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Research article

In-vitro bioaccessibility and mineral content of two *Ribes* species growing in Cumalikizik village, Bursa Türkiye

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Abstract

The fruits of the genus *Ribes*, also known as currant or gooseberries, can be consumed both as processed and fresh. These berries' health benefits have been well described in general but their biophysicochemical properties largely depend on geographical changes and genotype differences. Six *Ribes* genotypes including *Ribes rubrum* (RR1-RR4) and *Ribes nigrum* (RN1 and RN2) from Cumalikizik, Bursa were compared for their fruit properties, mineral content, and their bioaccessibility. Fruit characteristics were evaluated by analyzing fruit and seed number, soluble solids content (°Brix), fruit color properties, and pH. Potassium (K), calcium (Ca), iron (Fe), manganese (Mn), copper (Cu), zinc (Zn), and magnesium (Mg) contents of fruits were determined using ICP-OES (inductively coupled plasma optical emission spectrometry). The results indicated that all *Ribes* genotypes were rich in K, Ca, and Mg content while they had relatively poor in Mn, Cu, and Zn content. Bioaccessibility of K, Ca, Mg, Fe, Mn, Cu, or Zn was 85%, 84%, 63%, 30%, 50%, 37% or 44% respectively for two *Ribes* species. Significant differences were found between *R. rubrum* and *R. nigrum* genotypes in terms of fruit size and weight, bunch length, seed number, total soluble solids, pH and color, as well as Mn content and Zn accessibility. These data provide valuable information regarding the physicochemical properties, mineral content, and bioaccessibility of two currant species for breeding studies and show that the *Ribes* species is a good source of K, due both to its high content and considerable bioaccessibility. Further research should consider investigating the contents and bioaccessibilities of other nutritional factors that *Ribes* genotypes contain.

Keywords: *Bioaccessibility; mineral content; Ribes rubrum; Ribes nigrum*

1. Introduction

The genus *Ribes* (currants), which includes more than 150 species and varieties, is a member of *Grossulariaceae* family and is commonly grown in mild parts of the Northern Hemisphere (Soloshenko, 2018). Despite the confusion concerning *Ribes* taxonomy, today it is acknowledged that the genus *Ribes* has five subgenera: *Berisia* (European dioecious plants), *Grossularioides* (thorny currants), *Parilla* (South American natives), *Ribes* (currants) and *Grossularia* (gooseberries). The commercially cultivated forms of red and white currants belong to section-*Ribes* (or *Ribesia*) of subgenera

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Ribes (Messinger et al., 1999; Hummer and Dale, 2010). In Türkiye, 8 species of the genus *Ribes* L. are grown, and many other species are observed in the natural flora. Although a few numbers of studies have been implemented on naturally distributed *Ribes* taxa in our country, it is worth noting that this number has increased in recent years (Celenk, 2015).

Ribes exist in high number of bioactive metabolites and flavor compounds, such as sugars and organic acids. These berries are also valued for their food and flavoring qualities, as well as the potential health benefits for their high content of phenolic compounds (Adina et al., 2017; Tian et al., 2019; Montiel-Sánchez et al., 2021). Currants are also well-known fruits for their healing properties and are frequently utilized in the food and pharmaceutical industries. Berry consumption has been presented to have benefits for the treatment of age-related neurodegenerative diseases, metabolic syndrome, and several types of human cancers (da Silva Pinto et al., 2010). Moreover, fruit and bunch properties, which are genotype-specific traits, are important quality attributes for currants. As one of the quality parameters, coloration has a significant effect on the customers that makes it distinguishable as well as the aroma and the taste (Mikulic-Petkovsek et al., 2016). Additionally, berries like currants display diverse colors depending on genotypes and this is an attractive characteristic for the customer choices since they associate better taste with color. Environmental conditions such as temperature, strongly influence fruit color and fruit development by influencing the accumulation of healthy functional phytochemicals (Wang and Zhang, 2001; Krüger et al., 2011; Liang et al., 2023).

Black currants (*R. nigrum* L.) and red currants (*R. rubrum* L.) are two commonly cultivated species of the genus *Ribes* worldwide. In 2022, the total global production of currants was 764498.98 tons, with two countries dominating the market. The Russian Federation was the leading producer with 509500 tons, followed by Poland with 145800 tons (FAOSTAT, 2024). *R. nigrum* is recognized as a good source of polyphenols, anthocyanin, phenolic acid derivatives, flavonols, and proanthocyanidins (Paunović et al., 2017; Staszowska-Karkut & Materska, 2020; Ejaz et al., 2023; Maria-Beatrice et al., 2023). *R. rubrum* is also another currant species that is highly valued for its nutrients and antioxidant components, and they're also known to be especially rich in potassium, calcium, and magnesium (Cvetković et al., 2021; 2022; González et al., 2022). Studies reported that fruits especially currants contain high levels of minerals that can differ according to genotype, cultural practices, soil, and environmental conditions (Paunović et al., 2017; Tian et al., 2023). In addition, although the mineral contents of freshly consumed currants have been well-documented, little is known about the bioaccessibility of the minerals. This is a crucial information because bioaccessibility is not directly proportional to content and bioaccessibility of a given compound may be low despite a high content in the plant. The portion of a phytochemical that is released from the food matrix in a form that is easily absorbed is known as its bioaccessibility (Hu et al., 2023). Numerous elements influence it, such as the nature of phytochemicals, the composition of food matrix, and the working of gastrointestinal tract (Jo et al., 2021; Domínguez-Fernández et al., 2022). The portion of a phytochemical that enters the bloodstream and is used by tissues and organs is known as its bioavailability (Dima et al., 2021). Usually, the concentration of phytochemicals and their metabolites in the bloodstream following intake is used to make this determination. Therefore, research on the bioaccessibility of plants, along with their chemical characterization, is of great importance in scientific research. Cumalikizik village in Bursa was declared a protected area in 1980; the legal protection has preserved the authentic village with its street pattern, wooden houses, cottages, and green areas. In particular, agricultural activities continue in and around the Cumalikizik (Ahunbay et al., 2014). Knowledge about fruit species growing in Cumalikizik village is limited to a few articles (Cansev et al., 2022). Therefore, the present study targeted to investigate the mineral contents (K, Ca, Mg, Fe, Cu, Zn, and Mn) and bioaccessibility, as well as fruit quality parameters (color, fruit and seed number, soluble solids content (°Brix) and pH) of the total six genotypes belonging to *R. nigrum* and *R. rubrum*, which are grown in Cumalikizik village, Bursa, with considerable economic interest.

