	−0.07791	0.18702	0.12927	0.21312
4-Aminobenzoic	0.75531	0.20428	0.07655	−0.06125	−0.31573	−0.13326	−0.18100
Protocatechuic	0.41430	0.17077	−0.30220	−0.51951	0.12288	0.29212	0.04310
4-Hydroxybenzoic	0.18292	0.05979	−0.22181	0.49875	−0.60263	0.12739	−0.06428
(+) – catechin	0.76310	0.25505	−0.27625	0.04205	0.31984	0.03778	−0.01216
Chlorogenic	0.67698	0.38204	−0.38408	0.14952	0.18830	−0.31420	−0.08859
Caffeic	0.56767	0.21052	−0.33288	−0.04935	−0.41094	−0.28658	0.19418
(−) – epicatechin	0.49248	−0.12148	−0.36566	0.18633	0.08920	−0.01650	0.60226
<i>p</i> -coumaric	0.74430	0.25842	−0.10557	0.03260	−0.26298	−0.40690	−0.02032
Rutin	0.61761	−0.03842	−0.37315	0.02672	0.31302	0.13037	−0.16916
Kaempferol	0.63258	−0.02216	0.60411	−0.23337	−0.14620	0.11730	0.11333
Eigenvalue	7.0	3.7	2.3	1.7	1.6	1.1	1.0
Variance	30.6	16.1	9.9	7.4	6.8	4.7	4.4
Cumulative variance	30.6	46.7	56.6	64.0	70.8	75.5	79.9

Factor loading $\geq |0.39|$ are marked in bold

service accessions (U-4, U-11, U-12, U-14, U-15, U-16, U-18, U-20, U-21, U-22, U-24, U-27 and U-33). The second subcluster (B-2) included fifteen service accessions (U-1, U-2, U-3, U-5, U-9, U-10, U-17, U-23, U-28, U-29, U-30, U-31, U-32, U-34 and U-35). Fruit weight, fruit width, fruit length, fruit size, and pH of service accessions in this subcluster were higher than the other groups' mean (Fig. 3).

Correlations between the traits investigated are presented in Fig. 4. The fruit weight had a strong positive correlation with fruit width ($r=0.84^{***}$). Fruit size showed a strong positive correlation with fruit weight ($r=0.91^{***}$), fruit width ($r=0.92^{***}$), and fruit length ($r=0.77^{***}$). The total phenolic had a strong positive correlation with total flavonoid ($r=0.70^{***}$) and FRAP ($r=0.77^{***}$). It also showed a strong positive correlation with 4-aminobenzoic

acid ($r=0.79^{**}$) and kaempferol ($r=0.91^{***}$). FRAP showed a strong positive correlation with kaempferol ($r=0.70^{***}$). Catechin had a strong positive correlation with chlorogenic acid ($r=0.77^{**}$). *p*-Coumaric acid showed a strong positive correlation with 4-aminobenzoic acid ($r=0.72^{***}$) and chlorogenic acid ($r=0.75^{***}$), while it showed a moderate correlation with caffeic acid ($r=0.67^{**}$).

Conclusions

In this study, a high level of phenotypic diversity was determined among service tree accessions. The accessions U-1, U-2, and U-23 were found remarkable for fruit size. U-7 accession produced remarkable results in terms of total phenolics, total flavonoids, and

