

Effect of cultivar, year, and their interaction on nutritional and energy value components in *Aronia melanocarpa* berries

Ivona-Cristina ENESCU MAZILU^{1,2*}, Sina COSMULESCU^{3*}

¹University of Craiova, Faculty of Horticulture, Doctoral School of Plant and Animal Resources Engineering, 13 A.I. Cuza Street, 200585 Craiova, Romania; icmazilu@yahoo.com (*corresponding author)

²Research Institute for Fruit Growing Pitesti, 402 Marului Street, 117450 Pitesti, Arges, Romania

³University of Craiova, Faculty of Horticulture, Department of Horticulture and Food Science, 13 A.I. Cuza Street, 200585 Craiova, Romania; sina.cosmulescu@edu.ucv.ro (*corresponding author)

Abstract

Aronia melanocarpa has long been known for its small, purple-black, and sweet-bitter berries to which several human health benefits have been attributed. This study aimed to highlight the effect of cultivar, year, and their interaction on the berry level of some components with nutritional and energetic value in two chokeberry cultivars. The study was carried out on 'Melrom' and 'Nero' chokeberry cultivars, grown under climatic conditions specific to Muntenia region, Romania. Compared to 'Nero' cv., dry weight, total soluble solids, and carbohydrates were found in significantly higher quantity in 'Melrom' cv. (263.33 g kg⁻¹, 18.02 °Brix, 203.19 g kg⁻¹). Significantly higher energy value and acidity (946.81 kcal kg⁻¹ and 11.40 g malic acid kg⁻¹, respectively) were also determined for 'Melrom' cv. Except for total soluble solids for 'Melrom' cv., total titratable acidity and total sugar content presented the highest variations between the study years for each of the two cultivars. K was the major mineral, followed by Ca. 'Nero' cv. had a higher content of K (2.73 g kg⁻¹) and Zn (0.003 g kg⁻¹) and significantly higher levels of Ca (0.72 g kg⁻¹), Mg (0.35 g kg⁻¹), and P (0.52 g kg⁻¹). Both chokeberry cultivars can be considered as an alternative to complete the daily diet with fiber and minerals without high energy or sugar intake.

Keywords: carbohydrates; chokeberry; dietary fibers; minerals; sugars

Introduction

Aronia melanocarpa (Michx.) Britton is known for its fruits that have many benefits for human health. Consumed both fresh and processed, chokeberry fruits are nutritionally valuable food since they are sources of carbohydrates, minerals, organic acids, and vitamins, but low lipid and protein levels (Jurikova *et al.*, 2017; Gündeşli *et al.*, 2019; Aguilera and Toledo, 2022; Gurčik *et al.*, 2023; Negreanu-Pirjol *et al.*, 2023). Chokeberries are rich in antioxidants, vitamin C, and dietary fibers, and are often used in juices, jams, and other food products (Jurendic and Scetar, 2021). *A. melanocarpa* berries have also been studied for their potential health benefits, such as reducing inflammation, improving cardiovascular health, and boosting the immune system (Kulling and Rawel, 2008). Their components with biological activity may vary depending on the

Received: 22 Oct 2023. Received in revised form: 15 Nov 2023. Accepted: 02 Dec 2023. Published online: 19 Dec 2023.

From Volume 49, Issue 1, 2021, Notulae Botanicae Horti Agrobotanici Cluj-Napoca journal uses article numbers in place of the traditional method of continuous pagination through the volume. The journal will continue to appear quarterly, as before, with four annual numbers.

cultivar, harvest timeline, pedoclimatic conditions, and also the applied agrotechnical (fertilization, irrigation, growth in a protected environment, etc.). Different aronia cultivars can have varying levels of nutrients, antioxidants, and other components with nutritional value (Jeppsson and Johansson, 2000; Ochmian *et al.*, 2012; Tolic *et al.*, 2017; Enescu Mazilu *et al.*, 2021). Climatic factors can also affect aronia berry's nutritional value, and as a result, it is recommended to grow it in areas favorable to the crop as this enables the fruit to develop slowly and accumulate valuable nutrient content (Nicola *et al.*, 2020; Yang *et al.*, 2019). Soil conditions too can affect the nutritional value of aronia fruits as well-drained soil, rich in organic matter, helps promote healthy growth and nutrient absorption (Dordevic *et al.*, 2021; Jeppsson, 2000). Aronia is one of the richest sources of antioxidants, including anthocyanins, flavonoids, and phenolic acids. These antioxidants help protect cells against damage from harmful free radicals, which can contribute to the development of chronic diseases (Meng *et al.*, 2019; Oszmiański and Wojdylo, 2005). Aronia is also considered a good source of vitamins important for immune function and health. Aronia has become more and more sought after in the functional food market due to its health benefits and it is also a good source of minerals (Zhang *et al.*, 2021; Kaličanin *et al.*, 2022). Given the role of potassium in regulating blood pressure and heart health, magnesium in bone health and energy production, and iron in erythropoiesis (red blood cells production) and oxygen transport, the role of aronia fruits in human health is under ongoing research (Kulling and Rawel, 2008; Jurendic and Scetar, 2021). In terms of energy value, aronia fruits are relatively low in calories and rich in fiber, which can make them a good choice for weight-lost diets or to improve digestive system health. Their energy value may also vary depending on the cultivar and growing conditions (Kulling and Rawel, 2008). Several factors can directly or indirectly affect the nutritional quality of crops, and among them are environmental factors and cultivars, and as a result, such studies are necessary to identify the best management practices. Based on these considerations, this study aimed to highlight the effect of the interaction of cultivar and climatic year on the components with nutritional and energy value in chokeberry, in two cultivars ('Melrom' and 'Nero'), grown in the Pitesti, Arges County, to Muntenia region, Romania.

Materials and Methods

Materials

The plant material belongs to *A. melanocarpa* species, 'Melrom' and 'Nero' cultivars. In Romania, the cultivars 'Melrom' (of Romanian origin) and 'Nero' (of Czech origin) are cultivated, and these have good quality fruits and good productivity (Negreanu-Pirjol *et al.*, 2023). Aronia fruits were harvested from plants grown in the experimental plots of the Research Institute for Fruit Growing Pitesti, Arges County (Muntenia region), Romania (E44°54'11"N 24°52'29"E). The two plots of Aronia ('Melrom' and 'Nero') were divided into three parcels. For harvesting, 3 bushes were randomly chosen from each parcel. The bushes were harvested after chokeberries reached full maturity, appreciated by the specific color, black-purple. As not all chokeberry fruits ripen simultaneously, the berries of each bush included in the experiment were harvested in 6 moments in 2019 and 2022 (in both years the harvest started on July 27), 9 moments in 2020 (starting from August 1), and 7 moments in 2021 (starting from August 10), at 5-day intervals. The harvest was stopped when the first signs of berries dehydration appeared. Chokeberry samples were subjected to pre-cooling in a cold-storage room, at 5.0 °C (and relative humidity of 90-95%), for 12 hours and subsequently frozen and kept at -18 °C (for two months counted from the first harvest) and thawed before performing laboratory analyses. The average sample was obtained by combining 200 g of fruit at each moment of harvest. For analysis, the samples were divided into three replicates.

