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MINERAL NUTRITIONAL VALUE OF PRODUCTS CONTAINING ARONIA FRUITS AND JUICES: A REVIEW

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Abstract

The "superberry" Aronia melanocarpa has attracted a lot of attention due to its high content of phenolic phyto-chemicals. However, little attention has been paid to its mineral content. The main objective of this paper is to review the mineral content of black chokeberry fruits, products and by-products, focusing on the health importance of mineral intake from food, against supplements. A lot of food databases and scientific publications demonstrated that comparing to fresh apples, fresh black chokeberry fruits contain high concentrations of minerals such as potassium (290.3 mg/100g) - which contributes to human health by regulating protein synthesis and the metabolization of carbohydrates - and copper (0.211 mg/100 g), zinc (0.147 mg/100 g), selenium (0.028 mg/100 g) - which act as antioxidants. The fresh Aronia melanocarpa berries also contain manganese, which is an essential micronutrient for plant growth and development. Nevertheless, excessive manganese accumulation in human's body may lead to adverse effects like insomnia, memory loss, irreversible nerve damage. Few results have been found for manganese concentrations in black chokeberries (0.0829 mg/100 g dry weight) and in aronia juices (reported to vary between 0.298 ± 0.003 mg/100 g and 1.177 ± 0.005 mg/100 g). Therefore, extensive research conducted in this area is needed in order to identify and quantify the mineral concentrations of aronia fresh berries and products and to contribute to an advance knowledge of mineral content as a key role for healthy natural products. Additionally, the variability of the mineral's concentrations in the aronia fruits should be taken into consideration, as they are in direct relation with crop variety, soil characteristics, climate changes, fertilization and harvesting time.

Key words: *Aronia, juice, minerals, micronutrients, macronutrients.*

INTRODUCTION

Aronia melanocarpa is one of four accepted species of the genus *Aronia* Medik, in the *Rosaceae* family, also known as black chokeberry (Mahoney et al., 2019). It is a 2-3 m shrub (Jurendić & Ščetar, 2021) native to the Great Lakes region and the North-eastern U.S., with a southerly extension into the higher elevations of the Appalachian Mountains (Scott Peterson, n.d.). It was brought to Russia at the beginning of the 20th century from where it spread to Eastern Europe (Ochmian et al., 2012). The other three *Aronia* Medik accepted species are: *Aronia arbutifolia* (red chokeberry), *Aronia prunifolia* (purple chokeberry) and *Aronia mitschurinii* (Mahoney et al., 2019).
There are many cultivars documented in literature, most commonly researched being "Nero" (Czechia), "Rubina" (crossing from Russian and Finnish plants), "Viking" (Finland), "Kurkumäcki" (Finland), "Hugin" (Sweden), "Fertödi" (Hungary) and "Aron" (Denmark) (Kulling & Rawel, 2008) which are usually harvested between August and September (Jurendić & Ščetar, 2021).
Aronia melanocarpa has a very complex chemical composition, which can vary depending on many factors such as: soil composition, fertilisation, climate conditions, berry maturity, harvest method and storage conditions (Tolić et al., 2017).
Fertilisation has a large impact on berries production and quality. Following fertilisation, increased plant growth and berries yield were reported, alongside with a decrease in total acidity and pigment concentration (Kulling & Rawel, 2008).

Polyphenol content

Aronia has attracted a lot of attention due to its high content of polyphenols (proanthocyanidins, anthocyanins, flavonoids and phenolic acids), research showing that these compounds can have a meaningful beneficial impact on health through their antioxidative, anti-inflammatory, antiviral, anticancer, antiatherosclerotic, hypotensive, antiplatelet, and antidiabetic properties (Borowska & Brzóska, 2016).

Aronia melanocarpa was studied primarily for its phenolic constituents, aronia fruits being particularly rich in anthocyanins, flavanols, proanthocyanins and phenolic acids (King & Bolling, 2020a). A study conducted by Denev et al. (2018) shows that the total polyphenol content of aronia fruits varies between 1022mg/100g fresh weight and 1795 mg/100 g fresh weight from which 284-686 mg/100 g fresh weight are anthocyanins.

In a study conducted by Skupień & Oszmiański (2007), *Aronia melanocarpa* plants were fertilised with three types of fertilisers: manganese, commercial fertiliser (nitrogen, potassium and silicon) and a combination of both. The polyphenolic content decreased for all fruits from all treated plants compared to the control group (Skupień & Oszmiański, 2007).

