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ANTIOXIDANT CAPACITY, PHENOLIC COMPOUND CONTENT, AND MINERAL COMPOSITION OF ETHANOL EXTRACTS FROM *SORBUS AUCUPARIA* AND *SORBUS KUSNETZOVII*

Kübra CİNAR TOPCU[1], Pınar ANLAR[2*], Özlem ÇAKIR[3], Abdurrahman SEFALI[4]
[1]Bayburt University, Department of Food Processing, Aydıntepe, Bayburt, Türkiye
[2]Atatürk University, Department of Food Processing, Erzurum, Türkiye
[3]Bayburt University, Food Engineering, Bayburt, Türkiye
[4]Bayburt University, Primary Education Department, Bayburt, Türkiye

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ABSTRACT
Ethanol extracts of *Sorbus aucuparia* L. and *Sorbus kusnetzovii* Zinserl. fruits, belonging to the *Rosaceae* family, were obtained using an ultrasonic-assisted extraction method. The total phenolic contents of *S. aucuparia* and *S. kusnetzovii* were 8.44±0.66 mg GAE/g and 8.65±2.18 mg GAE/g, respectively, while their total flavonoid contents were 2.30±0.01 mg QE/g and 2.67±0.13 mg QE/g, respectively. The fruits' DPPH values were measured as 9.59±0.00 mg TE/g and 9.28±0.05 mg TE/g, FRAP values as 9.51±0.42 mg TE/g and 13.38±0.52 mg TE/g, and CUPRAC values as 13.43±0.01 mg TE/g and 23.21±0.74 mg TE/g. Furthermore, both *Sorbus* species were found to have a rich mineral content. Therefore, it can be concluded that *S. aucuparia* and *S. kusnetzovii* fruits contain potent antioxidants, abundant phenolic compounds, and valuable minerals. Furthermore, they have significant potential as functional foods and are strong candidates for further clinical research.
Keywords: *Sorbus aucuparia* L., *Sorbus kusnetzovii* Zinserl., antioxidant, phenolic, ICP-MS

SORBUS AUCUPARIA VE SORBUS KUSNETZOVII'DEN ELDE EDİLEN ETANOL EKSTRAKTLARININ ANTİOKSİDAN KAPASİTESİ, FENOLİK BİLEŞİK İÇERİĞİ VE MİNERAL KOMPOZİSYONU

ÖZ
Rosaceae familyasına ait *Sorbus aucuparia* L. ve *Sorbus kusnetzovii* Zinserl. meyvelerinin etanol ekstraktları, ultrasonik destekli ekstraksiyon yöntemi kullanılarak elde edildi. *S. aucuparia* ve *S. kusnetzovii*'nin toplam fenolik içerikleri sırasıyla 8.44±0.66 mg GAE/g ve 8.65±2.18 mg GAE/g iken, toplam

* *Corresponding author*/Sorumlu yazar
✉: pinar.anlar@atauni.edu.tr ☏: (+90) 442 231 6239 🖷: (+90) 442 231 2503

Kübra Cinar Topcu; ORCID no: 0000-0002-3715-8739
Pınar Anlar; ORCID no: 0000-0001-9832-553X
Özlem Çakır; ORCID no: 0000-0002-5080-7721
Abdurrahman Sefalı; ORCID no: 0000-0002-0092-0857

flavonoid içerikleri sırasıyla 2.30±0.01 mg QE/g ve 2.67±0.13 mg QE/g idi. Meyvelerin DPPH değerleri 9.59±0.00 mg TE/g ve 9.28±0.05 mg TE/g, FRAP değerleri 9.51±0.42 mg TE/g ve 13.38±0.52 mg TE/g ve CUPRAC değerleri 13.43±0.01 mg TE/g ve 23.21±0.74 mg TE/g olarak ölçüldü. Ayrıca, her iki *Sorbus* türünün de zengin mineral içeriğine sahip olduğu bulundu. Bu nedenle, *S. aucuparia* ve *S. kusnetzovii* meyvelerinin güçlü antioksidanlar, bol miktarda fenolik bileşik ve değerli mineraller içerdiği sonucuna varılabilir. Ayrıca, fonksiyonel gıda olarak önemli potansiyele sahiptirler ve daha ileri klinik araştırmalar için güçlü adaylardır.
Anahtar kelimeler: *Sorbus aucuparia* L., *Sorbus kusnetzovii* Zinserl., antioksidan, fenolik, ICP-MS