Experimental site

The experimental plot was established in 2011, with planting material obtained by micropropagation. The planting distances are 3.0×1.4 m (2380 plants/ha). The soil belongs to the class of wet phreatic aluviosol protisols, formed on fluvial deposits, with a loam-sandy granulometric composition (Nicola *et al.*, 2020). It is characterized by a strongly moderate acid reaction, a low humus content, and a low assimilable phosphorus content in the arable layer. No fertilizer or irrigation was applied. Climatic parameters (air temperature measured at 2 m above ground, rain, and sunshine hours) were registered with WatchDog900ET meteo station (Spectrum Technologies Inc., Aurora, IL, USA), placed near the experimental plots. The climate of the Pitesti-Arges area is humid continental temperate, with an average annual temperature of 10.0 °C and an annual amount of rainfall of 678 mm. As presented in Figure 1, compared with the multiannual average values (1969-2021), 2019, 2020 and 2021 were warmer (by 1.6-1.9 °C). The driest of the four study years was 2022 (by 153 mm less than normal), and it was followed by 2019 and 2021 (42-43 mm less). Although June is usually the rainiest month of the year, rain excesses of 97 mm in 2019 and 66 mm in 2020, respectively, were recorded compared to the normal value registered for June in the 1969-2021 interval, but also, exceptionally, in August 2022 (about 81 mm excess compared to the normal value registered for August between 1969 and 2021), following a dry June - July interval. Deviations from the normal were also observed concerning sunshine hours, especially in August 2019 and April 2020, but also in May 2022 (with 40-103 hours above the multiannual levels).

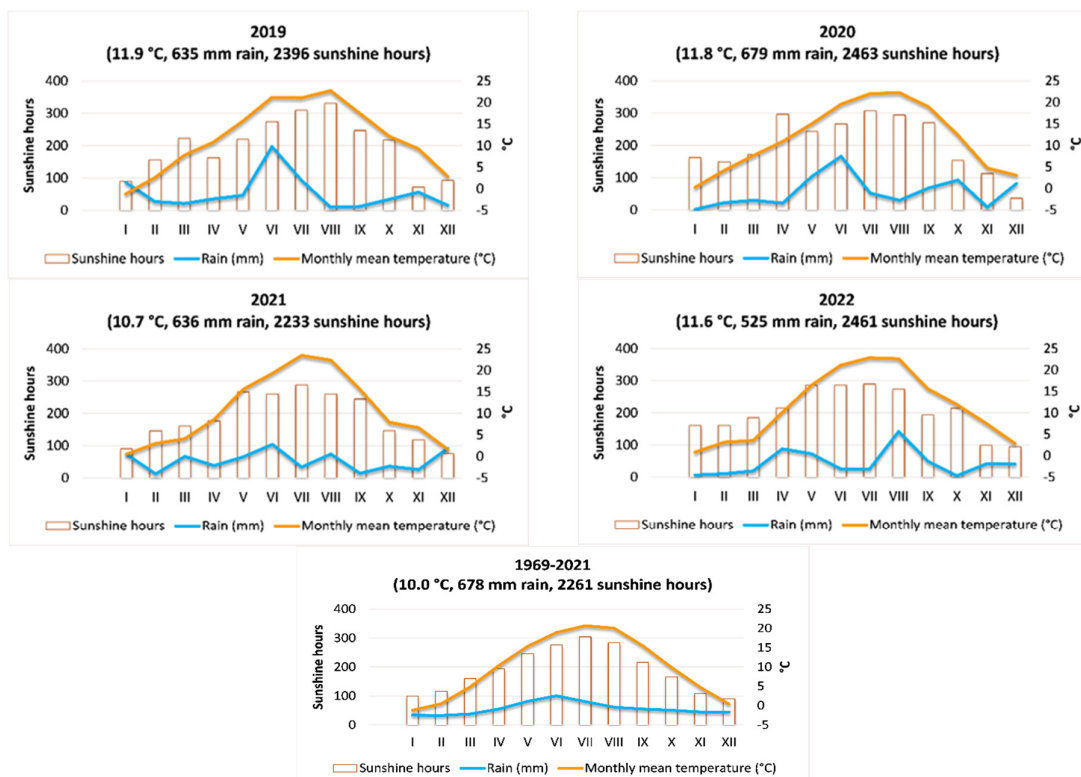


Figure 1. Monthly sum of sunshine hours, rain, and monthly mean temperature for the 2019-2022 interval compared to 1969-2021 in Pitesti, Arges county

Method

For each chokeberry analysis (dry weight, total soluble solids and pH, total titratable acidity, total protein content, total lipid content, and total dietary fiber content) samples of 90 g (30 g in three replicates)

were used, while samples of 450 g (150 g in three replications) chokeberries were used for mineral content determination.

Total dry weight (DW) was determined by removing water from the sample in an oven at 105 °C until constant weight and the results were expressed as g kg⁻¹. Total soluble solids (TSS) were measured with a digital refractometer (Kern, Germany) in fruit-pressed juice and the results were expressed in Brix degrees (°Brix). Determination of the fruit juice pH was carried out using an electronic pH meter. Total titratable acidity (TTA) was determined by titration of a known amount of chokeberry aqueous extract with 0.1 mol L⁻¹ NaOH using phenolphthalein as an indicator, and it was expressed as g malic acid kg⁻¹ fresh weight. The methods used for DW, TSS, and TTA were those presented by Ionica *et al.* (2018). Carbohydrate content (TCHC) was calculated by difference, according to Merrill and Watt method (1973): TCHC=100-MC-TPrC-TLC-MinC (g kg⁻¹) where TCHC=total carbohydrates content, MC=moisture content, TPrC=total protein content, TLC=total lipid content, MinC=mineral content.

Total protein content was determined according to STAS 9065/4-81, by the Kjeldahl method, while lipids were determined by the Soxhlet method.