The phenolic content of aronia products and other food products enriched with aronia were extensively studied. Aronia dried fruits have a high polyphenolic content, 40.15g GAE/kg; fresh aronia juice has 6.88±0.23g GAE/kg (Catană et al., 2017). High concentrations of polyphenols have been identified in other products as well: 6.9-12 g GAE/kg jam, 6.7 g GAE/kg compote, 2.6 g GAE/kg syrup (Kapci et al., 2013), 0.86 g GAE/l fruit tea (decoction), 0.89 g GAE/l fruit tea (infusion) (Šavikin et al., 2014), 0.88 g/l wine (Wilkowska et al., 2017), 0.429-2.339 g/l liqueur (Olas et al., 2008).

Yogurt with 2-3% added aronia juice increased its phenol content up to 54.05 mg GAE/g dry weight, showing a higher antioxidant activity (Nguyen & Hwang, 2016). Beer infused with aronia berries shows a higher polyphenol concentration and also a positive effect on sugar utilisation during fermentation (Jahn et al., 2020).

Aronia pomace total phenolic concentration was reported to be of 63.1g GAE/kg (Kapci et al., 2013). Adding Aronia pomace powder to replace 25% of starch for making ready-to-eat extruded cereals will increase the phenolic content of these products (Schmid et al., 2022). Adding either aronia juice or berries to different food products or beverages can increase their antioxidant activity.

Fibre content

After extracting the juice, the pomace fibre content is up to 57.8-71.5 g/100 g dry weight, out of which 43.8-61.7 g/100 g dry weight is insoluble fibre (Schmid et al., 2020). These include: cellulose (34g/100g dry weight), hemicellulose (32 g/100 g dry weight), lignin (22.7 g/100 g dry weight) and pectin (7.52 g/100 g dry weight) (Schmid et al., 2020). A study conducted by Schmid et al. (2021) shows that aronia pomace powder can be used to substitute starch in breakfast cereals and snacks and it’s a valuable source of dietary fibre and polyphenols.

Aronia berries contain 5.62 mg/100 g fresh weight of dietary fibre (Kulling & Rawel, 2008). Aronia fibres are a good sorbent for cadmium and led, facilitating the removal of these two heavy metals from the human body (Borycka, 2012).

Total sugar content

The reported total sugar in aronia berries varies between 6.21 g/100 g and 20.92 g/100 g (Ochmian et al., 2012; Skupień & Oszmiański, 2007; Naukowe & Kwiaciarstwa, 2007; Mayer-Miebach et al., 2012; Sidor et al., 2019). Fertilisation also has an impact on the total sugar content. The fruits from aronia plants fertilised with commercial fertilizer showed a decrease in total sugar by 1.6 g/100 g and those from plants treated with manganese fertiliser combined with commercial fertilizer showed a 1.10 g/100 g decrease in total sugars. In fruits from plants treated only with manganese fertiliser sucrose was not detected (Skupień & Oszmiański, 2007).

Total sugars in aronia juice were reported to be 11.0-14.3 g/100 ml by Mayer-Miebach et al. (2012) and 12.0-19.6 g/100 ml by Handeland et al. (2014). After juice extraction, a part of the sugars remain in the pomace, 84 g/kg, the dominant component being sorbitol (Jurendić & Ščetar, 2021). The extraction methods used during juice manufacturing process such as additional pomace extraction after first pressing, will influence the saccharide composition of the fruit pomace (Sójka et al., 2013).

Aronia in the form of juice cand be better tolerated by consumers, even if the astringent taste of the berries is still present. In a study conducted by Duffy et al. (2016), aronia fruits were harvested from August to September once a week for 7 consecutive weeks, and the juice obtained from each harvest was tested for sweetness, sourness, saltiness, bitterness, astringency, and liking/disliking. Additionally, the effects of added sucrose and ethyl butyrate were assessed (Duffy et al., 2016). Juices obtained from fruits harvested in the first three weeks had the lowest sweetness and greater sourness and astringency, compared to juices obtained from berries harvested in the last three weeks, which had greater sweetness (Duffy et al., 2016). Adding 5% sucrose or a mix of ethyl butyrate and 3% sucrose increased the juice sweetness and changed consumers' opinions changing from dislike to like (Duffy et al., 2016). Taking this into consideration, in addition to the complex mineral content, aronia juice can be considered a potential ingredient in different beverages.