INTRODUCTION

The extraction of valuable components from plants has recently attracted considerable attention from consumers and academic and industrial circles. This interest focuses on compounds, such as phenolic acids, phenolic diterpenes, flavonoids, essential oils, and other bioactive molecules (Beya et al., 2021; Aimone et al., 2024). Such compounds are characterized by their anti-inflammatory, antibacterial, and antiviral effects and their potential to prevent inflammation, cancer, neurodegenerative, and cardiovascular diseases (Perron and Brumaghim, 2009; Beya et al., 2021). Therefore, these naturally derived compounds can be used as dietary supplements or food additives or to increase the antioxidant activity of foods (Pereira et al., 2022). Furthermore, compounds with rich bioactive properties can also be used to produce various drugs (AlAli et al., 2021). In this respect, wild berries (mountain ash, blueberries, raspberries, blackberries, cranberries, forest strawberries, and cherries) attract attention due to their abundant bioactive compounds and unique flavors (Aurori et al., 2024). With 121 genera and 5997 species, the *Rosaceae* family has medicinal, nutritional, ecological, and economic importance and is one of the important plant families whose bioactive properties have been studied (Bánki et al., 2022). This family includes various fruits, such as apple, pear, medlar, plum, cherry, peach, rosehip, hawthorn, and quince, and ornamental plants, such as rose, meadow hyacinth, mountain ash, and firethorn (Dönmez et al., 2022).

Sorbus L. is an important genus belonging to the *Rosaceae* family (Öz Atasever and Gerçekcioğlu, 2013). It is commonly called rowan berry, mountain ash, or European fruit (Rutkowska et al., 2023). This genus, which is predominantly found in the Northern Hemisphere, typically consists of deciduous, thornless, small trees and/or shrubs (Lykholat et al., 2021). Its flowers are usually white, occasionally pink, and turn yellow, red, or orange upon ripening (Odunkıran, 2016). *Sorbus* species are recognized for their potential to protect against inflammation, rheumatism, diabetes, kidney disorders, and cardiovascular diseases. Additionally, they are valued for their appetite-stimulating properties and as a rich source of vitamins (Singh and Mijakovic, 2022). Due to their bitter and astringent taste, they are not commonly consumed fresh but are widely used to produce jellies, jams, and fruit juices (Aimone et al., 2024). Furthermore, in several European countries, e.g. Estonia, they are utilized in bread-making and to flavor, clarify, and preserve alcoholic beverages (Sulimanec et al., 2023). Eighty taxa worldwide and 18 taxa in Türkiye represent the *Sorbus* genus (Aksoy, 2013). In Türkiye, the regions with the highest species diversity are located in Eastern Anatolia, a part of the Caucasus region (Akyıldırım Beğen and Eminağaoğlu, 2022). The important *Sorbus* species found in Türkiye include *Sorbus aucuparia* (rowan) and *Sorbus kusnetzovii* (service tree).

S. aucuparia is one of the underutilized forest fruits, reaching a height of 15-20 m, and is a decorative plant with reddish-orange fruits (Aurori et al., 2024). *S. kusnetzovii* is another significant taxon belonging to the *Sorbus* genus. It is distributed across open rocky slopes at altitudes of 1200-2400 m above sea level in the middle and high mountain ranges of the Caucasus. This species reaches a height of 4-5 m and has red, shiny, and slightly hairy fruits (Ibrahimov and Matsyura, 2018). The fruits of the *Sorbus* genus contain organic acids (ascorbic acid), polyphenols (phenolic, chlorogenic, and neochlorogenic acids), carotenoids, and trace elements (Aurori et al., 2023). The range of *Sorbus* phenolics, from simple phenolic acids to complex tannin-type proanthocyanidins, highlights the importance of their bioactive compound content (Olszewska and Michel, 2009). Moreover, these fruits have historically been utilized in the treatment of diverse gastrointestinal, pulmonary, renal, hepatic, and cardiovascular disorders (Eremeevaa and Makarova, 2022). Additionally, *Sorbus* fruits have antidiabetic, diuretic, anti-inflammatory, antibacterial, and antipyretic properties (Bobinaitė et al., 2020). The pulp of *Sorbus* fruits and their seeds are nutritionally important since *Sorbus* seeds contain a high amount of unsaturated fatty acids (Şen, 2011).