Determination of total sugar content (TSC) was carried out using the phenol-sulfuric acid method Nielsen (2010). Two ml of sample (100 g mashed fruits per cultivar per year) was mixed with 1 ml of 5% aqueous solution of phenol in a reaction tube, then 5 ml of concentrated sulfuric acid is added. After 10 min, the mixture was vortexed for 30 sec, and placed for 20 min in a water bath, at room temperature for color development. The absorbance of the sample at 490 nm was read, and recorded by the spectrophotometer. The reference and the standard solutions were prepared identically to the previously described protocol, except that the 2 ml sample was replaced by distilled water and different concentration glucose solutions, respectively. The phenol used in this process was redistilled and the solution containing 5% phenol (w/w) was prepared immediately before determination. Total sugar content (TSC) was expressed in g kg⁻¹.

Determination of dietary fibers (TDFC) was made by the gravimetric-enzymatic AOAC method 991.43 proposed by Lee *et al.* (1992), and the content was expressed in g kg⁻¹.

Energy value (EV) determination was made by calculation, using the formula proposed by Alemu *et al.* (2022), based on ATWATER factors (kcal carbohydrates = 4.0 kcal g⁻¹; lipid = 9.0 kcal g⁻¹; protein = 4.0 kcal g⁻¹), and the content was expressed in kcal kg⁻¹.

For the analysis of mineral content, the samples of plant material (500 g frozen chokeberries) were subjected to calcination in quartz ampoules, at the temperature of 550 °C for 18 h. The ash resulting from calcination was weighed, and placed in a bowl containing 10 ml of nitric acid 1M, and subsequently, the mixture was subjected to boiling for 5 min. Then the solution was filtered after the boiling stage and then bringing it to a final volume of 50 ml with 1M nitric acid. The analysis of mineral elements was performed using an atomic absorption spectrometer with a flame of 50 mm. For the determination of mineral elements, except for calcium, the acetylene-air flame was used. In the determination of calcium, the acetylene-N₂O flame was used and the method was the one described by Cosmulescu *et al.* (2013, 2017). For calibration, standard solutions purchased from the Sigma-Aldrich company were used.

Statistical analysis

The IBM SPSS 28 statistics software was used to analyse the data. Statistical descriptors of the central trend (mean and median), dispersion (standard deviation, extreme values, and amplitude of variation), and the variation coefficient were calculated. The relationships between the characteristics were analysed using the coefficients of Pearson correlations. Shapiro-Wilk and Levene's tests were used to test data distribution normality and the homogeneity of variances. Both tests were non-significant and therefore the significance of data oscillation depending on the experimental factors was established by two-way analysis of variance ANOVA. Tukey's range test ($\alpha = 0.05$) was used to highlight the differences between variants. In graphical representations, different types of letters (lower/upper case, italic lower/upper case, and bold lower case) were

used to emphasize the significance of the differences between the values obtained for each of the two cultivars and their average.

Results and Discussion

Results regarding chokeberry dry weight, total soluble solids, carbohydrates, sugar and fiber content, berry acidity, and energy value

Table 1 shows the statistical descriptors of dry weight content, total soluble solids, carbohydrates, sugar and fiber content, the pH of the juice, total titratable acidity, and the energy value of 'Melrom' and 'Nero' chokeberry cultivars. As can be observed, on average, in 'Melrom' cv. total carbohydrate content represented about 77.16% of the total dry weight content, while total sugar content reached up to 59.20% of the total carbohydrate content. Total dietary fiber content accounts for 25.44% of total dry weight content. Regarding 'Nero' cv., total carbohydrate content was up to 74.05% from berry dry weight while total sugar content was better represented (65.52% from TCHC) compared to 'Melrom' cv. As reported to the dry weight, total dietary fiber content represented about 26.42%. The energy value varied from 919.00 to 990.30 kcal kg⁻¹ for 'Melrom' cv. and from 783.00 to 910.30 kcal kg⁻¹, for 'Nero' cv. 'Melrom' cv. dry weight content had a lower variation coefficient (VC 4.54%), and averaged 26.33 g 100 g⁻¹, while for 'Nero' cv. averaged 24.37 g 100 g⁻¹, and a higher variation coefficient (VC 7.15%) was determined. According to other authors, in general, the dry weight of aronia berries varied between 15% and 31% (Ochmian *et al.*, 2012; Pop *et al.*, 2022), and the amount of sugar found in ripe black fruits, was 338.4 g/kg⁻¹ (Sosnowska *et al.*, 2022). Total soluble solids followed on opposite trend, with a wide variation for 'Melrom', around 18.02°Brix (VC 12.87%), but lower for 'Nero' (VC 3.90%, mean TSS of 17.43°Brix), both of them close to other studies, which reported total soluble solids between 14.2 and 24.4°Brix (Ochmian *et al.*, 2012; Skupien and Oszmianski, 2007). Regarding total carbohydrate content, a smaller variation was registered for 'Melrom' (VC 1.78%), from 196.40 to 209.80 g kg⁻¹, compared to 'Nero' (Table 1). According to King (King and Bolling, 2020), carbohydrates in *Aronia* berries are mainly sugars and fiber, and fresh Aronia berries contain 15 to 20.9 g/100 g FW. of carbohydrates. Total sugar content and total dietary fiber content varied similarly to total soluble solids, wider for 'Melrom' cv. (Table 1).

Chokeberry acidity (Table 1) was described by the parameters total titratable acidity (TTA) and pH, which recorded average values of 11.40 g malic acid kg⁻¹ for 'Melrom' and 9.20 g malic acid kg⁻¹ for 'Nero' cv., with higher variation for 'Melrom' (VC 20.70%). Unlike TTA, the pH varied close for both cultivars, from 3.40 to 3.80 for 'Melrom' and from 3.46 to 3.86 for 'Nero', while EV had almost three times lower VC in 'Melrom' compared to 'Nero' (1.97% vs. 5.93%).