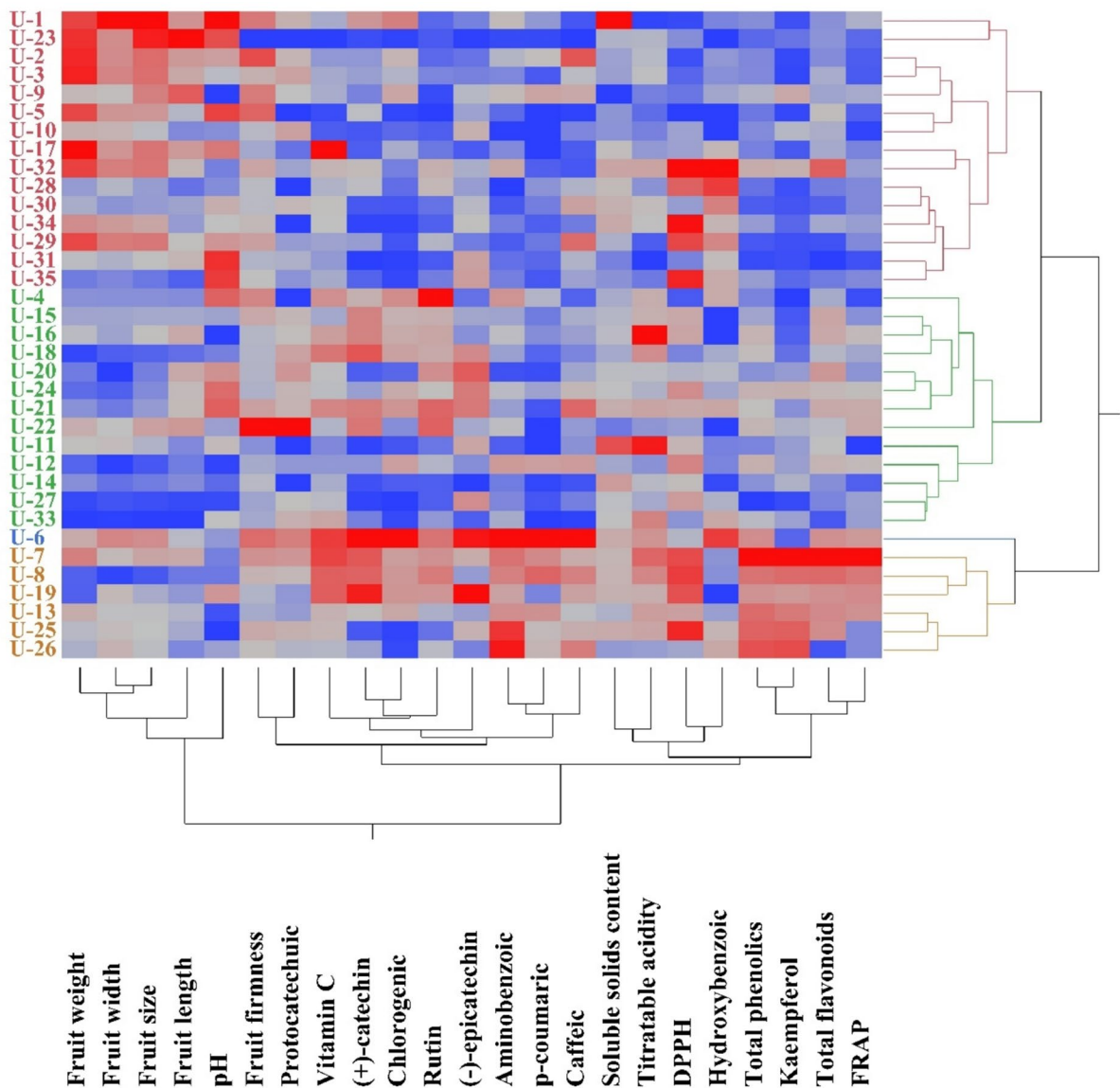


Fig. 3 Heatmap analysis and grouping of service tree accessions investigated based on fruit traits and bioactive compounds

antioxidant activity (according to FRAP assay). Catechin, caffeic, epicatechin, and rutin were determined as major individual phenolics. U-6 accession was found remarkable for these phenolics (except rutin). PCA, heatmap, and correlation analyses revealed important relationships between morphological and biochemical traits, and once again emphasized the importance of phenotypic markers in genotype

discrimination. These findings improve our understanding of the human health benefits of service tree fruits and provide important genetic material for breeding programs aiming to develop service tree varieties with high bioactive content. In addition, this research highlights the importance of genetic diversity in fruit species to support human health and sustainable production.