In the literature, various studies have examined the bioactive impacts of *S. aucuparia* (Petkova et al., 2020; Sarv et al., 2021; Eremeevaa and Makarovab, 2022; Sulimanec et al., 2023; Krzywicka and Kobus, 2023; Ryszczynska et al., 2024). However, few studies have focused on *S. kusnetzovii* (Ekin et al., 2016). Furthermore, few studies have investigated the mineral content of these fruits (Raspe et al., 2000; Aslantas et al., 2007; Sulimanec et al., 2023). Therefore, the current research determined the total phenolic content (TPC) and flavonoid content (TFC), as well as the DPPH (1,1-diphenyl-2-picryl-hydrazyl), FRAP (ferric-reducing antioxidant power), and CUPRAC (cupric ion reducing capacity) of ultrasonic-assisted ethanol extracts of two *Sorbus* species (*S. aucuparia* and *S. kusnetzovii*). Additionally, the macro- and micro-mineral content of the fruits was analyzed with an ICP-MS (inductively coupled plasma-mass spectrometry) device. This study investigated in detail the bioactive properties of the two important *Sorbus* species, aiming to fill the gap in the literature in this area. Moreover, the high bioactive properties of these fruits, their potential applications in food and traditional medicine, and the widespread occurrence of the *Sorbus* genus in Türkiye further highlight this study's significance.

MATERIAL AND METHODS

Material

S. aucuparia and *S. kusnetzovii* utilized in the study were collected from Bayburt province in August 2022. References, such as "Flora of Turkey and the Eastern Aegean Islands" (Davis, 1965-1985; Davis et al., 1988; Güner et al., 2000), "List of Plants of Turkey (Vascular Plants)" (Güner et al., 2012), and "Identification of Wild Fruits Growing in Bayburt Province and Some Studies" (Sefalı, 2023), were taken as a basis when identifying the plants. The fourth author identified the plants. Afterward, the samples were brought to the Food Engineering Laboratory of Bayburt University, dried at 50^{o}C for 2 days, and stored under appropriate conditions until being analyzed. The plants turned into herbarium specimens are preserved in the Science Laboratory of the Faculty of Education at Bayburt University.

Extraction

Extraction was carried out using an ultrasonic-assisted technique, modified from the method described by Meng et al. (2011). Ultrasonic-assisted extraction was performed in an ultrasonic bath (WiseClean WUC-D06H) with a solvent mixture of 80% ethanol and distilled water. Initially, 3 g of the sample was mixed with 30 mL of ethanol and sonicated. After extraction, the samples were centrifuged at 2282×g for a period of 30 min. The supernatants obtained were carefully separated, transferred into dark bottles, and stored at a temperature of -18°C until the subsequent analysis.

TPC

To determine the samples' TPC, a mixture of 5 mL of Folin-Ciocalteu reagent (Merck) (diluted 1:10 with water), 4 mL of 7.5% Na_2CO_3 solution, and 1 mL of the extract was prepared. After the mixture was incubated at room temperature in the dark for a period of 60 min, the absorbance was recorded with a spectrophotometer (Shimadzu

UV-1800) at 750 nm. The results were presented as gallic acid equivalents (GAE) (Fluka) in mg GAE per gram of extract (mg GAE/g) (McDonald et al., 2001).