2. Materials and methods

2.1. Sampling location

The present study includes six *Ribes* genotypes from *R. nigrum* and *R. rubrum* collected from Cumalikizik village in Bursa, Türkiye (Fig. 1; Latitude: 40° 11' 25.1340", Longitude: 29° 10' 20.1360"). The sampling area is located at an altitude of 360 meters with surrounding natural chestnut and pine forests, and the soil is rich in organic matter with approximately 50% loamy structure and an average pH of 6.5.

Fruits of a total 6 *Ribes* genotypes (4 *R. rubrum* and 2 *R. nigrum*; abbreviated as RR1-RR4 and RN1 and RN2 from here in) grown in Cumalikizik village of Bursa province were used (Fig. 2).

Fig. 1. Coordinates of Cumalikizik village of Bursa province in Türkiye where *Ribes* genotypes were collected.

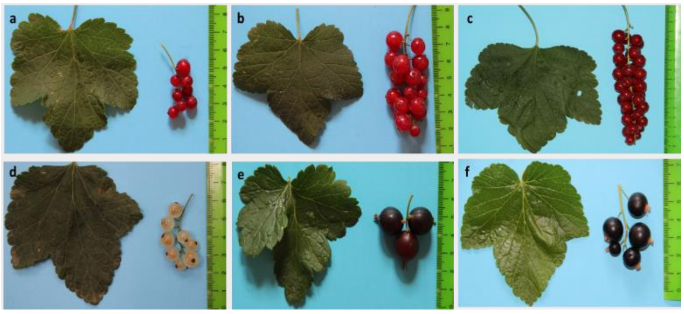

Fig. 2. Images of *R. rubrum* (a=RR1, b=RR2, c=RR3, d=RR4) and *R. nigrum* (e=RN1, f=RN2).

2.2. Physico-chemical analysis and physical properties

Two hundred of fruits were homogenized using a blender.

Total soluble solids and pH were determined using the methods outlined in the Association of Official Analytical Chemists, Official Method 932.12 (AOAC, 2000) and TS 1728 ISO 1842, respectively (TSE, 2001).

Berry diameter, berry height, and bunch height were measured with a digital caliper, and berries were weighed with a regular lab scale.

2.3. Color analysis

The color values of fruit samples were measured using a Chroma Meter (Konica Minolta CR-400, Osaka, Japan), and the CIE system was used to determine color. Color values were determined via calculation of the average of the reflectance values at three different points on each fruit.

2.4. Mineral content and bioaccessibility

Solutions in this analysis were prepared with ultrapure water with 18 MΩ.cm resistance using a water purification device (TKA Ultra Pacific and Genpura). HNO_3 (67%) was used (Merck, Darmstadt, Germany) and carrier gas was chosen as Argon (99.9995% purity, Linde, Türkiye). Standard stock solutions for each element were prepared in 1000 mg/L concentration to comply with Merck calibration standards (Darmstadt, Germany) using HNO_3 (0.3%).

The experimental method was validated by using Certified Cabbage: IAEA - 359 Austria, Certified Strawberry LGC7162 UK, Certified Tea NCSZC 73014 - (GSB-7) China. Lithium (Li), Cerium (Ce), Thallium (Tl), Yttrium (Y), and Cobalt (Co) were utilized as external standard solutions at 10 µg L^{-1}. The digestion process of the samples was carried out with a microwave digestion system (Milestone Brand MLS 1200 Mega, Italy). For disinfection of the containers, 10% HNO_3 (67% v/v), ultra-pure water, and oven-dried at 40°C were applied, respectively.

Table 1
Operating conditions of the ICP-OES.

Parameter	Value
Instrument	Optima 2100 DV
Detector	CCD detector
Nebulizer	Concentric
RF generator	40 MHz
RF power	1300 W
Plasma gas flow rate	15.0 L/min
Auxiliary gas flow rate	0.8 mL/min
Nebulizer gas flow rate	0.5 L/min
Pump speed	15 rpm
Auxiliary flow rate	1.0 L/min
Integration mode	Field
Wavelengths	Ca 317.933. nm; Cu 324.754 nm; Fe 238.204 nm; Mg 285.213 nm; Mn 257.610 nm; K 766.490 nm; Zn 213.856 nm (standard BS EN 16943:2017 Foodstuffs)

Samples (0.5 g) were homogenized and placed in each container and a mixture consisting of H_2O_2 (35%, 1 mL) and HNO_3 (65%, 6 mL) was added. A microwave burner (Milestone Brand MLS 1200 Mega) was used for digesting the samples in a five-step program (250 W/2 min, 0 W/2 min, 250 W/6 min, 400 W/5 min, and 600 W/5 min). After digestion, ultra-pure water (Millipore Milli-Q, 18.2 MΩ.cm resistant) was added to each sample up to 25 ml and then filtered (Hydropinilic PVDF Millipore Millex-HV, 0.45 µm). ICP-OES (TS EN 13805) was used for analyzing the filtered samples. Table 1 presents the operating conditions of the ICP-OES device and standard solutions were diluted from the stock solution (1000 mg L^{-1}) for the analyses. Besides, recovery studies, detection (LOD), and quantification (LOQ) limits were determined. At least six parallel samples were prepared and analyzed in three replicates. Recovery values were found out from the results indicated in Table 2. ICP-OES (Perkin Elmer 2100 USA) was used to determine the amount of K, Ca, Mg, Fe, Cu, Zn, and Mn for each sample. The results were expressed as mg per kg fresh weight.