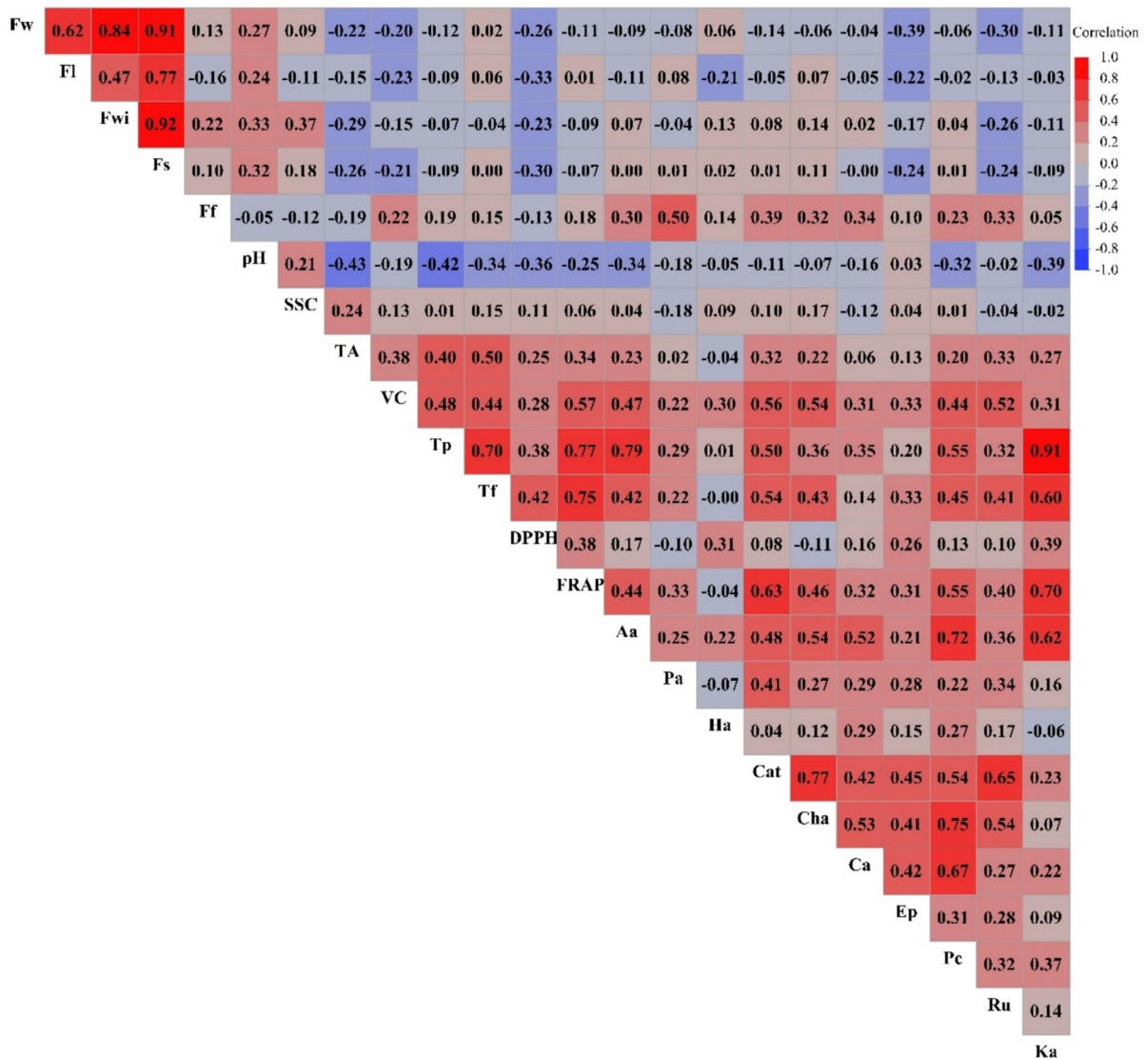


Fig. 4 Correlation among the examined characteristics of service tree accessions investigated

Author contributions MFB: Investigation, methodology, conceptualization, validation. HK: Investigation, methodology, conceptualization. FB: Investigation, methodology, conceptualization, validation. SU: Investigation, conceptualization, formal analysis, writing – original draft. OK: Investigation, formal analysis, visualization, writing – review editing.

Funding Open access funding provided by the Scientific and Technological Research Council of Türkiye (TÜBİTAK). This research received no external funding.

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

Declarations

Conflict interest The authors declare no conflict of interest.

Open Access This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if changes were made. The images or other third party material in this article are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit <http://creativecommons.org/licenses/by/4.0/>.