Fat content

Very few studies have reported the total fat content of aronia fruits. One paper reported a total fat content in aronia berries of 0.14 g/ 100 g fresh weight (Kulling & Rawel, 2008). Aronia seed oil had the highest content of linoleic acid, over 70%, and α-tocopherol, 166.0-1104.8 mg/kg (Milala et al., 2018).

Aronia juice contains less than 0.1 g/100 g of fat (Sidor & Gramza-Michałowska, 2019). After juice extraction, the dried pomace contains 5.15% of fat (Pieszka et al., 2015) of which 90.49% are polyunsaturated fatty acids and 9.51% are saturated fatty acids (King & Bolling, 2020b).

Protein content

Generally aronia fruits do not contain high amount of protein. Lancrajan (2012) found 0.7 g/100 g fresh weight of protein in aronia berries. A very small amount of protein was reported in aronia juice - 0.2 g/100 g (Sidor et al., 2019). After juice extraction, the pomace contains 10.77% of protein (Pieszka et al., 2015). The seedless part of the pomace has a lower protein content than the seed fraction (Sójka et al., 2013).

Organic acids content

Organic acids are constituents of ripe fruits and are responsible for their sourness and flavour (Famiani et al., 2015). In aronia berries organic acids are represented mainly by quinic acid - 404.4 mg/100 g fresh weight, malic acid - 328.1 mg/100 g fresh weight and ascorbic acid - 65.2 mg/100 g fresh weight (Denev et al., 2018).

The concentration of organic acids extracted from the aronia berries to the juice varies between 12.27 g/l and 21.87 g/l (Sosnowska et al., 2016). During juice fermentation with *L. paracasei*, malic acid is transformed in lactic acid which enhances the preservation of food in time, making aronia juice a potential substrate for the production of functional beverages of enhanced nutritional value (Bontsidis et al., 2021).

Vitamin content

Aronia melanocarpa fruits are high in vitamin C, which is an antioxidant necessary for the human body to prevent scurvy, gum disease and to boost immunity (Lupascu & Sîrbu, 2020). Fresh fruits contain 31.85 mg/100g Vitamin C (Catană et al., 2017), but it has also been reported to be 13.7 mg/100 g fresh weight (Kulling & Rawel, 2008), 2.3 mg/100 g fresh weight (Andrzejewska et al., 2015) and 7.2 mg/100 g (Skrede et al., 2012). Frozen berries have a 9.6% lower amount of Vitamin C compared to fresh berries (Catană et al., 2017). Other vitamins have been also reported in aronia berries: Vitamin B_1 (0.017- 0.019 mg/100 g), Vitamin B_2 (0.016-0.027 mg/100 g), Vitamin B_6 (0.024-0.029 mg/100 g), Vitamin A (0.77 mg/100 g), carotenoids (total carotenoids 48.6 mg/100 g) (Sidor et al., 2019).

In a study conducted by Catană et al. (2017), Vitamin C was quantified in different aronia products: aronia compote - 7.96 mg/100 g, aronia jam - 7.25 mg/100 g, aronia fresh juice - 98.75 mg/100 g, dried aronia fruits - 15.11 mg/100 g. Aronia fresh juice also contains Vitamins B1 (25-90 μg/100 ml), B2 (25-110 μg/100 ml), B6 (30-85 μg/100 ml), pantothenic acid (50-80 μg/100 ml) and niacin (100-550 μg/100 ml) (Kulling & Rawel, 2008), and the total carotenoid content is up to 97.8 μg/l (Oprea et al., 2014).

Mineral content

Research also shows a complex mineral content in aronia fruits, most abundant being calcium, potassium, iron, molybdenum, manganese, phosphorus and iodine (Pavlovic et al., 2015). High amounts of potassium and zinc were found in aronia juice (Kulling & Rawel, 2008). Heavy metal content will depend on harvest site and vegetation period (Ognik et al., 2006).

There are not that many studies that quantify the mineral content in aronia, focusing on aronia fruits, very few also mentioning the mineral content in aronia products (juice, filter bags for infusion and pomace) (Cindrić et al., 2017; Jurendić & Ščetar, 2021; King & Bolling, 2020a; Kulling & Rawel, 2008; Sidor et al., 2019; Pieszka et al., 2015; Pavlovic et al., 2015).