Table 2
Performance characteristics of the method.

Element	LOD (mg/kg)	LOQ (mg/kg)	Recovery %
K	2.2	7.4	105
Ca	2.7	9.1	91
Mg	2.1	6.9	75
Fe	0.3	1.0	77
Cu	0.2	0.7	100
Zn	0.3	0.8	84
Mn	0.1	0.4	90

An artificial stomach and intestinal system were created sequentially for bioaccessibility studies with *in vitro* gastrointestinal extraction (Vitali et al., 2009). The bioaccessibility ratio was calculated as below;

Bioaccessibility %= [The value of the mineral content of the fruit after *in vitro* gastrointestinal extraction (mg kg^{-1}) / the value of the total mineral content of the fruit (mg kg^{-1})] x 100

2.5. Statistical analyses

At least three trees of each genotype were used, and six parallel samples were used for the parameters. Therefore, both biological and technical replicates were used for statistical analyses. Three ICP-OES measurements were performed for extracted samples. SPSS 23.0 software package was used for the statistical data evaluation. Statistically different groups between the average values obtained by the LSD test at a p-value of less than 0.05 ($p<0.05$).

3. Results and discussion

Significant variations ($p\leq0.05$) in physical and chemical properties were obtained between the genotypes of *R. rubrum* and *R. nigrum* (Tables 3, 4 and 5). These differences may be influenced by various factors including genetic, maturity, phenotypic differences, growing conditions and agricultural practices. In terms of average fruit sizes, RN1 had the biggest (16.13 mm in diameter,18.05 mm in height, and 2.5 g in weight) and RR1 had the smallest (7.59 mm in diameter, 7.56 mm in height and 0.32 g) berries. Kowalski and Gonzalez de Mejia (2021) evaluated ten blackcurrant variates and berry weights ranged between 0.47 to 1.22 g and diameters from 7.42 to 14.42 mm. This means *R. nigrum* genotypes have bigger berries compared to *R. rubrum* in general. Bunch lengths of RR3 and RR2 (150 and 113 mm respectively) were significantly greater than all others and RN1 (49 mm) had the shortest bunch length. The average number of berries per bunch was the highest in RR3 (32) and the lowest in RN1 (4). Seed numbers were also signifi-

Table 3
Fruit characteristics of *R. rubrum* (RR1-RR4) and *R. nigrum* (RN1 and RN2) genotypes.

Ribes genotypes	Berry diameter (mm)	Berry height (mm)	Berry weight (g)	Bunch length (mm)	Berry number in a bunch (number)
RR1	7.59±0.52^{e}	7.56±0.56^{e}	0.32±0.06^{e}	52.14±4.88^{d}	7.43±1.82^{c}
RR2	10.32±0.52^{d}	9.66±0.38^{d}	0.67±0.12^{d}	113.00±12.55^{b}	21.20±7.33^{b}
RR3	12.63±0.56^{c}	11.43±0.54^{c}	1.28±0.04^{c}	150.00±35.78^{a}	32.17±13.12^{a}
RR4	9.93±0.85^{d}	9.13±0.55^{d}	0.60±0.08^{d}	72.92±16.02^{c}	8.40±1.96^{c}
RN1	16.13±0.48^{a}	18.05±1.24^{a}	2.50±0.46^{a}	49.00±4.8^{d}	4.00±0.71^{d}
RN2	13.64±0.47^{b}	12.94±0.68^{b}	1.56±0.21^{b}	51.00±6.52^{d}	4.60±0.55^{d}

Seed number (number/fruit)	Total soluble solid (°Brix)	pH	Color		
			L*	a*	b*
3.00±1.00^{c}	9.13±0.06^{e}	2.83±0.04^{a}	26.13±1.69^{b}	19.64±2.38^{b}	9.60±1.90^{c}
4.00±1.83^{c}	7.73±0.06^{f}	2.77±0.01^{ab}	24.06±1.79^{c}	24.45±3.09^{a}	12.35±3.28^{b}
10.75±2.75^{b}	12.07±0.15^{c}	2.70±0.04^{b}	21.71±1.32^{d}	19.16±3.24^{b}	8.30±1.93^{c}
4.67±1.03^{c}	10.77±0.06^{d}	2.69±0.01^{b}	42.28±1.60^{a}	5.10±1.02^{c}	16.06±1.71^{a}
9.11±5.69^{b}	12.57±0.40^{b}	2.80±0.09^{a}	23.86±0.98^{c}	2.73±1.27^{d}	0.77±0.46^{d}
26.90±8.18^{a}	13.40±0.00^{a}	2.86±0.00^{a}	24.50±1.25^{c}	0.15±0.11^{e}	0.05±0.19^{d}

Different letters in the same lines represent results with statistical difference, according to the Fisher's LSD test ($p \leq 0.05$).

cantly differed between the genotypes. Among six genotypes RN2 had a significantly greater seed number (27 approximately) while RR1 had the lowest (3). In general, greater values in berry diameter, height, weight, and seed number were recorded in *R. nigrum* genotypes. On the other hand, *R. rubrum* genotypes were superior in bunch length and berry number. Studies also declare that environmental factors can affect fruit sizes dramatically, although genotypes rankings tend to stay consistent (Brennan et al., 2008; Kaldmäe et al., 2013).