TFC

To determine the TFC, 2 mL of 2% aluminum chloride solution was added to 2 mL of the diluted extract. The mixture was kept at room temperature for 15 min. Afterward, the samples' absorbance was read at a wavelength of 420 nm. The results were presented as quercetin equivalents (QE) in mg QE per gram of dry matter (mg QE/g) (Chandra et al., 2014).

Antioxidant capacity

For the purpose of evaluating the extracts' impacts on the DPPH radical scavenging activity assay radical (Fluka), 3.9 mL of DPPH solution (6×10^{-5} M) was added to 100 μL of the diluted extract, and the mixture was kept in the dark for a period of 30 min. Afterward, the absorbance of the color formed as a result of the reaction between the extracts and DPPH was measured at 515 nm. The results were given as Trolox equivalents (TE) in mg TE per gram of dry matter (mg TE/g) (Bao et al., 2005; Zhou et al., 2009).

To determine the extracts' FRAP values, a working solution was prepared by mixing acetate buffer, TPTZ (Sigma-Aldrich), and $FeCl_3$-$6H_2O$ and then heated to 37°C. A 150 μL portion of the extract was reacted with 2850 μL of FRAP solution in the dark for a period of 30 min. The colored product was measured at a wavelength of 593 nm, and the results were given as Trolox equivalents (mg TE/g) (Upadhyay et al., 2010).

To determine the extracts' CUPRAC values, 1.10×10^{-2} M $CuCl_2.2H_2O$ solution, 1 M ammonium acetate buffer (pH 7.0), and 7.5×10^{-3} M neocuproine solution were prepared. The copper solution, ammonium acetate buffer, neocuproine solution, water, and 0.1 mM extract were mixed at 1 ml each to achieve a total volume of 4.1 mL. The mixture was kept in the dark for a period of 30 min, and absorbance values were measured at 450 nm (Apak et al., 2009).

Mineral composition

The samples' macro- and micro-element contents were analyzed with an ICP-MS (Agilent Technologies 7800) instrument by making some modifications to the method described by Mayda et al. (2020). The results were expressed in mg/kg. The following macro- and micro-elements were identified within the scope of the current research: sodium (Na), magnesium (Mg), phosphorus (P), potassium (K), calcium (Ca), manganese (Mn), iron (Fe), zinc (Zn), aluminum (Al), copper (Cu), lithium (Li), beryllium (Be), chromium (Cr), cobalt (Co), nickel (Ni), arsenic (As), selenium (Se), ruthenium (Ru), rhodium (Rh), palladium (Pd), silver (Ag), cadmium (Cd), barium (Ba), and lead (Pb).

Statistical analysis

The results were subjected to analysis of variance using the IBM SPSS Statistics 27 package program. Afterward, Duncan's multiple comparison test compared the averages. Furthermore, Pearson's correlation test examined the relationship between the results for TPC, TFC, DPPH, FRAP, and CUPRAC. This study analyzed the differences between the mineral contents of two *Sorbus* genotypes using PCA (principal component analysis). The first principal component (PC1) was determined to represent 100% of the total variance.

RESULTS

TPC and TFC

The total phenolic contents of *S. aucuparia* and *S. kusnetzovii* fruits were 8.44±0.66 and 8.65±2.18 mg GAE/g, respectively (Figure 1). The results obtained agree with the literature. A similar study found the TPC of methanol extracts from *S. aucuparia* fruits collected from 12 populations in the Alpine-Dinaric region of Croatia to be 932 mg/100 g on average (Sulimanec et al., 2023). Another study evaluated the phenolic content in the fruits, juices, and pomaces of 16 sweet rowan berry varieties and wild rowan berries (*S.*

aucuparia). The samples' TPC values varied between 2.53-15.05 mg GAE/g dry weight for whole fruits, 0.53-14.8 mg GAE/g dry weight for juices, and 15.97-44.68 mg GAE/g dry weight for pomace fractions (Sarv et al., 2021). Another research examined the TPC values of aqueous and methanol extracts of *S. aucuparia* fruits. The study concluded that the TPC values of water extracts (2.07-3.33 mg GAE/g dry matter) were lower than those of methanol extracts (2.71-4.15 mg GAE/g dry matter) (Ryszczynska et al., 2024). Considering both the current work and the literature, it can be inferred that rowan berries are a good source of polyphenols. Therefore, these fruits are considered valuable functional components for food and non-food applications.