Table 1. 'Melrom' and 'Nero' cvs. berries' nutrient content and energy value*

Cultivar	Statistic descriptors	DW (g kg ⁻¹)	TSS (°Brix)	TCHC (g kg ⁻¹)	TSC (g kg ⁻¹)	TDFC (g kg ⁻¹)	TTA (g malic acid kg ⁻¹)	pH	EV (kcal kg ⁻¹)
Melrom	Mean	263.33	18.02	203.19	120.30	67.00	11.40	3.56	946.81
	SD	11.97	2.32	3.63	15.22	5.28	2.36	0.13	18.68
	VC%	4.54	12.87	1.78	12.65	7.88	20.70	3.69	1.97
	Minimum	218.90	16.20	196.40	100.40	58.80	8.90	3.40	919.00
	Maximum	284.60	22.00	209.80	156.80	75.50	16.00	3.80	990.30
Nero	Mean	243.68	17.43	180.44	118.22	64.43	9.23	3.61	850.63
	SD	17.43	0.68	10.74	11.61	4.26	1.45	0.11	50.41
	VC%	7.15	3.90	5.95	9.82	6.61	15.68	3.16	5.93
	Minimum	219.80	16.30	165.40	96.90	58.00	7.30	3.46	783.00
	Maximum	277.80	18.10	193.40	143.00	70.30	12.90	3.86	910.30

*DW=dry weight, TSS=total soluble solids, TCHC= total carbohydrate content, TSC=total sugar content, TDFC= total dietary fiber content, TTA=total titratable acidity, EV=energy value; the averages of three determinations per cultivar per year are presented.

Regarding the TDFC, a lightly smaller level, of 56 g fiber kg⁻¹ fruit was revised by Kulling and Rawell (2008). Lower pH variation was also found in other studies, where aronia juice pH ranged between 3.3 and 3.9 (Sosnowska *et al.*, 2022), while the values registered for total titratable acidity were close to those mentioned in the literature: 0.7-1.4% (Snebergrova *et al.*, 2014) or 0.74-1.03% (Paunović *et al.*, 2022).

The correlations between nutritional components and the energy value of the two chokeberry cultivars are presented in Table 2. For 'Melrom' cv. the most intense correlation ($r=0.828^{***}$) showed that TCHC is responsible for berry EV. Only a weak positive correlation was established between DW and TCHC ($r=0.580^*$), while contrary to 'Nero' berries with higher TSS had higher TCHC ($r=0.586^*$) and a similar positive correlation was found for TSS and TSC ($r=0.752^{**}$). TSC and TDFC had smaller although positive contributions to berry EV ($r=0.681^*$ for TSC and $r=0.633^*$ for TDFC). The most intense correlations between berry quality parameters were found for 'Nero' and showed that DW was negatively correlated with TSS ($r=-0.911^{***}$) and pH ($r=-0.570^*$), although positive very strong correlations were observed with TCHC ($r=0.949^{***}$), TDFC ($r=0.895^{***}$), and EV ($r=0.961^{***}$). Berries with higher TSS had higher pH ($r=0.744^{**}$), but lower TCHC ($r=-0.861^{***}$), TDFC ($r=-0.753^{**}$), and EV ($r=-0.862^{***}$). A higher TCHC was also found when TDFC was well represented ($r=0.840^{**}$) and both of them increased when the pH was low ($r=-0.778^{**}$ for TCHC and $r=-0.604^*$ for TDFC). As expected, higher TSC was correlated with lower berry total titratable acidity ($r=-0.787^{**}$) and more acid berries had low EV ($r=-0.767^{**}$).

Table 2. Correlation matrix between chokeberries, cultivars 'Melrom' and 'Nero', nutrient content, and energy value

Cultivar		TSS	TCHC	TSC	TDFC	TTA	pH	EV
Melrom	DW	0.358	0.580 [*]	-0.096	-0.048	-0.114	-0.376	0.423
	TSS	1	0.586 [*]	0.752 ^{**}	0.304	-0.470	-0.434	0.627 [*]
	TCHC		1	0.474	0.089	0.031	-0.280	0.828 ^{***}
	TSC			1	0.555	-0.254	0.116	0.681 [*]
	TDFC				1	-0.237	0.063	0.633 [*]
	TTA					1	-0.277	-0.112
	pH						1	-0.182
Nero	DW	-0.911 ^{***}	0.949 ^{***}	-0.310	0.895 ^{***}	0.378	-0.570 [*]	0.961 ^{***}
	TSS	1	-0.861 ^{***}	0.413	-0.753 ^{**}	-0.789 [*]	0.744 ^{**}	-0.862 ^{***}
	TCHC		1	-0.177	0.840 ^{**}	0.428	-0.778 ^{**}	0.996 ^{***}
	TSC			1	-0.208	-0.787 ^{**}	0.025	-0.187
	TDFC				1	0.519	-0.604 [*]	0.886 ^{***}
	TTA					1	-0.371	0.455
	pH						1	-0.767 ^{**}

***Correlation is significant at level 0.001 (two-tailed); **Correlation is significant at level 0.01 (two-tailed);

*Correlation is significant at level 0.05 (two-tailed). DW=dry weight, TSS=total soluble solids, TCHC = total carbohydrate content, TSC=total sugar content, TDFC=total dietary fiber content, TTA=total titratable acidity, EV=energy value.

Table 3 shows the effect of the cultivar, climatic factors, as well as their interaction on the components with nutritional value and the energy value of aronia berries. Thus, significant oscillations of dry weight, total soluble solids, carbohydrates, and energy value under the influence of the cultivar × year interaction are highlighted. Also, total sugar content and pH were mainly influenced by the year, while TTA oscillated depending on the cultivar, but also the study year. Regarding the effects of weather conditions on fruit quality in chokeberry, also Tolic *et al.* (2017) considered that the large variations and discrepancies during different growing seasons are due to different air temperatures, sunlight, and rainfall rate. The cultivars respond differently to environmental factors and as a result, this effect is found in the nutritional composition.

As shown in Figure 2, in general, the trend followed by dry weight (DW) for the two cultivars was the opposite. If for 'Melrom' the highest content of dry matter was determined in 2019 (268.98 g kg⁻¹) and did not

show significant differences compared to 2021 and 2022, for ‘Nero’ an increasing trend was noted from 2019 (the lowest DW, 226.57 g kg⁻¹) to 2022 (maximum DW, 257.77 g kg⁻¹). Similar to ‘Melrom’ cv., ‘Nero’ DW determined in the last 2 years did not show significant differences, even on the background of the intense water stress recorded in 2022, in June and July, during the growth and ripening period. The smallest differences between the cultivars were observed in 2021, while ‘Melrom’ had a higher DW content (with 268.98 g kg⁻¹) compared to ‘Nero’ in 2019. Other similar significant differences were also noted in 2022.