Significant differences observed in soluble solids (ºBrix, $p \leq 0.05$) between *R. rubrum* and *R. nigrum* genotypes. RN2 showed the highest values (13.40 ◦Brix) in terms of soluble solid contents while the lowest was in RR2 (7.73 ◦Brix). These results are consistent with results obtained in varieties of Netherlands, Scotland, England, Germany, etc. origin presented by Zdunić (2016). Soluble solid contents in *R. nigrum* were reported to range from 13.89 ◦Brix to 16.14 ◦Brix (Rubinskiene et al., 2005; Contessa et al., 2013) and between 7.40-10.70 ◦Brix in the *R. rubrum* varieties (Pantelidis et al., 2007). According to Clark et al., (2018), soluble solid content of up to 24 ºBrix was reported among blackcurrant selections but the mean was 14 ºBrix. Likewise, soluble solid content for some blackcurrant varieties was reported as 20.80°Brix in the study of de Souza et al. (2014).

Acidity is another factor that may affect the consumer's preferences and a significant difference was found between *R. rubrum* and *R. nigrum* genotypes in terms of pH values which ranged from 2.86 (RN2) to 2.69 (RR4) in the present study. In good agreement with our findings, Kowalski and Gonzalez de Mejia (2021) reported the pH values of ten blackcurrants between 2.80 to 2.96. On the other hand, the pH of a newly introduced blackcurrant variety *R. anatolica* Behcet was determined as 4.12 in the study of Yurt et al. (2021).

We observed that *R. rubrum* and *R. nigrum* species differed in color (Fig. 2, Table 3). Significant differences in L* and b* values were recorded in RR4 (42.28 and 16.06, respectively), and a* value (24.45) was recorded in RR2 among the detected currant species. These results are already expected because RR4 has the lightest color among all genotypes. *R. rubrum* genotypes had relatively higher a* values indicating that those berries reflected red color more than *R. nigrum* genotypes. Eksi Karagac et al., (2020) reported that a red currant, the 'Red Lake' cultivar showed higher values according to other varieties, with 32.88, 19.40, and 8.04 for L*, b*, and a*. In addition, *R. anatolica* Behcet cultivar L*, a*, and b* values were determined as 57.79, 10.19, and 4.03, respectively.

Three minerals, namely K, Ca, and Mg, were prominent in the blackcurrant genotypes in this study. The K was determined as the most prevalent element among the samples and the amounts of minerals decreased with the following order: Ca, Mg, Fe, Cu, Zn, and Mn (Table 4). Our finding is in line with Cosmulescu et al. (2015), who reported that K was the most abundant mineral in their analyses of black and red currants. In the present study, the order of nutritive element contents/100 g of fruits was presented as K > Ca > Mg > Fe > Al > Na > Mn > B > Cu. In another study about the mineral content of 7 black currants cultivars, among them cultivar named the "Ben Sarek" had the highest amount of K (330.90-327.10 mg/100g) and the mineral contents of those cultivars were ranked in the following order: K > P > Ca > Mg > Na > Fe > Cu > Zn > Se > Mn (Paunovic et al., 2017). Significant differences were observed ($p \leq 0.01$) in terms of the concentration of minerals between *Ribes* genotypes cultivated in the Cumalikizik village of Bursa. It is thought that these variations in the mineral contents of genotypes are related to the properties that are inherent to each genotype because all of them were grown in the same climate and soil conditions. K levels ranged from 2215,4 mg kg^{-1} (RN1) to 1875.50 mg kg^{-1} (RR3) in the samples. According to Eksi Karaagac et al. (2020) K concentration of the Red Lake variety was 10205.91 mg kg^{-1} dw. Compared to this study greater K concentrations obtained in our study that consists of per dry weight evaluation.

The highest value of Ca was determined in RR1 (603.10 mg kg^{-1}), followed by RN1 (403.40 mg kg^{-1}) and RN2 (383.90 mg kg^{-1}). Fe content was the highest in the RR4 genotype as 10.30 mg kg^{-1}, while the lowest Fe content was determined in RR3 as 5.1 mg kg^{-1}. In addition, Mn and Mg contents were the highest in the RN2 genotype with 1.90 mg kg^{-1} and 212.90 mg kg^{-1}, respectively. Cu content was found the highest in RN1 as 2.80 mg kg^{-1}. Moreover, the highest value in Zn content was detected in RR1 as 4.70 mg kg^{-1}, followed by *R. nigrum* genotypes (2.60 mg kg^{-1} for RN1 and 2.40 mg kg^{-1} for RN2). K and Mg contents in our study were lower than those reported by Nour et al. (2011). K, Mg, and Cu contents found in our study were also lower than those reported by Paunović et al. (2017), while Ca and Mn contents found in our study were higher. These differences might have arisen due to the differences in weather,

Table 4
Mineral contents of *R. rubrum* (RR1-RR4) and *R. nigrum* (RN1 and RN2) genotypes.