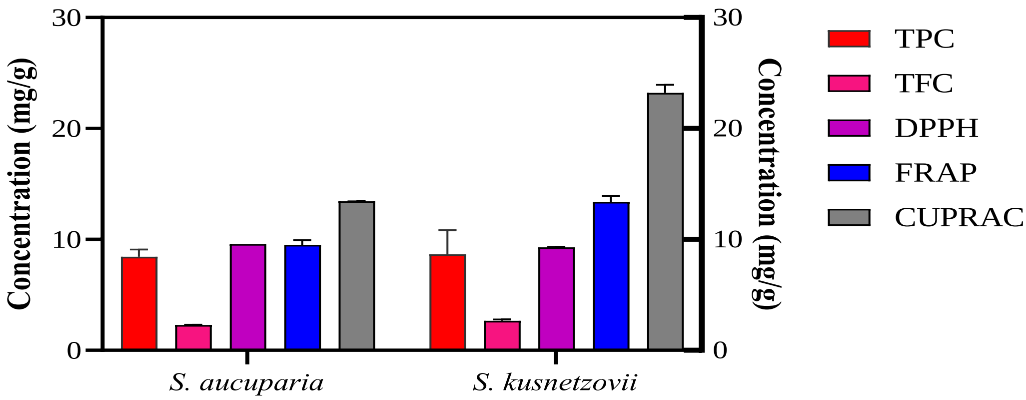

Figure 1. TPC, TFC, DPPH, FRAP, and CUPRAC contents of *S. aucuparia* and *S. kusnetzovii*

Flavonoids are the most common polyphenols in foods, consisting of anthocyanidins, flavones, flavonols, flavanones, catechins, and proanthocyanidins (Kocaimamoğlu, 2014). Anthocyanidins and anthocyanins represent the most abundant groups of flavonoids in red, blue, and purple fruits. There are no anthocyanins in the content of rowan berry extracts, and other pigments determine their coloration (Eremeevaa and Makarovab, 2022). The TFC of *S. aucuparia* and *S. kusnetzovii* fruits was 2.30±0.01 and 2.67±0.13 mg QE/g, respectively (Figure 1). A study by Eremeevaa and Makarovab (2022) found the TFC value of *S. aucuparia* extract to be 1.92±0.04 mol C/L, while Aurori et al. (2024) reported the TFC value of its ethanol extract as 537.58±3.255 g QE/mL.

Antioxidant capacity

Substances with antioxidant properties are involved in delaying and/or preventing oxidation by inhibiting the formation of free radicals or suppressing their propagation (Dorman et al., 2003). In this regard, butylated hydroxytoluene, butylated hydroxyanisole, ascorbic acid, tocopherol, and gallic acid are antioxidants commonly used in foods (García-Valencia et al., 2022). However, since these compounds are synthetic, they are not fully accepted by consumers due to their potential toxicity and carcinogenic effects (Mostafa and Azab, 2022). Hence plants, fruits, and their extracts with natural antioxidant properties have attracted considerable attention (Wang et al., 2022). Accordingly, research on natural antioxidants that could replace synthetic antioxidants that are utilized in the food industry at present is progressing rapidly.