The aim of this paper is to review the mineral content of black chokeberry fruits, products and by-products, focusing on the health importance of mineral intake from food, against supplements, taking into consideration the variability of the minerals' concentrations in the aronia fruits as influenced by cultivar/variety, soil characteristics, climate changes, fertilization and harvesting time.

MATERIALS AND METHODS

Search strategy

Publications were identified through ScienceDirect Freedom Collection, Elsevier, Scopus, Elsevier, SpringerLink Journals, Springer, Mendeley Reference Manager, Google Scholar. Other international databases were used: Office of Dietary Supplements part of the Nation Institutes of Health, the United States Department of Agriculture, the United Stated Environmental Protection Agency.

The search strategy was comprised on two key elements:

- Aronia mineral content - searching with different keywords and permutations of the keywords: "Aronia melanocarpa", "black chokeberry", "aronia review", "aroinia juice", "aronia tea", "aronia pomace powder", "aronia minerals", "aronia mineral profile";
- Identification of the daily recommended intake for macro and micro-nutrients and of maximum accepted levels of heavy metals.

Inclusion criteria and selection process

Studies were filtered between 2005 and 2022. The following keywords were used:

- "aronia" – 1296 results;
- "Aronia melanocarpa" – 848 results;
- "black chokeberry" – 455 results;
- "aronia minerals" – 45 results;
- "aronia review" – 42 results;
- "aronia meta-analysis" – 4 results;
- "aronia juice" – 286 results;
- "aronia tea" – 50 results;
- "aronia pomace powder" – 7 results;
- "aronia fertilisation" – 9 results.

Articles chosen had to include direct measurements of mineral concentrations in aronia berries and products or a literature review on aronia and/or aronia products. From all found articles *only three* of them reported direct measurements on minerals concentrations from aronia berries, *one article* reported direct measurements on minerals from aronia juice and tea, *two articles* reported direct measurements on minerals from aronia pomace and *four articles* were literature reviews that included mineral content in either aronia berries or aronia products.

RESULTS AND DISCUSSIONS

1. Mineral content in aronia fruits

There are very few authors that have studied the mineral composition in *Aronia melanocarpa* fruits (Šnebergrová et al., 2014; Pavlovic et al., 2015; Cindrić et al., 2017; Lancrajan, 2012). Results are shown in Table 1.

Aronia berries are not too popular within consumers due to their bitter and astringent taste. A study on consumer preference and willingness to pay for a new type of berry in the US market shows that US consumers prefer to purchase and consume sweet berries (blueberries, strawberries, raspberries and blackberries), refusing to buy and consume aronia fruits due to their taste.

Positive health information on aronia fruits might persuade customers to purchase this new berry, but because of the bitter taste they might have buyer's remorse and refuse to consume it in the future (Hoke et al., 2017). Provided this information, even if the mineral content of aronia fruits has a lot of potential for the human's health, new products containing aronia need to be developed and tested for consumer acceptance.

Table 1. Mineral concentration in *Aronia melanocarpa* berries

Mineral	Concentration mg/kg	Reference
Na	12.5[a]; 16.8[b]	Pavlovic et al., 2015
	4.27	Cindrić et al., 2017
	26	Lancrajan, 2012
K	2707[a]; 4977[b]	Pavlovic et al., 2015
	6790	Cindrić et al., 2017
	2180	Lancrajan, 2012
Ca	601[a]; 1167[b]	Pavlovic et al., 2015
	1212	Cindrić et al., 2017
	3220	Lancrajan, 2012
	min 119; max 552[c]	Šnebergrová et al., 2014
Mg	164[a]; 578[b]	Pavlovic et al., 2015
	669	Cindrić et al., 2017
	168	Lancrajan, 2012
	min 83.3; max 314.2[c]	Šnebergrová et al., 2014
P	239[a]; 956[b]	Pavlovic et al., 2015
Zn	4.09[a]; 8.40[b]	Pavlovic et al., 2015
	0.55	Cindrić et al., 2017
Fe	9.4[a]; 14.2[b]	Pavlovic et al., 2015
	1.32	Cindrić et al., 2017
	9.3	Lancrajan, 2012
Se	0.21[a]; 0.28[b]	Pavlovic et al., 2015
Cu	0.82[a]; 2.11[b]	Pavlovic et al., 2015
	1.58	Cindrić et al., 2017
Mo	0.021[a]; 0.016[b]	Pavlovic et al., 2015
	0.039	Cindrić et al., 2017
Mn	5.49[a]; 17.89[b]	Pavlovic et al., 2015
	0.829	Cindrić et al., 2017
Ni	0.143[a]; 0.741[b]	Pavlovic et al., 2015
	0.38	Cindrić et al., 2017
V	0.40[a]; 1.58[b]	Pavlovic et al., 2015
Si	2.37[a]; 6.37[b]	Pavlovic et al., 2015
Cr	0.49[a]; 0.53[b]	Pavlovic et al., 2015
	0.029	Cindrić et al., 2017
Li	6.75	Pavlovic et al., 2015
	0.012	Cindrić et al., 2017
Sr	1.57[a]; 7.05[b]	Pavlovic et al., 2015
	1.66	Cindrić et al., 2017
Al	2.88[a]; 4.40[b]	Pavlovic et al., 2015
	158	Cindrić et al., 2017
Sn	0.62[a]; 0.72[b]	Pavlovic et al., 2015