Ribes genotypes	K	Ca	Fe	Mn	Cu	Zn	Mg
RR1	2068.80±44.10[ab]	603.10±29.50[a]	6.80±0.20[d]	1.30±0.10[bc]	2.20±0.10[bc]	4.70±1.50[a]	198.20±3.30[b]
RR2	1997.20±111.20[bc]	304.30±33.10[c]	8.00±0.10[c]	1.00±0.00[d]	1.20±0.00[e]	1.30±0.10[c]	136.10±5.10[d]
RR3	1875.50±4.50[c]	296.80±19.20[c]	5.10±0.20[e]	1.20±0.00[cd]	2.30±0.00[b]	1.20±0.20[c]	117.90±0.30[e]
RR4	2208.10±42.00[a]	200.40±16.40[d]	10.30±0.40[a]	1.20±0.20[cd]	1.30±0.00[d]	1.20±0.10[c]	155.90±3.30[c]
Mean	**2037.40±137.30**	**351.20±162.70**	**7.50±2.00**	**1.20±0.20**	**1.80±0.50**	**2.10±1.70**	**152.10±32.00**
RN1	2215.40±82.60[a]	403.40±26.10[b]	9.40±0.10[b]	1.50±0.00[b]	2.80±0.10[a]	2.60±0.50[b]	158.30±3.20[c]
RN2	2188.20±62.10[a]	383.90±0.00[b]	7.80±0.40[c]	1.90±0.10[a]	2.10±0.10[c]	2.40±0.10[b]	212.90±1.40[a]
Mean	**2201.80±61.70**	**393.70±18.80**	**8.60±1.00**	**1.70±0.20**	**2.40±0.40**	**2.50±0.30**	**185.60±31.60**

Data were presented as means ± standard deviations; values were expressed as mg kg^{-1} fresh weight for minerals. Different letters in the same lines represent results with statistical difference, according to the Fisher's LSD test ($p \leq 0.05$).

soil, and cultivation conditions which the plants were grown. Nevertheless, the mineral contents reported in the present study do not yield fold differences when compared with relevant reports in the literature. The average mineral analysis of in genotypes of *R. nigrum* and *R. rubrum* revealed no differences between genotypes for both species except for Mn content. Black currants were superior to red currants regarding Mn contents. A previous study reported similar contents for K, Ca, and Mn while Mg content was higher in *R. nigrum* and Fe content was higher in *R. rubrum* (Eksi Karaagac et al., 2020).

Ribes species were found to contain higher K, Mg, Ca, and Cu content compared to other berries like strawberry, raspberry blackberry, blueberry, and (Karlsons et al., 2018; Pereira et al., 2018). In addition, K, Mg, Ca, Fe, and Zn contents of Ribes species were also reported to be higher than those in other fruits like apple and pear (Turkkomp, 2024; USDA, 2024). In accordance, our analyses suggest that *Ribes* species is a good source of minerals.

Table 5
Bioaccessibility (%) of the mineral contents of *R. rubrum* (RR1-RR4) and *R. nigrum* (RN1 and RN2) genotypes.

Ribes genotypes	K	Ca	Fe	Mn	Cu	Zn	Mg
RR1	66%	47%	28%	45%	31%	43%	42%
RR2	71%	98%	37%	56%	54%	16%	64%
RR3	95%	95%	40%	63%	39%	18%	72%
RR4	89%	97%	21%	50%	42%	17%	54%
Mean	80%	84%	32%	54%	42%	24%	58%
RN1	91%	72%	28%	48%	25%	84%	66%
RN2	95%	97%	24%	38%	29%	88%	82%
Mean	93%	85%	26%	43%	27%	86%	74%

However, the total amount of the mineral content is not always correlated with real nutritional values since the whole digested amount of nutrients is not completely absorbed (Usal and Sahan, 2020). Thus, a compound with high content in a plant product might have low bioaccessibility value. Therefore, research on the chemical characterization of plants must be accompanied by bioaccessibility studies to estimate their health benefits. In this study, bioaccessibility values (%) of the mineral contents of *R. rubrum* (RR1-RR4) and *R. nigrum* (RN1 and RN2) genotypes were presented in Table 5. The mineral bioaccessibility ranged from 17 to 98% in the present study. The minerals were aligned as per bioaccessibility from high to low as K (71-95 %), Ca (47-98%), Mg (42-82%), Zn (17-88%), Mn (38-63%), Cu (27-54%) and Fe (21-40%) for all genotypes.

RN1 genotype had the highest K concentration but its bioaccessibility was lower (91%) than those of RR3 and RN2 (95% for all). Similarly, Ca concentration was the highest in RR1 with 603.10 mg kg^{-1} but was the lowest in bioaccessibility with 47% among all genotypes. Mg bioaccessibility was the highest in RN2 with 82% (212.90 mg kg^{-1}) but lowest in RR1 with 42% even the Mg content was measured as 198.2 mg kg^{-1}. When the two *Ribes* species were compared, bioaccessibilities of Cu, Fe, and Mn were higher in *R. rubrum* and bioaccessibilities of K, Ca, Zn, and Mg were higher in *R. nigrum*. A striking difference concerning average bioaccessibility of genotypes was noted for Zn which was analyzed as 24% in *R. rubrum* and 86% in *R. nigrum*.

The highest bioaccessibility on average was detected for K in both *Ribes* species. A previous study reported that the average value of K bioaccessibility in fruits and vegetables was approximately 67%, specifically 64% in fruits (avocado, banana, and kiwifruit), and 72% in vegetables (Ceccanti et al., 2022). Thus, results of our study show that both the content and the bioaccessibility of K might be greater in *Ribes* species than those in most fruit and vegetables. Therefore, *Ribes* species could be considered as a good K source. It has been proposed that the indigestible cell walls found in plants could form a physical barrier that reduces the intracellular nutrients' bioaccessibility (Naismith and Braschi, 2008). Therefore, their high content of mineral substances but their low bioaccessibility in fruit and vegetables may cause an overestimation of the contribution of fruits or vegetables to the diet. When it comes to mineral intake, the comparatively low bioaccessibility of minerals reduces the perceived nutritional value of food. The relatively poor bioaccessibility of minerals reduces the nutritive value of foods with regard to mineral intake.