References

- Ahmad R, Akbar Anjum M, Naz S, Mukhtar Balal R (2021) Applications of molecular markers in fruit crops for breeding programs: a review. *Phyton (b Aires)* 90:17–34. <https://doi.org/10.32604/phyton.2020.011680>
- Altuntaş E, Yildiz M, Gul EN (2015) The effect of ripening periods on physical, chemical and mechanical properties of service tree fruits (*Sorbus domestica* L.). *Agric Eng Int: CIGR J* 17:259–266
- Atasever O, Erdem S (2022) Molecular characterization of service tree (*Sorbus domestica* L.) genotypes selected from Tokat Province. *Proc Bulg Acad Sci* 75:1227–1233. <https://doi.org/10.7546/CRABS.2022.08.16>
- Atasever ÖÖ, Gerçekcioğlu R (2013) Some vegetative characteristic of service tree (*Sorbus domestica* L.) genotypes, selected from Tokat ecology. *Res J Agric Sci* 2:97–101
- Ates U (2023) Harvest time influences quality attributes and phenolic composition of fig fruit: insights from physicochemical analysis and antioxidant activity assessment. *Erwerbs-Obstbau* 65:1627–1632. <https://doi.org/10.1007/s10341-023-00921-9>
- Balta MF, Karakaya O, Kurt H, Yılmaz M, Uzun S, Balta F (2022) Phytochemical variation of native apple germplasm resources from the eastern black Sea region, Turkey. *Erwerbs-Obstbau* 64:685–695. <https://doi.org/10.1007/s10341-022-00735-1>
- Benzie IFF, Strain JJ (1996) The ferric reducing ability of plasma (FRAP) as a measure of “antioxidant power”: the FRAP assay. *Anal Biochem* 239:70–76. <https://doi.org/10.1006/ABIO.1996.0292>
- Beyhan Ö, Elmas M, Gedikli F (2010) Total phenolic compounds and antioxidant capacity of leaf, dry fruit and fresh fruit of feijoa (*Acca sellowiana*, Myrtaceae). *J Med Plant Res* 4:1065–1072
- Blois MS (1958) Antioxidant determinations by the use of a stable free radical. *Nature* 181:1199–1200. <https://doi.org/10.1038/1811199a0>
- Brindza J, Červeňáková J, Tóth D, Bíro D, Sajbidor J (2009) Unutilized potential of true service tree (*Sorbus domestica* L.). *Acta Hort* 806:717–726. <https://doi.org/10.17660/ActaHortic.2009.806.89>
- Brus R, Ballian D, Bogunić F, Bobinac M, Idžojić M (2011) Leaflet morphometric variation of service tree (*Sorbus domestica* L.) in the Balkan Peninsula. *Plant Biosyst* 145(2):278–285. <https://doi.org/10.1080/11263504.2010.549660>
- Camadan Y, Akyıldırım Beğen H, Ceylan Ş, Saral A, Eminağaoğlu Ö (2023) Investigating In vitro antioxidant and antimicrobial activity of different *Sorbus* species in Artvin province of Türkiye. *J Inst Sci Technol* 13:2818–2828. <https://doi.org/10.21597/jist.1259358>
- Di Nunzio M (2019) Hazelnuts as source of bioactive compounds and health value underestimated food. *Cur Res Nutr Food Sci* 7(1):17–28. <https://doi.org/10.12944/CRNFSJ.7.1.03>
- Drvodelić D, Oršanić M, Jemrić T (2009) Morphological characteristics of fruits and seed of the service tree (*Sorbus domestica* L.). *Radovi* 44:5–14
- Drvodelić D, Oršanić M, Vuković M, Jatoi MA, Jemrić T (2018) Correlation of fruit size with morphophysiological properties and germination rate of the seeds of Service tree (*Sorbus domestica* L.). *South-East Eu Forest* 9:47–54. <https://doi.org/10.15177/see-for.18-01>
- Egea I, Sánchez-Bel P, Romojaro F, Pretel MT (2010) Six edible wild fruits as potential antioxidant additives or nutritional supplements. *Plant Foods Hum Nutr* 65:121–129. <https://doi.org/10.1007/s11130-010-0159-3>
- Elgailani IEH, Gad-Elkareem MAM, Noh EAA, Adam OEA, Alghamdi AMA (2017) Comparison of two methods for the determination of Vitamin C (Ascorbic acid) in some fruits. *Am J Chem* 2(1):1–7. <https://doi.org/10.20448/812.2.1.1.7>
- Enescu CM, de Rigo D, Houston Durrant T, Caudullo G (2016) *Sorbus domestica* in Europe: distribution, habitat, usage and threats. European atlas of forest tree species; San-Miguel-Ayán, J, de Rigo, D, Caudullo, G, Houston Durrant, T, Mauri, A, Eds e019db5
- Ercişli S (2004) A short review of the fruit germplasm resources of Turkey. *Genet Resour Crop Evol* 51:419–435
- Escudero CY (2020) *Sorbus domestica* L. (Rosaceae) en Extremadura (España). *Acta Bot Malacitana* 45:173–178. <https://doi.org/10.24310/Actabotanicaabmbm.v45i.5450>
- Figueroa-Pérez MG, Pérez-Ramírez IF, Paredes-López O, Mondragón-Jacobo C, Reynoso-Camacho R (2018) Phytochemical composition and in vitro analysis of Nopal (*O. Ficus-Indica*) cladodes at different stages of maturity. *Int J Food Prop* 21(1):1728–1742. <https://doi.org/10.1080/10942912.2016.1206126>
- Fu L, Xu B-T, Xu X-R, Gan R-Y, Zhang Y, Xia EQ, Li H-B (2011) Antioxidant capacities and total phenolic contents of 62 fruits. *Food Chem* 129:345–350. <https://doi.org/10.1016/j.foodchem.2011.04.079>
- Gazdik Z, Reznicek V, Adam V, Zitka O, Jurikova T, Krska B, Matuskovic J, Plsek J, Saloun J, Horna A, Kizek R (2008) Use of liquid chromatography with electrochemical detection for the determination of antioxidants in less common fruits. *Molecules* 13(11):2823–2836. <https://doi.org/10.3390/molecules131102823>
- George J-P, Konrad H, Collin E, Thevenet J, Ballian D, Idžojić M, Kamm U, Zhelev P, Geburek T (2015) High molecular diversity in the true service tree (*Sorbus domestica*) despite rareness: data from Europe with special reference