[a] This value is the lowest concentration found in one of the two samples analyzed by Pavlovic et al. (2015) who analyzed two samples from different plants without specifying if they are different varieties or different cultivars.
[b] This value is the concentration found in the second sample analyzed by Pavlovic et al. (2015) who analyzed two samples from different plants without specifying if they are different varieties or different cultivars.
[c] Šnebergrová et al. (2014), reported maximum and minimum Ca and Mg concentrations in berries from nine locations in the Czech Republic and one sample from Poland without giving explicit values for the ten samples.

The cited authors in Tables 1 and 2 did not mention if the aronia berries are locally grown or imported. The only information provided is that the berries were purchased in local markets as follows: Cindrić et al. (2017) – Croatia, Pavlovic et al. (2015) – Serbia, Lancranjan (2012) did not report anything about the provenience of the aronia berries of which he used an alcoholic extract. In Table 1, the cited values from Šnebergrová et al. (2014), are maximum and minimum Ca and Mg concentrations in berries from nine locations in the Czech Republic and one sample from Poland, the authors not giving explicit values for the ten samples.

Table 2. Mineral concentration in *Aronia melanocarpa* berries

Mineral	Concentration mg/kg	Reference
As	0.20[a]; 0.36[b]	Pavlovic et al., 2015
Cd	0.016[a]; 0.041[b]	Pavlovic et al., 2015
	0.055	Cindrić et al., 2017
Ba	1.48[a]; 6.66[b]	Pavlovic et al., 2015
Pb	0.048[a]; 0.091[b]	Pavlovic et al., 2015
	0.041	Cindrić et al., 2017
Sb	0.29	Pavlovic et al., 2015
Co	0.019[a]; 0.043[b]	Pavlovic et al., 2015
	0.019	Cindrić et al., 2017
B	2.88[a]; 14.22[b]	Pavlovic et al., 2015

[a] This value is the lowest concentration found in one of the two samples analyzed by Pavlovic et al. (2015) who analyzed two samples from different plants without specifying if they are different varieties or different cultivars.
[b] This value is the concentration found in the second sample analyzed by Pavlovic et al. (2015) who analyzed two samples from different plants without specifying if they are different varieties or different cultivars.

As it has been shown in Tables 1 and 2, there are large differences between the reported values by different authors. These differences might come from different analytical methods used (Table 3) or from analysing different varieties/cultivars of aronia, or due to different harvest times.

All fruits for which mineral concentrations values were reported were not sampled according to sampling methods for trees and shrubs, and also have not been sampled according to sampling methods from containers or silos (Wulfsohn D, 2010).

Table 3. Analytical methods used for determining the mineral concentrations in aronia fruits and products

Author	Fruit/ product	Analytical method
Pavlovic et al., 2015	aronia berries and aronia juice	iCAP 6000 (Thermo Scinentific, Cambridge, UK); operating conditions: flush pump rate 100 rpm, analysis pump rate 50 rpm, RF power 1150 W, nebulizer gas flow rate 0.7 L min−1, coolant gas flow rate 12 L min−1, auxiliary gas flow rate 0.5 L min−1, sample uptake delay 30s.
Cindrić et al., 2017	aronia berries	ICP-AES spectrometer from Teledyne Leeman (Hudson, NH, USA); operating conditions: flush pump rate 1.0 ml/min, RF-Generator 40 MHz "free-running", Argon flow Coolant:18 L/min, Auxiliary: 0.8 L/min, Nebulizer: 1 L/min, Peristaltic pump 1.0 mL min−1, Sample uptake delay 30s
Lancrajan, 2012	aronia berries	Not specified
Šnebergrová et al., 2014	aronia berries	Cations (potassium, magnesium and calcium) were determined by isotachophoresis according to Kvasnicka et al. (1993)
Pieszka et al., 2015	aronia pomace	ICP-MS; operating conditions: not specified; method details: not specified
Sójka et al., 2013 cited by Jurendić & Ščetar, 2021	aronia pomace	Not specified