According to Larsson et al. (2008), a high intake of minerals like K, Mg, and Ca has a direct connection to reduced risk of stroke, hypertension, and osteoporosis. FDA updated the intake of daily values of minerals and there are increases and decreases for some minerals. For example, Ca daily value (DV) increased from 1000 to 1300 mg, K DV increased from 3500 to 4700 mg, Mg DV increased from 400 to 420 mg, and Mn DV from 2 to 2.3 mg. Cu and Zn DV decreased from 15 to 11 mg and 2 to 0.9 mg respectively. Fe DV remains the same as 18 mg before (FDA, 2021). Therefore, knowledge of the amount and bioaccessibility of minerals in fruits can be decisive in guiding the consumer's preferences.

According to the results of mineral content analyses and bioaccessibility results, the investigated *Ribes* species were found as a potential source of K, Ca, and Mg minerals. Although bioaccessibilities of bioactive compounds of *Ribes* were reported previously (Trych et al., 2022), to our knowledge this is the first study to provide data on bioaccessibilities of the mineral contents of *Ribes*.

4. Conclusion

Since breeders continuously need to monitor crops for phenotypic variations from a large genetic pool it is necessary to analyze the physical, chemical, and nutritional characteristics of the genotypes presented in these studies.

In this study, six *Ribes* genotypes (RR1-RR4 and RN1-RN2) were examined in terms of their biophysicochemical properties, mineral content, and bioaccessibility, providing required data for breeding studies. According to the results, compared to other minerals K, Ca, and Mg are abundant in *Ribes* genotypes.

On the other hand, *R. nigrum* genotypes consist of higher mineral levels and better quantified physical properties than *R. rubrum* genotypes. Consequently, this study does not only reveal promising varieties for cultivation but also can present useful guidance for future studies.

Conflict of interest: The authors declare that they have no conflict of interests.

Informed consent: The authors declare that this manuscript did not involve human or animal participants and informed consent was not collected.

References

Adina, F., Cecilia, G., Felicia, G., Carmen, D., & Ovidiu, T. (2017). Identification and quantification of phenolic compounds from red currant (*Ribes rubrum* L.) and raspberries (*Rubus idaeus* L.). *International Journal of Pharmacology, Phytochemistry and Ethnomedicine*, *6*, 30-37.

Ahunbay, Z., Ayrancılar, T., Polat, A., & Uray, A. (2014). Conservation of the vernacular heritage in the villages of Bursa, Turkey. In: Mileto C., Vegas F., García Soriano L., Cristini V. (eds) *Vernacular Architecture: Towards a Sustainable Future* (pp. 59-64). CRC Press.

AOAC, (2020). Association of Official Analytical Chemists, & Association of Official Agricultural Chemists (US). *Official methods of analysis of the Association of Official Analytical Chemists* 17th ed.; AOAC: Washington, DC, USA.

Brennan, R., Jorgensen, L., Hackett, C., Woodhead, M., Gordon, S., & Russell, J. (2008). The development of a genetic linkage map of blackcurrant (*Ribes nigrum* L.) and the identification of regions associated with key fruit quality and agronomic traits. *Euphytica*, *161*, 19-34.

Cansev, A., Ipek, M., Celik, G., Taskesen, S., Sahan, Y., Ipek, A., & Akpınar, A. (2022). Comparative characterization of the content and in vitro bioaccessibility of minerals in two *Cornus* species. *Mediterranean Agricultural Sciences*, *35*(3), 115-120.

Ceccanti, C., Guidi, L., D'Alessandro, C., & Cupisti, A. (2022). Potassium bioaccessibility in uncooked and cooked plant foods: results from a static in vitro digestion methodology. *Toxins*, *14*(10), 668.

Celenk, A.G. (2015). Bazı *Ribes* L. (Grossulariaceae) taksonlarinin molekuler karakterizasyonu, Yüksek Lisans Tezi, (pp. 1-62). İstanbul Universitesi, Fen Bilimleri Enstitusu.

Clark, C. J., Cooney, J. M., Hopkins, W. A., & Currie, A. (2018). Global mid-infrared prediction models facilitate simultaneous analysis of juice composition from berries of *Actinidia*, *Ribes*, *Rubus* and *Vaccinium* species. *Food Analytical Methods*, *11*(11), 3147-3160.

Contessa, C., Mellano, M. G., Beccaro, G. L., Giusiano, A., & Botta, R. (2013). Total antioxidant capacity and total phenolic and anthocyanin contents in fruit species grown in Northwest Italy. *Scientia Horticulturae*, *160*, 351-357.

Cosmulescu, S., Trandafir, I., & Nour, V. (2015). Mineral composition of fruit in black and red currant. *South Western Journal of Horticulture, Biology and Environment*, *6*(1), 45-51.

Cvetković, M., Ilić, D., Petrović, S., & Miladinović, B. (2021). Determination of mineral composition of the Red Pool type of red currant (*Ribes rubrum* L, Grossulariaceae). *Archives of Pharmacy*, *71*(Suppl. 5), S66-S66.

Cvetković, M., Ilić, D., Petrović, S., & Miladinović, B. (2022). Mineral composition of the red currant (*Ribes rubrum* L.) variety Redpoll lyophilized waste extract. *Archives of Pharmacy*, *72*(Suppl. 4), S501-S502.