- to the Austrian occurrence. *Ann Bot* 115:1105–1115. <https://doi.org/10.1093/aob/mcv047>
- Güler E (2023) Polyphenols, organic acids, and their relationships in red grapes of *Vitis vinifera* and *Isabella* (*Vitis labrusca*) under arid conditions. *Eur Food Res Technol* 249:913–921. <https://doi.org/10.1007/s00217-022-04183-9>
- Gunness P, Kravchuk O, Nottingham SM, D'Arcy BR, Gidley MJ (2009) Sensory analysis of individual strawberry fruit and comparison with instrumental analysis. *Postharvest Biol Technol* 52:164–172. <https://doi.org/10.1016/j.postharvbio.2008.11.006>
- Işık E (2017) Determination of some phenolic compounds in wild *Prunus*, *Sorbus*, *Diospyros* and development of a new antioxidant capacity determination method (Chromac). Doctoral Thesis, Uludağ University, Bursa, Türkiye.
- Jeran N, Židovec V, Dujmović Purgar D, Vokurka A, Mešić A, Karlović K, Duralija B (2021) Utilization value of *Sorbus* s.l. in Croatia and its potential enhancement. *Acta Hort.* <https://doi.org/10.17660/ActaHortic.2021.1308.13>
- Kamm U, Rotach P, Gugerli F, Siroky M, Edwards P, Holdegger R (2009) Frequent long-distance gene flow in a rare temperate forest tree (*Sorbus domestica*) at the landscape scale. *Heredity* 103:476–482. <https://doi.org/10.1038/hdy.2009.70>
- Karakaya O, Özdemir İO, Ateş U, Öztürk B, Uluca M, Tuncer C (2024) Effect on total phenolic, total flavonoid, and antioxidant activity in hazelnut kernels damaged by brown marmorated stink bug, *Halyomorpha halys* Stal (Hemiptera: Pentatomidae). *BSJ Eng Sci* 7:1321–1326. <https://doi.org/10.34248/bsengineering.1555222>
- Kepenek Şahin G (2018) Performances of service tree (*Sorbus domestica* L.) genotypes selected from Tokat province, Master Thesis, Gaziosmanpaşa University, Tokat, Türkiye.
- Kim M-B, Park J-S, Lim S-B (2010) Antioxidant activity and cell toxicity of pressurised liquid extracts from 20 selected plant species in Jeju, Korea. *Food Chem* 122:546–552. <https://doi.org/10.1016/j.foodchem.2010.03.007>
- Kurnaz OC, Ozturk A, Faizi ZA, Ates U, Ozturk B (2024) Pomological, bioactive compounds, and antioxidant activity of selected superior genotypes from a highly diversified loquat population. *Genet Resour Crop Evol* 71:1507–1520. <https://doi.org/10.1007/s10722-023-01711-8>
- Lim TK (2012) *Sorbus domestica*. Edible medicinal and non-medicinal plants. Springer, Netherlands, pp 590–593
- Macit M, Ahıskalı M, Özbay N (2022) A review on the botanical and phytochemical properties of some species belonging to *Sorbus* sp. *Int J Food Agric Anim Sci* 2:31–37
- Majić B, Šola I, Likić S, Cindrić IJ, Rusak G (2015) Characterisation of *Sorbus domestica* L. bark, fruits and seeds: nutrient composition and antioxidant activity. *Food Technol Biotechnol* 53:463–471
- Mditshwa A, Magwaza LS, Tesfay SZ (2019) Shade netting on subtropical fruit: effect on environmental conditions, tree physiology and fruit quality. *Sci Hortic* 256:108556. <https://doi.org/10.1016/j.scienta.2019.108556>
- Miletić R, Paunović S (2012) Research into service tree (*Sorbus domestica* L.) population in eastern Serbia. *Genetika* 44:483–490. <https://doi.org/10.2298/GENSR1203483M>