2. Mineral content in aronia products

2.1. Mineral content in aronia juice

Mineral content in aronia commercial juice was quantified by Pavlovic et al. (2015) from 4 different commercially available aronia juices from Serbia, results being shown in Tables 4, 5 and 6. There is a huge variability in the results, information on other juice ingredients and preparation (raw vs. pasteurised) are missing.

Results were compared with the Dietary Reference Intake for children between 4-8 years old, adolescents between 14-18 years old and adults 19+ years old (*Dietary Reference Intakes (DRIs): NCBI Bookshelf*, n.d.), with maximum accepted levels of heavy metals in drinking water in the US (*National Primary Drinking Water Regulations | US EPA*, n.d.).

Based on Pavlovic et al. (2015) findings, aronia juice has a huge potential in providing a fair amount of calcium, magnesium and phosphorus. A 200g portion of aronia juice ensures up to 24.5% DRI (Daily Reference Intake) of Ca, 28.04% DRI of Mg and 29.62% DRI of P for adults. Up to 90.61% DRI of Mg for children 4-8y can be provided with the same portion of aronia juice. Magnesium excess is not a concern for healthy individuals if it's provided from food intake (*Magnesium - Health Professional Fact Sheet*, n.d.).

Aronia juice has a high concentration of chromium, 200g of juice ensuring 3 to 10 times more chromium than the DRI. There's no limit established for Cr since there are no adverse effects linked to high intakes in healthy humans (*Chromium - Health Professional Fact Sheet*, n.d.). Trivalent chromium has been shown to reduce insulin resistance (Hua et al., 2012), but there's no study on the bioavailability of this mineral after aronia juice consumption. Although hexavalent Cr is harmful it was not found in food samples (Vacchina et al., 2015). The absence of hexavalent chromium in foods may be due to its instability in presence of antioxidants (Vacchina et al., 2015).

Copper is an essential mineral present in aronia juice; Pavlovic et al. (2015) reported between 15% of DRI up to 100.22% of DRI for adults. Copper in food and dietary supplements (total of 2.5-3mg/day) shows good results in terms of slowing down bone mineral loss and reducing resorption markers, confirming the effectiveness of copper supplementation on bone metabolism (Rondanelli et al., 2021). Excess copper can result in liver damage and gastrointestinal symptoms (*Copper - Health Professional Fact Sheet*, n.d.). For individuals with liver pathology, caution is advised in the consumption of chokeberry juice due to its possible high Cu concentration (*Copper - Health Professional Fact Sheet*, n.d.).

Pavlovic et al. (2015) also shows a huge amount of selenium in aronia juice, 2-10 times more than the DRI in a 200g portion. Selenium plays an important role in maintaining the homeostasis of the human body, but excess selenium (more than 5mg/d) can cause hair loss, skin and nail lesions, anemia and may increase the risk of type 2 diabetes (Kieliszek, 2019).

A particular concern is manganese. As per Pavlovic et al. (2015), 200 g aronia juice ensures between 25-100% of DRI for adolescents and adults and up to 156% of DRI for children.

Manganese may be used as a fertiliser to lower the sugar content of aronia fruits (Skupień & Oszmiański, 2007) being one of the 17 essential elements for plant growth and reproduction (Alejandro et al., 2020).

Even if manganese treatments will lower significantly the sugar content in aronia fruits, the accumulation of this mineral in the fruits and products and in the human body after consumption need to be taken into consideration as it may lead to adverse effects like insomnia, memory loss, irreversible nerve damage (*Manganese - Consumer,* n.d.).

Compared to the maximum accepted levels of heavy metals in water (*National Primary Drinking Water Regulations | US EPA*, n.d.), a 200g portion of aronia juice contains double the amount of cadmium accepted in water, and almost double the amount of led. This information needs to be corelated with the pollution of the soils and types of treatments used on the aronia plants.