Dima, C., Assadpour, E., Dima, S., & Jafari, S. M. (2021). Nutraceutical nanodelivery; an insight into the bioaccessibility/bioavailability of different bioactive compounds loaded within nanocarriers. *Critical Reviews in Food Science and Nutrition*, *61*(18), 3031-3065.

Domínguez-Fernández, M., Yang, P. Y. T., Ludwig, I. A., Clifford, M. N., Cid, C., & Rodriguez-Mateos, A. (2022). In vivo study of the bioavailability and metabolic profile of (poly) phenols after sous-vide artichoke consumption. *Food Chemistry*, *367*, 130620.

de Souza, V. R., Pereira, P. A. P., da Silva, T. L. T., de Oliveira Lima, L. C., Pio, R., & Queiroz, F. (2014). Determination of the bioactive compounds, antioxidant activity and chemical composition of Brazilian blackberry, red raspberry, strawberry, blueberry and sweet cherry fruits. *Food Chemistry*, *156*, 362-368.

Ejaz, A., Waliat, S., Afzaal, M., Saeed, F., Ahmad, A., Din, A., ... & Khan, M. R. (2023). Biological activities, therapeutic potential, and pharmacological aspects of blackcurrants (*Ribes nigrum* L): A comprehensive review. *Food Science & Nutrition*, *11*(10), 5799-5817.

Eksi Karaagac, H., Cavus, F., Kadioglu, B., Ugur, N., Tokat, E., & Sahan, Y. (2020). Evaluation of nutritional, color and volatiles properties of currant (*Ribes* spp.) cultivars in Turkey. *Food Science and Technology*, *41*(2), 304-313.

FAOSTAT, (2024). Food and agriculture organization of the United Nations (FAO), http://www.fao.org/ faostat /en / -data/QC, Last accessed on August 25, 2024.

FDA, (2020). Food and Drug Administration. Retrieved from, Daily value on the new nutrition and supplement facts labels, https://www.fda.gov/, Last accessed on August 25, 2024.

González, M. J. A., Carrera, C., Barbero, G. F., & Palma, M. (2022). A comparison study between ultrasound–assisted and enzyme–assisted extraction of anthocyanins from blackcurrant (*Ribes nigrum* L.). *Food Chemistry: X*, *13*, 100192.

Hu, Y., Lin, Q., Zhao, H., Li, X., Sang, S., McClements, D. J., ... & Qiu, C. (2023). Bioaccessibility and bioavailability of phytochemicals: Influencing factors, improvements, and evaluations. *Food Hydrocolloids*, *135*, 108165.

Hummer, K. E., & Dale, A. D. A. M. (2010). Horticulture of *Ribes*. *Forest Pathology*, *40*(3-4), 251-263.

Jo, M., Ban, C., Goh, K. K., & Choi, Y. J. (2021). Enhancement of the gut-retention time of resveratrol using waxy maize starch nanocrystal-stabilized and chitosan-coated Pickering emulsions. *Food Hydrocolloids*, *112*, 106291.

Kaldmaee, H., Kikas, A., Arus, L., & Libek, A. V. (2013). Genotype and microclimate conditions influence ripening pattern and quality of blackcurrant (*Ribes nigrum* L.) fruit. *Zemdirbyste-Agriculture*, *100*(2), 167-174.

Karlsons, A., Osvalde, A., Čekstere, G., & Pormale, J. (2018). Research on the mineral composition of cultivated and wild blueberries and cranberries. *Agronomy Research*, *16*(2), 454-463.

Kowalski, R., & de Mejia, E. G. (2021). Phenolic composition, antioxidant capacity and physical characterization of ten blackcurrant (*Ribes nigrum*) cultivars, their juices, and the inhibition of type 2 diabetes and inflammation biochemical markers. *Food Chemistry*, *359*, 129889.

Krüger, E., Dietrich, H., Hey, M., & Patz, C. D. (2012). Effects of cultivar, yield, berry weight, temperature and ripening stage on bioactive compounds of black currants. *Journal of Applied Botany and Food Quality*, *84*(1), 40.

Larsson, S. C., Virtanen, M. J., Mars, M., Männistö, S., Pietinen, P., Albanes, D., & Virtamo, J. (2008). Magnesium, calcium, potassium, and sodium intakes and risk of stroke in male smokers. *Archives of Internal Medicine*, *168*(5), 459-465.

Liang, X., Ye, Y., Zhu, Y., Xiao, J., & Qiao, Y. (2023). Multivariate comparative analysis of chemical constituent changes and antioxidant properties of polysaccharides in *Ribes stenocarpum* maxim. at different maturity stages on the Qinghai-Tibet Plateau. *Scientia Horticulturae*, *308*, 111556.

Solcan, M. B., Fizeșan, I., Vlase, L., Vlase, A. M., Rusu, M. E., Mates, L., Petru, A. E., ... & Popa, D. S. (2023). Phytochemical profile and biological activities of extracts obtained from young shoots of blackcurrant (*Ribes nigrum* L.), european blueberry (*Vaccinium myrtillus* L.), and mountain cranberry (*Vaccinium vitis-idaea* L.). *Horticulturae*, *9*(11), 1163.

Messinger, W., Hummer, K., & Liston, A. (1999). Ribes (Grossulariaceae) phylogeny as indicated by restriction-site polymorphisms of PCR-amplified chloroplast DNA. *Plant Systematics and Evolution*, *217*, 185-195.

Mikulic-Petkovsek, M., Koron, D., & Veberic, R. (2016). Quality parameters of currant berries from three different cluster positions. *Scientia Horticulturae*, *210*, 188-196.