Table 3. Cultivar, year, and their interaction effect on chokeberries’ nutrients and energetic value

Analysed constituent		Cultivar	Year	Cultivar × Year
DW	Sig.	0.000	0.000	0.003
	Partial Eta Squared	0.473	0.366	0.292
TSS	Sig.	0.000	0.000	0.000
	Partial Eta Squared	0.667	0.974	0.959
TCHC	Sig.	0.000	0.000	0.000
	Partial Eta Squared	0.947	0.782	0.781
TSC	Sig.	0.200	0.000	0.148
	Partial Eta Squared	0.073	0.621	0.212
TDFC	Sig.	0.186	0.338	0.225
	Partial Eta Squared	0.107	0.185	0.233
EV	Sig.	0.000	0.000	0.000
	Partial Eta Squared	0.932	0.772	0.778
pH	Sig.	0.116	0.000	0.465
	Partial Eta Squared	0.108	0.682	0.107
TTA	Sig.	0.000	0.000	0.069
	Partial Eta Squared	0.661	0.811	0.350

*DW=dry weight, TSS=total soluble solids, TCHC =carbohydrates, TSC=total sugar content, TDFC=total dietary fiber content, TTA=total titratable acidity, EV=energy value.

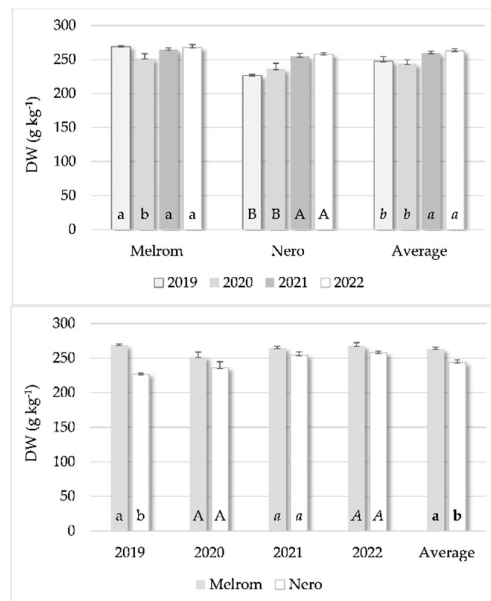


Figure 2. Chokeberries’ dry weight (DW) content variation between cultivars and study years (mean of three determinations per year per each cultivar are presented; different letters at the column base indicate significant differences between means, according to the Tukey post hoc test, p<0.05).

TSS followed a similar trend for ‘Melrom’ cv. (Figure 3), but showed an opposite tendency for ‘Nero’ cv., where it decreased from the first two years (18°Brix) to the last one (16.6°Brix). The differences between the cultivars were significant only in the 2019-2021 period, with maximum values for ‘Melrom’ in 2019 and minimum values in the other two.

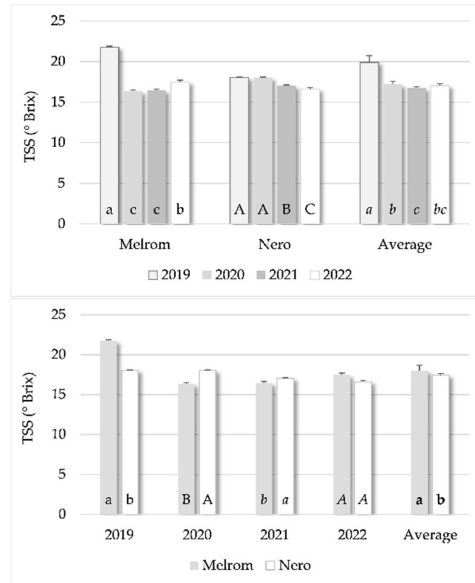


Figure 3. Chokeberries’ total soluble solids (TSS) variation between cultivars and study years (mean of three determinations per year per each cultivar are presented; different letters at the column base indicate significant differences between means, according to the Tukey post hoc test, $p < 0.05$).

Carbohydrate content (TCHC) oscillations were more intense for ‘Nero’ (Figure 4), where the highest TCHC was determined in 2021 and 2022 (196.93 and 195.65 g kg^{-1}), although ‘Melrom’ had superior TCHC compared to ‘Nero’ during the entire period. The cultivars differed significantly in terms of TCHC, but the biggest differences were those recorded in 2019 and 2020.

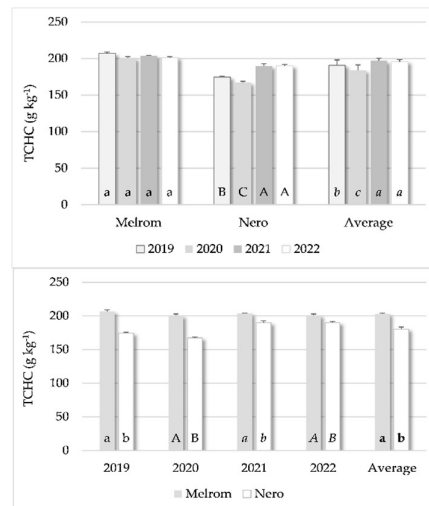


Figure 4. Chokeberries’ carbohydrate (TCHC) content variation between cultivars and study years (mean of three determinations per year per each cultivar and standard deviation are presented; different letters at the column base indicate significant differences between means, according to the Tukey post hoc test, $p < 0.05$).

Total sugar content (TSC) did not follow the trends recorded for carbohydrates (Figure 5). Their evolution was similar for the two studied cultivars and consisted of a decrease from the maximum level reached in 2019 (142.80 g kg⁻¹ for ‘Melrom’ and 134.67 g kg⁻¹ for ‘Nero’) to 2022 at ‘Melrom’ (111.05 g kg⁻¹) and 2021 for ‘Nero’ (107.50 g kg⁻¹). In all four years of study, the differences between the cultivars were small and insignificant. It was observed that both TSS and TSC were reduced for ‘Melrom’ cv., but also for ‘Nero’ cv. with the increase of maximum temperatures and thermal amplitude in July, but also with the decrease of the rainfall level.

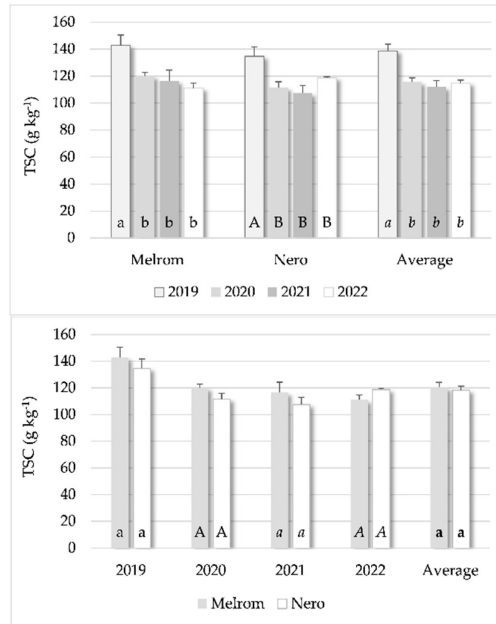


Figure 5. Chokeberries’ total sugar content (TSC) variation between cultivars and study years (mean of three determinations per year per each cultivar and standard deviation are presented; different letters at the column base indicate significant differences between means, according to the Tukey post hoc test, $p < 0.05$).