Antioxidant activity determination methods depend on various parameters, such as the substrate in the studied system, reaction conditions, concentrations, and the structure of the compound to be analyzed. Therefore, there is no standard method for determining a compound's antioxidant activity (Şen, 2011). For this reason, multiple antioxidant activity measurements should be performed to account for phenolics exhibiting various antioxidant mechanisms (Olszewska and Michel, 2009). In this respect, the current research determined the antioxidant capacity of rowan berries using the DPPH, FRAP, and CUPRAC methods, and Figure 1 displays the results. The DPPH radical represents a stable free radical commonly utilized to measure antioxidants' free radical scavenging activity (Sanchez-Moreno, 2002). The DPPH values of *S. aucuparia* and *S. kusnetzovii* fruits were 9.59±0.00 and 9.28±0.05 mg TE/g, respectively. A study by Olszewska and Michel (2009) obtained methanol extracts of *S. aucuparia, S. aria*, and *S. intermedia* fruits. The DPPH values of these fruits were determined to be 105.5, 181.1, and 86.9 μmol TE/g dry matter, respectively. Another study analyzed the effects of final reactor sizes on the efficiency of ultrasound-assisted extraction of *S. aucuparia*. The study reported DPPH values between 23.63-73.28 μmol TE/g for a 35-mm-diameter vessel and between 24.48-74.92 μmol TE/g for a 25-mm-diameter vessel (Krzywicka and Kobus, 2023).

The FRAP assay, measuring the antioxidant activity of rowan berries, determined the FRAP values of *S. aucuparia* and *S. kusnetzovii* to be 9.51±0.42 and 13.38±0.52 mg TE/g, respectively (Figure 1). In the research by Raudonis et al. (2014), the FRAP values of different *Sorbus* species ranged from 7.34 to 42.66 μmol/g dry matter, with the FRAP value of *S. aucuparia* identified as 11.83 μmol/g dry matter. Another study reported the FRAP value of the methanol extract of *S. aucuparia* fruits to be 441.5±5.8 μmol Fe(II)/g dry matter (Olszewska and Michel, 2009). A study analyzing the effects of final reactor sizes on the efficiency of ultrasound-assisted extraction of *S. aucuparia* bioactive compounds found FRAP values to range from 59.46 to 119.00 μmol TE/g for a 35-mm-diameter vessel and from 52.98 to 154.27 μmol TE/g for a 25-mm-diameter vessel (Krzywicka and Kobus, 2023). The research by Ekin et al. (2016) obtained ethanol extracts of 34 taxa from the genera *Amelanchier, Cotoneaster, Pyrus*, and *Sorbus*. The FRAP values of *S. aucuparia* collected from four cities (Rize, Erzincan, Artvin, and Trabzon) varied between 0.565±0.03 and 0.974±0.07 μg/mL. The FRAP value of *S. kusnetzovii* extract was determined to be 1.077±0.02 μg/mL. Bozhuyuk (2011) reported that genetic factors affect the FRAP activity of *S. aucuparia*, with the FRAP values of 12 species ranging from 2.93 to 5.68 mM TE/100 g.

CUPRAC is another method used to determine reducing power. In the above-mentioned method, copper ions are reduced, and it serves as an antioxidant activity index for hydrophilic and lipophilic antioxidant compounds (Apak et al., 2009). In the current work, the CUPRAC values of *S. aucuparia* and *S. kusnetzovii* fruits were 13.43±0.01 and 23.21±0.74 mg TE/g, respectively (Figure 1). No studies in the literature have analyzed the CUPRAC values of *S. aucuparia* and *S. kusnetzovii* fruits. However, a study reported the CUPRAC value of *S. aria* fruits collected from Bulgaria to be 370.70 mM TE/100 g dry matter in fresh fruits and 783.17 mM TE/100 g dry matter in dried fruits (Petkova et al., 2020).

Pearson's correlation analysis

Table 1 contains the test results of Pearson's correlation analysis for the variables TPC, TFC, DPPH, FRAP, and CUPRAC. The table shows that the TPC variable does not correlate statistically significantly with the other variables. The TFC variable was found to correlate significantly (*P<0.05*) with DPPH, FRAP, and CUPRAC. A highly significant correlation of DPPH (*P<0.01*) with FRAP and CUPRAC was observed. Furthermore, a highly significant correlation was identified between FRAP and CUPRAC (*P<0.01*), showing that both methods are based on a similar measurement of antioxidant capacity.