- Milošević T, Milošević N, Glišić I, Mladenović J (2012) Fruit quality attributes of blackberry grown under limited environmental conditions. *Plant Soil Environ* 58:322–327
- Moskalets V, Hulko B, Rozhko I, Moroz V, Ivankiv M (2023) Morpho-physiological characteristics of plants and biochemical parameters of rowan berries, common rowan, and domestic rowan grown in the conditions of the Northern Forest-Steppe of Ukraine. *Sci Horiz* 26:78–92. <https://doi.org/10.48077/scihor10.2023.78>
- Moulehi I, Bourgou S, Ourghemmi I, Tounsi MS (2012) Variety and ripening impact on phenolic composition and antioxidant activity of mandarin (*Citrus reticulata* Blanco) and bitter orange (*Citrus aurantium* L.) seeds extracts. *Ind Crops Prod* 39:74–80. <https://doi.org/10.1016/j.indcrop.2012.02.013>
- Ňorbová M, Vollmannová A, Pintér E, Šnirc M, Franková H, Fedorková S, Čeryová N (2023) The content of vitamin C and antioxidant activity in less-known types of fruit. *J Microbiol Biotechnol Food Sci* 13(1):e9937. <https://doi.org/10.55251/jmbfs.9937>
- Ognyanov M, Denev P, Petkova N, Petkova Z, Stoyanova M, Zhelev P, Matev G, Teneva D, Georgiev Y (2022) Nutrient constituents, bioactive phytochemicals, and antioxidant properties of service tree (*Sorbus domestica* L.) fruits. *Plants* 11(14):1832. <https://doi.org/10.3390/plant11141832>
- Ozturk B, Hekimoglu CA, Olcer MA, Ates U, Uzun S, Karakaya O (2024) Changes in quality characteristics of strawberry tree (*Arbutus unedo* L.) fruit packed with perforated polyethylene terephthalate during cold storage. *Appl Fruit Sci* 66:1377–1386. <https://doi.org/10.1007/s10341-024-01104-w>
- Piagnani MC, Debellini C, LoScalzo R (2012) Phyllometry and carpometry, chemical and functional characterization of fruits of *Sorbus domestica* L. (service tree) selections. *J Berry Res* 2:7–22
- Poljak I, Vahčić N, Liber Z, Tumpa K, Pintar V, Zegnal I, Vidaković A, Valković B, Kajba D, Idžojić M (2021) Morphological and chemical diversity and antioxidant capacity of the service tree (*Sorbus domestica* L.) fruits from two eco-geographical regions. *Plants* 10:1691. <https://doi.org/10.3390/plants10081691>
- Rahman MM, Khan MMR, Hosain MM (2007) Analysis of vitamin C (ascorbic acid) contents in various fruits and vegetables by UV-spectrophotometry. *Bangladesh J Sci Ind Res* 42:417–424
- Raigón Jiménez MD, García-Martínez MD, Esteve Ciudad P, Fukalova T (2024) Nutritional, bioactive, and volatile characteristics of two types of *Sorbus domestica* undervalued fruit from Northeast of Iberian Peninsula. *Spain Mol* 29:4321. <https://doi.org/10.3390/molecules29184321>
- del Río J, de Azagra Paredes AM, de Rueda JAO (2009) Ecología del paisaje del género " *Sorbus* " L. en la península Ibérica y Baleares. *Ecología* 25–44
- Sagdic O, Polat B, Yetim H (2022) Bioactivities of some wild fruits grown in Turkey. *Erwerbs-Obstbau* 64:299–305. <https://doi.org/10.1007/s10341-021-00631-0>
- Šebek G (2020) The phenological and pomological traits of biotypes of service tree (*Sorbus domestica* L.) in the area of Donja Morača important for the production of