Total dietary fiber content (TDFC) fluctuations were also insignificant for ‘Melrom’ cv. (with a maximum of 68.97 g kg⁻¹ in 2019 and a minimum of 65.63 g kg⁻¹ in 2020, Figure 6), although for ‘Nero’ cv. TDFC in the first two years (approximately 61.00 g kg⁻¹) was significantly lower compared to its level in 2021 and 2022 (about 68.00 g kg⁻¹).

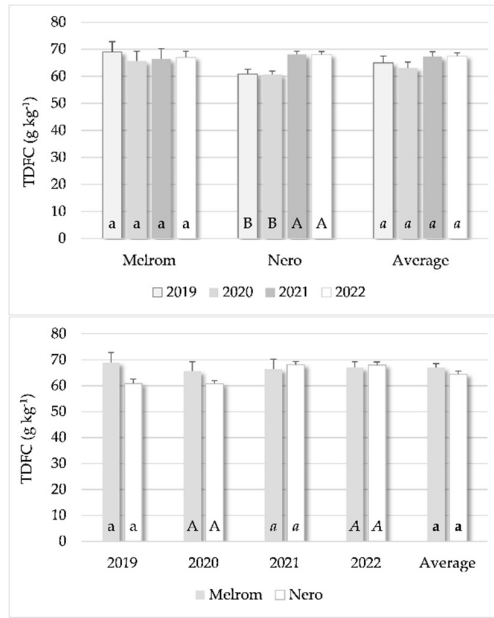


Figure 6. Chokeberries’ total dietary fiber content (TDFC) variation between cultivars and study years (mean of three determinations per year per each cultivar and standard deviation are presented; different letters at the column base indicate significant differences between means, according to the Tukey post hoc test, $p < 0.05$).

Total titratable acidity (TTA) recorded the highest levels in 2021 for both cultivars (15.07 g malic acid kg⁻¹ for ‘Melrom’ and 11.07 g malic acid kg⁻¹ for ‘Nero’). The acidity of the ‘Melrom’ cv. berry was superior to ‘Nero’ cv. over the entire period of the study and significant differences between cultivars were registered except for 2020 (Figure 7).

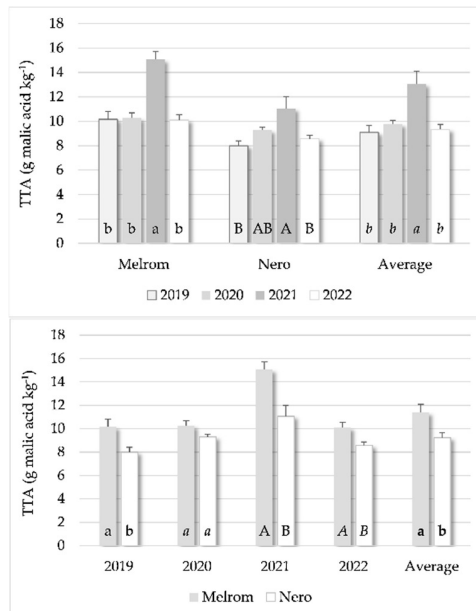


Figure 7. Chokeberries’ total titratable acidity (TTA) variation between cultivars and study years (mean of three determinations per year per each cultivar and standard deviation are presented; different letters at the column base indicate significant differences between means, according to Tukey post hoc test, $p < 0.05$).

However, the differences between the berry pH of the two cultivars were insignificant and only slightly higher for 'Nero' (Figure 8). For each cultivar, the pH increased significantly in 2020 (up to 3.8 for both, 'Melrom' and 'Nero' cvs.).

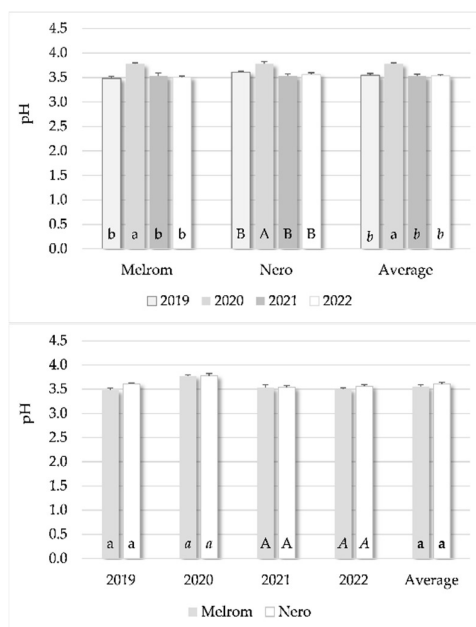


Figure 8. Chokeberries' pH variation between cultivars and study years (mean of three determinations per year per each cultivar and standard deviation are presented; different letters at the column base indicate significant differences between means, according to the Tukey post hoc test, $p < 0.05$).

From the point of view of the berry energy value (Figure 9), although with a higher EV, 'Melrom' cv. presented the smallest variations in the interval 2019-2022 (933.90-965.60 kcal kg⁻¹), while for 'Nero' EV decreased from 2019 to 2020 and reached the maximum in the last two years of the study (about 896.00 kcal kg⁻¹). For aronia species, the optimal harvesting time can be difficult to establish. If the exposure of fruits to higher temperatures is also considered (July 2021 and 2022) it would be expected to observe earlier dehydration processes, especially over periods of water deficiency (July 2022). In our study, this was reflected in a higher DW content. In turn, the accumulation of carbohydrates gives indications of the period favorable to the conduct of the photosynthetic process especially in 2021 and 2022, when the sum of sunshine hours immediately after the fruit set (May) was higher compared to the other three years. Under the influence of high temperatures in July, solar radiation, and limited rainfall, the breathing process could be intensified, and the rate of photosynthesis may also be diminished. Therefore, lower amounts of sugar were recorded, as observed between 2020 and 2022, compared to 2019. It is noted that the cultivar and the climatic year influenced the nutritional composition of fruits. This has been also observed for other components during the harvest season. Tolic *et al.* (2017) considers that the high variations and discrepancies during the different growing seasons are due to air temperature, sunlight, and different rainfall rates. The values in this study were within the limits presented by Snebergrova *et al.* (2014) for total soluble solids (15.20 and 22.90°Brix), although the level of sugars reported by the authors was almost 5 times higher. In Paunović *et al.* (2022) experiment, mulching with black plastic foil significantly increased TSS and TTA in chokeberry fruits, although TSC had lower levels compared to the variant not covered. Even in the version covered with mulch, the sugar content of chokeberry fruits in Paunović *et al.* (2022) study was lower, and the acidity was even twice as high compared to the data recorded for the 'Melrom' and 'Nero' cvs. At the same time, other studies (Jurendic and Scetar, 2021), found a

wider variation for the total sugar level and lower acidity and fibers, while Engin and Mert (2020) also determined slightly lower DW contents, but higher TSC in 'Nero' and 'Viking' cultivars grown in Turkey.