Montiel-Sánchez, M., García-Cayuela, T., Gómez-Maqueo, A., García, H. S., & Cano, M. P. (2021). *In vitro* gastrointestinal stability, bioaccessibility and potential biological activities of betalains and phenolic compounds in cactus berry fruits (*Myrtillocactus geometrizans*). *Food Chemistry*, *342*, 128087.

Naismith, D. J., & Braschi, A. (2008). An investigation into the bioaccessibility of potassium in unprocessed fruits and vegetables. *International Journal of Food Sciences and Nutrition*, *59*(5), 438-450.

Nour, V., Trandafir, I., & Ionica, M. E. (2011). Ascorbic acid, anthocyanins, organic acids and mineral content of some black and red currant cultivars. *Fruits*, *66*(5), 353-362.

Pantelidis, G. E., Vasilakakis, M., Manganaris, G. A., & Diamantidis, G. R. (2007). Antioxidant capacity, phenol, anthocyanin and ascorbic acid contents in raspberries, blackberries, red currants, gooseberries and Cornelian cherries. *Food Chemistry*, *102*(3), 777-783.

Paunovic, V., Nikolic, M., Miletić, R., & Mašković, P. (2017). Vitamin and mineral content in black currant (*Ribes nigrum* L.) fruits as affected by soil management system. *Acta Scientiarum Polonorum Hortorum Cultus*, *16*(5), 135-144.

Pereira, C. C., da Silva, E. D. N., de Souza, A. O., Vieira, M. A., Ribeiro, A. S., & Cadore, S. (2018). Evaluation of the bioaccessibility of minerals from blackberries, raspberries, blueberries and strawberries. *Journal of Food Composition and Analysis*, *68*, 73-78.

Rubinskiene, M., Viskelis, P., Jasutiene, I., Viskeliene, R., & Bobinas, C. J. F. R. I. (2005). Impact of various factors on the composition and stability of black currant anthocyanins. *Food Research International*, *38*(8-9), 867-871.

Da Silva Pinto, M., Kwon, Y. I., Apostolidis, E., Lajolo, F. M., Genovese, M. I., & Shetty, K. (2010). Evaluation of red currants (*Ribes rubrum* L.), black currants (*Ribes nigrum* L.), red and green gooseberries (*Ribes uva-crispa*) for potential management of type 2 diabetes and hypertension using *in vitro* models. *Journal of Food Biochemistry*, *34*(3), 639-660.

Soloshenko, V. (2018). Taxonomic composition of the *Ribes* L. in the collecting plantations in Ukrainian botanic institutions. *Revista Botanică*, *17*(2), 64-68.

Staszowska-Karkut, M., & Materska, M. (2020). Phenolic composition, mineral content, and beneficial bioactivities of leaf extracts from black currant (*Ribes nigrum* L.), raspberry (*Rubus idaeus*), and aronia (*Aronia melanocarpa*). *Nutrients*, *12*(2), 463.

Tian, Y., Laaksonen, O., Haikonen, H., Vanag, A., Ejaz, H., Linderborg, K., ... & Yang, B. (2019). Compositional diversity among blackcurrant (*Ribes nigrum*) cultivars originating from European countries. *Journal of Agricultural and Food Chemistry*, *67*(19), 5621-5633.

Tian, Y., Karhu, S., Virtanen, M., Linderborg, K. M., Yang, B., & Laaksonen, O. (2023). Variation of chemical and sensory profiles of blackcurrant (*Ribes nigrum*) juices produced from different cultivars of European origins. *LWT*, *173*, 114353.

Trych, U., Buniowska, M., Skąpska, S., Starzonek, S., & Marszałek, K. (2020). The bioaccessibility of antioxidants in black currant puree after high hydrostatic pressure treatment. *Molecules*, *25*(15), 3544.

TSE, (2001). TS 1728 ISO 1842: Meyve Sebze Urunleri -pH Tayini. Ankara: TSE.

Turkkomp, (2024). Ulusal Gida Kompozisyonlari Veri Tabani, http://www.turkomp.gov.tr/, Last accessed on August 25, 2024.

Usal, M., & Sahan, Y. (2020). *In vitro* evaluation of the bioaccessibility of antioxidative properties in commercially baby foods. *Journal of Food Science and Technology*, *57*, 3493-3501.

USDA, (2024). U.S. Department of Agriculture, Food Data Central, https://fdc.nal.usda.gov/error.html, Last accessed on August 25, 2024.

Vitali, D., Dragojević, I. V., & Šebečić, B. (2009). Effects of incorporation of integral raw materials and dietary fibre on the selected nutritional and functional properties of biscuits. *Food Chemistry*, *114*(4), 1462-1469.

Yurt, B., Behcet, L., Demir, N., & Hayaloglu, A. A. (2021). Lokal endemik *Ribes anatolica* Behçet (Grossulariaceae) meyvelerinin bazi fizikokimyasal özellikleri, toplam fenolik madde miktari, antioksidan kapasiteleri ve fenolik kompozisyonunun belirlenmesi. *Adıyaman Üniversitesi Mühendislik Bilimleri Dergisi*, *8*(14), 277-282.

Wang, S. Y., & Zheng, W. (2001). Effect of plant growth temperature on antioxidant capacity in strawberry. *Journal of Agricultural and Food Chemistry*, *49*(10), 4977-4982.

Zdunić, G., Šavikin, K., Pljevljakušić, D., & Djordjević, B. (2016). Black (*Ribes nigrum* L.) and red currant (*Ribes rubrum* L.) cultivars. In: Simmonds M. S. J., Preedy V. R. (eds) *Nutritional Composition of Fruit Cultivars* (pp. 101-126). Academic Press.

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