Table 4. Mineral concentrations of *Aronia melanocarpa* commercial juice compared to Dietary Reference Intakes

Aronia juice (Pavlovic et al., 2015)[a]				**Dietary Reference Intakes (DRI) (Dietary Reference Intakes (DRIs): NCBI Bookshelf, n.d.) in mg/day**			**% of DRI for 200g portion of aronia juice**		
Mineral		**mg/kg**	**mg/200g portion**	**Children 4-8y**	**Adolescents 14-18y**	**Adults 19+**	**Children 4-8y**	**Adolescents 14-18y**	**Adults 19+**
Ca	Min	138	27.60	1000	1300	1000	2.76	2.12	2.76
	Max	1225	245				24.5	18.84	24.5
Cr	Min	0.55	0.11	0.015	0.035	0.03	733.33	314.29	366.66
	Max	0.74	0.148				986.66	422.86	493.33
Cu	Min	0.68	0.136	0.44	0.89	0.9	30.9	15.28	15.11
	Max	4.51	0.902				205	101.34	100.22
Fe	Min	0.72	0.144	10	11	8	1.44	1.30	1.80
	Max	1.73	0.346				3.46	3.14	4.32
K	Min	848	169.6	2300	3000	3400	7.37	5.65	4.98
	Max	3204	640.8				27.86	21.36	18.84
Mg	Min	209	41.8	130	410	420	32.15	10.19	9.95
	Max	589	117.8				90.61	28.73	28.04
Mn	Min	2.98	0.596	1.50	2.20	2.30	39.73	27.09	25.91
	Max	11.77	2.354				156.93	107	102.34
Mo	Min	0.05	0.01	0.022	0.043	0.045	45.45	23.25	22.22
	Max	0.064	0.0128				58.18	29.76	28.44
Na	Min	19.60	3.92	1000	1500	1500	0.39	0.26	0.26
	Max	56.30	11.26				1.12	0.75	0.75
P	Min	568	113.60	500	1250	700	22.72	9.08	16.22
	Max	1037	207.40				41.48	16.59	29.62
Se	Min	0.72	0.144	0.03	0.055	0.055	480	261.81	261.81
	Max	1.73	0.346				1153.33	629.09	629.09
Zn	Min	0.89	0.178	5	11	11	3.56	1.61	1.61
	Max	3.45	0.69				13.80	6.27	6.27

[a] Pavlovic et al. (2015) analysed 4 different aronia juices. The Min and Max values are the lowers and the highest values from all four samples.

Table 5. Heavy metal content in *Aronia melanocarpa* juice compared to Maximum Accepted Levels in drinking water by EPA (National Primary Drinking Water Regulations | US EPA, n.d.)

Aronia juice (Pavlovic et al., 2015)[a]				**Maximum accepted level in drinking water (EPA)**
Mineral		**mg/kg**	**mg/200g portion**	**mg/kg**
As	Min	0.37	0.074	0.01
	Max	0.79	0.158	
Cd	Min	0.05	0.01	0.005
	Max	0.064	0.0128	
Ba	Min	0.77	0.154	2
	Max	2.06	0.412	
Pb	Min	0.061	0.0122	0.015
	Max	0.143	0.0286	

[a] Pavlovic et al. (2015) analysed 4 different aronia juices. The Min and Max values are the lowers and the highest values from all four samples.

The minerals in Table 6 may be quantified in aronia products however their concentrations in foods are not regulated in official regulations and provisions.

Table 6. Other minerals in *Aronia melanocarpa* juice

Aronia juice (Pavlovic et al., 2015)[a]			
Mineral		mg/kg	mg/200g portion
Sb	Min	0.13	0.026
	Max	0.54	0.108
Co	Min	0.01	0.002
	Max	0.092	0.0184
B	Min	1.44	0.288
	Max	9.32	1.864
Ni	Min	0.13	0.026
	Max	0.86	0.172
V	Min	0.47	0.094
	Max	1.43	0.286
Si	Min	3.3	0.66
	Max	7.4	1.48
Li	Min	0.016	0.0032
	Max	0.072	0.0144
Sr	Min	0.34	0.068
	Max	3.67	0.734
Al	Min	1.64	0.328
	Max	9.7	1.94
Sn	Min	0.86	0.172
	Max	1.09	0.218

[a] Pavlovic et al. (2015) analysed 4 different aronia juices. The Min and Max values are the lowers and the highest values from all four samples.