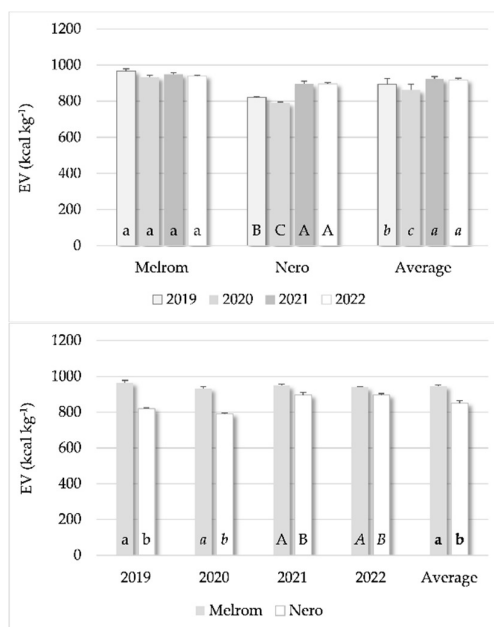


Figure 9. Chokeberries' energy value (EV) variation between cultivars and study years (mean of three determinations per year per each cultivar and standard deviation are presented; different letters at the column base indicate significant differences between means, according to Tukey post hoc test, $p < 0.05$).

Results regarding chokeberries Ca, Mg, K, Zn, and P content

Similar to other research (Jaćimović *et al.*, 2022), in this study the analysis of some mineral elements in *Aronia* berries indicated potassium as the predominant element, followed by phosphorus, calcium, and magnesium, while zinc was the least represented. Table 4 shows the statistical indicators of the central trend and dispersion of values recorded for calcium, magnesium, potassium, zinc, and phosphorus content of aronia fruits. Significantly lower phosphorous (0.28 g kg^{-1}), calcium (0.35 g kg^{-1}), and magnesium (0.19 g kg^{-1}), were determined for 'Melrom' cv., almost twice lower if compared to 'Nero'. The differences between cultivars' potassium and zinc content were not statistically assured, although 'Nero' cv. also had higher levels of both minerals.

Table 4. 'Melrom' and 'Nero' cultivars, Ca, Mg, K, Zn, and P content

Cultivar		Ca (g kg^{-1})	Mg (g kg^{-1})	K (g kg^{-1})	Zn (g kg^{-1})	P (g kg^{-1})
Melrom	Mean	0.35	0.19	2.62	1.90×10^{-3}	0.28
	Std. deviation	0.09	0.04	0.58	0.3×10^{-3}	0.06
	VC%	27.00	20.99	22.00	13.93	20.84
	Minimum	0.26	0.15	2.04	1.60×10^{-3}	0.22
	Maximum	0.44	0.23	3.20	2.10×10^{-3}	0.33
Nero	Mean	0.72	0.35	2.73	3.00×10^{-3}	0.52
	Std. deviation	0.19	0.07	0.60	0.9×10^{-3}	0.11
	VC%	27.00	20.99	22.00	30.00	20.99
	Minimum	0.53	0.28	2.13	2.10×10^{-3}	0.41
	Maximum	0.91	0.43	3.34	3.90×10^{-3}	0.63

The level of the five mineral elements in chokeberry (Figure 10) indicated significant differences between cultivars for calcium, magnesium, and phosphorous and 'Nero' cv. showed a 51.59% higher calcium level, 47.04% more magnesium, and 47.23% more phosphorous. The minerals concentrations in the two chokeberry cultivars were within the ranges reported in the literature, although in Kulling and Rawel (2008) study slightly lower amounts of calcium, magnesium, and potassium were recorded, compared to those determined for 'Melrom' cultivar, respectively, 0.32 g Ca, 0.16 g Mg, 2.18 g K and 0.14 g Zn per kg FW. Pavlovic *et al.* (2015) reported higher contents of K (2.71-4.98 g kg⁻¹), but also Ca (0.60-1.17 g kg⁻¹), Mg (0.16-0.58 g kg⁻¹), P (0.24-0.96 g kg⁻¹) and Zn (0.004-0.008 g kg⁻¹). In other research, values between 4.40 g kg⁻¹ and 5.80 g kg⁻¹ were reported for chokeberry mineral content (Tanaka and Tanaka, 2001).

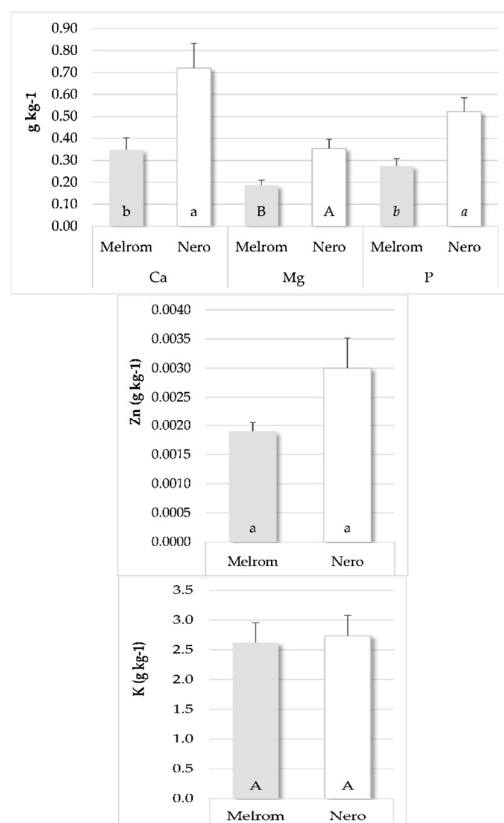


Figure 10. Chokeberries' Ca, Mg, P, Zn, and K content variation between cultivars (mean of three determinations per each cultivar and standard deviation are presented; different letters at the column base indicate significant differences between means, according to Tukey post hoc test, $p < 0.05$). Different types of letters (lower/upper case, italic lower/upper case, and bold upper case) were used to emphasize the significance of the differences between the Ca, Mg, P, Zn, and K levels determined for each of the two cultivars.