Table 1. The test results of Pearson's correlation analysis for the variables TPC, TFC, DPPH, FRAP, and CUPRAC

	TPC	TFC	DPPH	FRAP	CUPRAC
TPC	1				
TFC	0.402	1			
DPPH	-0.230	-0.981*	1		
FRAP	0.246	0.966*	-0.991**	1	
CUPRAC	0.162	0.961*	-0.997**	0.993**	1

*:*P<0.05*, **:*P<0.01*

ICP-MS

Minerals are important in plant metabolism. P is essential for vital growth processes in plants, while Ca and Mg are cell wall components. K is used in the formation of carbohydrates and proteins. S is a component of amino acids. Fe and Mn are necessary for the formation of chlorophyll, whereas Zn and Fe are cofactors. Na replaces K in regulating stomata opening and closing (Mishra et al., 2012). Furthermore, plants' macro- and micro-element content have a synergistic effect with other compounds, making the plant's elemental content important (Kremer et al., 2012).

The present study examined in detail the macro- and micro-element contents of rowan fruits (Table 2). In the literature, very few studies have investigated the mineral content of *S. aucuparia*. However, no study on *S. kusnetzovii* has been found. Na, Mg, P, K, Ca, and Al contents of *S. aucuparia* and *S. kusnetzovii* fruits were determined to be the highest. Moreover, the contents of minerals with antioxidant properties (Zn, Cu, Fe, and Mn) are also quite high (Shin et al., 2012). Additionally, minerals such as Li, Cr, Co, Ni, Pd, Ag, Ba, and Pb have been identified. The maximum permissible limits for the toxic elements Cd and Pb, set by the World Health Organization (WHO) in plant materials, are 0.3 and 10 mg/kg, respectively. The available fruits do not exceed these critical values and can, therefore, be considered safe (WHO 2007). A study determined the mineral content of *S. aucuparia* fruits collected from the Alpine-Dinaric region of Croatia. The study obtained the following results: K 2485>Ca 459>P 206>Mg 193>Na 6.29>Fe 3.68>Mn 3.58>Zn 1.11>Cu 0.731>Mo 0.098>Co 0.003>Se 0.001 mg/kg (Sulimanec et al., 2023). The differences in some elements can be attributed to the differences in soil characteristics between Croatia and Türkiye. However, Aslantas et al. (2007) determined the K, P, Ca, Mg, Fe, Fe, Cu, Zn, and Mn contents of *S. aucuparia* fruits collected from Northeastern Anatolia to be 1540, 123, 299, 278.4, 24.2, 2.94, 8.61, and 5.03 mg/kg, respectively.

This study analyzed the differences between the mineral contents of the two *Sorbus* genotypes by PCA (Figure 2). The PCA plot shows the differences between *S. aucuparia* and *S. kusnetzovii* species in terms of mineral composition. PC1 component explained 100% of the variance in the entire data and clearly showed the distinction between the species. *S. aucuparia* species was found in negative PC1 values and was associated with Na mineral. *S. kusnetzovii* species was found in positive PC1 values and was associated with K mineral. Mg and Li minerals in the center were found in neutral positions between the species.

The results obtained and the findings of the current work are similar. In this respect, the results of the current work and the results obtained from the literature show that rowan fruits have valuable nutritional properties and can be used in the food industry.

Table 2. The concentration of macro and micro elements of *S. kusnetzovii* and *S. aucuparia*