2.2. Mineral content in aronia pomace

After juice extraction, the pomace will still be rich in minerals as shown by Pieszka et al. (2015) and Sójka et al. (2013) cited by Jurendić & Ščetar, 2021 (Table 7).

Aronia pomace powder has been studied mainly for the fibre and phenolic content and currently it is used as substitute for cocoa powder in biscuits (Molnar et al., 2020), as a substitute for starch in ready-to-eat extruded cereals (Schmid et al., 2022) and as a colouring foodstuff (Nemetz et al., 2021). Mineral analysis and bioavailability were not presented in these studies.

Table 7. *Aronia melanocarpa* pomace mineral concentrations

Mineral	Concen-tration mg/kg	Reference
Na	37[a]	Pieszka et al., 2015
	50-90[b]	Sójka et al., 2013 cited by Jurendić & Ščetar, 2021
K	2780[a]	Pieszka et al., 2015
	1810-3080[b]	Sójka et al., 2013 cited by Jurendić & Ščetar, 2021
Ca	2750[a]	Pieszka et al., 2015
	2190-4080[b]	Sójka et al., 2013 cited by Jurendić & Ščetar, 2021
Mg	880[a]	Pieszka et al., 2015
	370-2500[b]	Sójka et al., 2013 cited by Jurendić & Ščetar, 2021
P	2390[a]	Pieszka et al., 2015
	2390[b]	Sójka et al., 2013 cited by Jurendić & Ščetar, 2021
Zn	15.7[a]	Pieszka et al., 2015
	06-37[b]	Sójka et al., 2013 cited by Jurendić & Ščetar, 2021
Fe	197[a]	Pieszka et al., 2015
	75-80.6[b]	Sójka et al., 2013 cited by Jurendić & Ščetar, 2021
Cu	1.95[a]	Pieszka et al., 2015
	5-12[b]	Sójka et al., 2013 cited by Jurendić & Ščetar, 2021
Mn	31.5[a]	Pieszka et al., 2015
	32[b]	Sójka et al., 2013 cited by Jurendić & Ščetar, 2021

[a] Pieszka et al., 2015 quantified the minerals in dried pomace.
[b] Sójka et al., 2013 cited by Jurendić & Ščetar, 2021 did not mention if the values are an interval or minum and maximum, nor the number of samples analysed.

CONCLUSIONS

High concentrations of Se, Mn and Cr were reported by Pavlovic et al. (2015) in aronia commercially available juice showing that a 200 mg serving of juice may provide several times the amount of DRI for all age groups. A serving of 200mg of juice will provide up to 11 times the DRI for selenium for 4-8 years old children and up to 6 times for adults 19+ years old. For chromium the same serving will provide between more than 4 times the DRI for adolescents 14-18 years old and adults 19+ years old and up to more than 9 times the DRI for 4-8 years old children.

Based on the reported data, the mineral content of aronia berries shows a large variability. For potassium it was found to be up to 3 orders of magnitude, varying from 2707mg/kg (Pavlovic et al., 2015) to 6790mg/kg (Cindrić et al., 2017b).

Fertilisation will have a strong impact on saccharides concentrations in berries however no reports were found on the influence of fertilisation on mineral concentrations in berries.

Based on the current knowledge, *Aronia melanocarpa* has a large potential to be a good dietary source of essential minerals such as K, Ca, Mg, P, Se, Cu, Cr, Mn, containing highly significant concentrations of polyphenols and a low content in sugar which can be controlled through fertilisation.

It is not adequate to compare the reported values for aronia berries and juices for mineral concentrations due to the fact that the analysed juices are commercially available and not extracted from the berries for which minerals have been reported. Moreover, there is no information on the varieties and harvest conditions of aronia berries used for the commercially available juices. Therefore, research is needed to identify the relationship between concentrations of minerals in aronia berries and juices and to identify the most relevant cultivars/varieties of aronia to produce juices with high mineral content.

There is an acute lack of information on the mineral content of aronia fruits and food products. Using the Mendeley Elsevier searching engine, a total of three article on minerals in aronia products (juice, pomace) were found and a total of 4 articles on minerals in aronia berries in over 1296 article published from 2005.

Extensive research is needed in order to identify and quantify the mineral concentrations of aronia fresh berries and products and to contribute to an advance knowledge of mineral content as a key role for healthy natural products. Additionally, the variability of the mineral's concentrations in the aronia fruits should be studied in relation with crop variety, soil characteristics, climate changes, fertilization and harvesting time.

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