- generative rootstocks. *J Hyg Eng des* 29:58–67. <https://doi.org/10.13140/RG.2.2.21600.64007>
- Špišek Z, Otto L-G, Vašut RJ (2022) Genotypic variability of *Sorbus domestica* in central Europe revealed by the SSR markers. *Plant Biosyst* 156:938–946. <https://doi.org/10.1080/11263504.2021.1984999>
- Tang C, Chen X, Deng Y, Geng L, Ma J, Wei X (2022) Complete chloroplast genomes of *Sorbus sensu stricto* (*Rosaceae*): comparative analyses and phylogenetic relationships. *BMC Plant Biol* 22:495. <https://doi.org/10.1186/s12870-022-03858-5>
- Tas A, Gundogdu M, Ercisli S, Orman E, Celik K, Marc RA, Buckova M, Adamkova A, Mlcek J (2023) Fruit quality characteristics of service tree (*Sorbus domestica* L.) genotypes. *ACS Omega* 8(22):19862–19873. <https://doi.org/10.1021/acsomega.3c01788>
- Termentzi A, Kefalas P, Kokkalou E (2006) Antioxidant activities of various extracts and fractions of *Sorbus domestica* fruits at different maturity stages. *Food Chem* 98:599–608. <https://doi.org/10.1016/j.foodchem.2005.06.025>
- Ulaszewski B, Jankowska-Wróblewska S, Świło K, Burczyk J (2021) Phylogeny of Maleae (*Rosaceae*) based on complete chloroplast genomes supports the distinction of *Aria*, *Chamaemespilus* and *Torminalis* as separate genera, different from *Sorbus* sp. *Plants* 10:2534. <https://doi.org/10.3390/plants10112534>
- Yaman M, Balta MF, Karakaya O, Kaya T, Necas T, Yildiz E, Dirim E (2023) Assessment of fatty acid composition, bioactive compounds, and mineral composition in hazelnut genetic resources: implications for nutritional value and breeding programs. *Horticulturae* 9:1008. <https://doi.org/10.3390/horticulturae9091008>
- Yayla S (2019) Pomological and morphological characterization of pear genotypes in Seben (Bolu) region. Master Thesis, Bolu Abant İzzet Baysal University, Bolu, Türkiye.
- Zeiner M, Juranović Cindrić I, Majić B, Stingeder G (2017) Study of the accumulation of toxic and essential ultra-trace elements in fruits of *Sorbus domestica* L. *Int J Environ Res Public Health* 14:341
- Zhishen J, Mengcheng T, Jianming W (1999) The determination of flavonoid contents in mulberry and their scavenging effects on superoxide radicals. *Food Chem* 64:555–559. [https://doi.org/10.1016/S0308-8146\(98\)00102-2](https://doi.org/10.1016/S0308-8146(98)00102-2)

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.