Element	*S. kusnetzovii*		*S. aucuparia*		LOD	LOQ
	Content (ppm)	RSD	Content (ppm)	RSD		
Na	942.50	0.43	1322.72	0.92	0.227	0.758
Mg	1898.57	0.28	396.17	0.57	0.580	1.934
P	2279.93	0.96	560.14	0.63	3.702	12.341
K	18413.10	0.22	2002.18	1.99	9.582	31.938
Ca	500.12	0.92	176.18	0.59	1.896	6.321
Mn	14.27	1.82	8.05	0.15	0.015	0.050
Fe	46.60	0.21	26.12	0.97	0.126	0.422
Zn	15.95	0.19	4.58	0.98	0.434	1.448
Al	63.02	1.11	53.27	1.14	0.654	2.179
Cu	34.86	1.21	26.68	0.95	0.033	0.110
Li	1.52	0.84	62.45	1.25	0.048	0.161
Be	<LOQ	1.68	<LOQ	24.68	0.005	0.017
Cr	0.16	1.86	0.07	3.23	0.040	0.135
Co	0.09	1.09	<LOQ	5.06	0.011	0.037
Ni	1.45	0.71	0.43	1.61	0.064	0.214
As	<LOQ	10.66	<LOQ	14.09	0.014	0.045
Se	<LOQ	69.28	<LOQ	21.65	0.242	0.806
Ru	<LOQ	33.26	<LOQ	56.93	0.001	0.004
Rh	<LOQ	8.84	<LOQ	11.23	0.000	0.001
Pd	0.02	1.36	0.01	2.39	0.003	0.009
Ag	0.20	2.63	0.35	1.05	0.019	0.063
Cd	<LOQ	4.85	<LOQ	18.86	0.109	0.363
Ba	7.62	1.43	3.20	0.46	0.008	0.028
Pb	0.38	0.89	0.25	1.18	0.007	0.024

RSD: Relative standard deviation; LOD/LOQ: Limit of detection/limit of quantitation

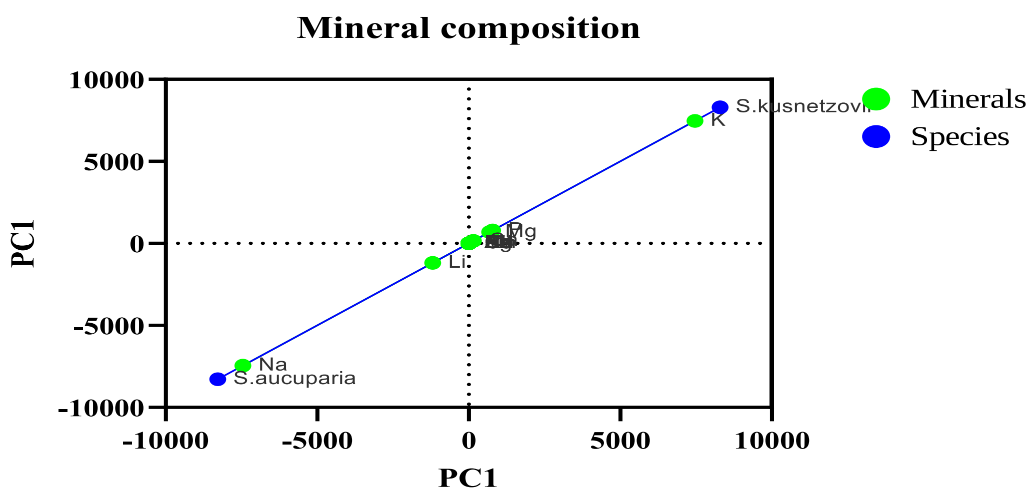

Figure 2. PCA analysis of mineral composition differentiating *S. aucuparia* and *S. kusnetzovii*

CONCLUSION

This study demonstrates that *S. aucuparia* and *S. kusnetzovii* fruits are rich sources of antioxidants, phenolic compounds, and essential minerals, supporting their potential use as natural bioactive ingredients. Their nutritional profile suggests that rowan berries may contribute to functional food development and dietary supplementation.

Future research should focus on the key aspects to further explore their applications. Investigating the bioavailability and metabolic pathways of their bioactive compounds is essential to understanding their physiological effects. There is a need for clinical studies to validate their health benefits and assess long-term safety. Additionally, research on incorporating rowan berries into food formulations and optimizing processing methods could enhance their industrial applicability while preserving nutritional properties.

Overall, the findings above highlight the need for further interdisciplinary studies to determine the role of rowan berries in the pharmaceutical and food industries.

AUTHOR CONTRIBUTIONS

Kübra Cinar Topcu: Formal Analysis, writing – review and editing; Pınar Anlar: Statistical analysis, writing – original draft; Özlem Çakır: Formal Analysis, writing – review and editing; Abdurrahman Sefalı: Material collection, taxonomic description, writing – review and editing.

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