Also, in the study by Paunović *et al.* (2022), the K level of chokeberry fruits approached the maximum concentration determined in the present study, and Mg had a level similar to the average content determined in this study for 'Melrom'. However, Ca and P concentrations were rather close to the minimum levels recorded in the 'Melrom' variety. The same authors found Zn concentrations above the levels determined in the two analyzed varieties, 'Melrom' and 'Nero'. Zhang *et al.* (2021) revised studies that reported lower concentrations of K, Mg, Ca, and also Zn, similar to those reported for Ca, Mg, and K in other research (Jurendic and Sctar, 2021; Jaćimović *et al.*, 2022). Nevertheless, according to Cindric *et al.* (2017), a daily intake of 10 g of dried *Aronia* fruits can cover only 1.2%, 0.2%, 0.8%, 0.2%, 1.7%, 4%, 0.3%, and 0.05% of daily needs of Ca, Cr, Cu,

Fe, Mg, Mn, Mo, and Zn, respectively, so it can be concluded that fresh aronia fruits can have only a small contribution of metals in the diet.

Chokeberry infusions are considered another dietary source of essential metals, especially in terms of Ca, Cu, Fe, K, Mg, Mn, Na, Ni, and Zn, and the percentage of mineral elements varies from 4 (for Al and Mn) to 44% (for Na) (Cindric *et al.*, 2017). Similar to our results, the study of King and Bolling (King and Bolling, 2020) indicated K as the main mineral element present in fresh aronia fruits (1.35-6.79 g kg⁻¹), followed by Ca (0.12-1.17 g kg⁻¹), P (0.24-0.96 g kg⁻¹) and Mg (0.08-0.67 g kg⁻¹).

Conclusions

The fluctuations of nutritional components and differences between chokeberry cultivars studied during the study period were influenced by the climatic features of the experimental years. It was thus highlighted that the highest differences between cultivars were recorded in 2019 regarding DW, TSS, and TCHC, in 2019 and 2020 for EV, and 2021 for TTA. Our results showed that dietary fiber levels showed only insignificant differences either between cultivars or study years. Higher DW, TSS, TCHC, and TDFC found in 'Melrom' cv. Nevertheless, although both cultivars had important K levels, 'Nero' cv. has the advantage of an almost double concentration of Ca, Mg, and P than 'Melrom'. The information provided in this study is an important first step for *Aronia* growth programs and various chokeberry processors. This study provides insight into the selection of *Aronia* cultivars, and it can be used for various complementary foods and other chokeberry-enriched foods.

Authors' Contributions

Conceptualization, S.C. and I.-C.E.M.; methodology, I.-C.E.M.; software, I.-C.E.M.; validation, S.C.; data curation, I.-C.E.M.; writing—original draft preparation, S.C. and I.-C.E.M.; writing—review and editing, S.C.; supervision, S.C. All authors have read and agreed to the published version of the manuscript. All authors read and approved the final manuscript.

Ethical approval (for researches involving animals or humans)

Not applicable.

Acknowledgements

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Conflict of Interests

The authors declare that there are no conflicts of interest related to this article.

References

- Aguilera JM, Toledo T (2022). Wild berries and related wild small fruits as traditional healthy foods. *Critical Reviews in Food Science and Nutrition* 1-15. <https://doi.org/10.1080/10408398.2022.2156475>.
- Alemu B, Pu Z, Debele G, Goshu A, Jida M, Abdikadir A, ... Chun-hong M (2022). Proximate analysis of endangered evergreen leguminous shrub Yeheb-nut (*Cordeauxia edulis* Hemsl.) reveals high content of carbohydrate than protein. *Measurement: Food* 7:100051. <https://doi.org/10.1016/j.meafoo.2022.10005>.
- Cindric IJ, Zeiner M, Mihajlov-Kononov D, Stinger G (2017). Inorganic macro- and micronutrients in “superberries” black chokeberries (*Aronia melanocarpa*) and related teas. *Journal of Japan Society of Nutrition and Food Sciences* 14(5):539. <https://doi.org/10.3390/ijerph14050539>.
- Cosmulescu S, Botu M, Trandafir I (2013). The mineral source for human nutrition of nuts in different hazelnut (*Corylus avellana* L.) cultivars. *Notulae Botanicae Horti Agrobotanici Cluj-Napoca* 41(1):250-254. <https://doi.org/10.15835/nbha411830>.
- Cosmulescu S, Trandafir I, Nour V, Botu M (2017). Variation in minerals of skin and pulp of different cultivars of plum. *Acta Horticulturae* 1175:93-98. <https://doi.org/10.17660/ActaHortic.2017.1175.17>
- Dordevic B, Pljevljakusic D, Savikin K, Bigovic D, Jankovic T, Menkovic N, Zdunic G (2021). Effects of fertiliser application and shading on pomological properties and chemical composition of *Aronia melanocarpa* fruit in organic production. *Biological Agriculture & Horticulture* 1-16. <https://doi.org/10.1080/01448765.2021.2013942>.
- Engin SP, Mert C (2020). The effects of harvesting time on the physicochemical components of aronia berry. *Turkish Journal of Agriculture and Forestry* 44(4):361-370. <https://doi.org/10.3906/tar-1903-130>
- Günderli MA, Korkmaz N, Okatan V (2019). Polyphenol content and antioxidant capacity of berries: a review. *International Journal of Agriculture Forestry and Life Sciences* 3(2):350-361.
- Gurčík L, Bajusová Z, Ladvenicová J, Palkovič J, Novotná K (2023). Cultivation and processing of modern superfood - *Aronia melanocarpa* (black chokeberry) in Slovak Republic. *Agriculture* 13(3):604. <https://doi.org/10.3390/agriculture13030604>.
- Ionica ME, Cosmulescu SN, Tutunaru I (2018). Evolution of some physical and chemical characteristics of the myrobalan plum fruits (*Prunus cerasifera* EHRH.) during their growth and ripening. *South-Western Journal of Horticulture, Biology & Environment* 9(2):53-63.
- Jačimović S, Dojčinović B, Kiproovski B, Pantelić N (2022). Determination of selected macro-and microelements in black chokeberries (*Aronia melanocarpa* L.). In: *Book of Abstracts, 1st European Symposium on Phytochemicals in Medicine and Food I-EuSPMF, 7-9 September 2022, Belgrade* (p. 85). Belgrade: University of Belgrade, Faculty of Agriculture.
- Jeppsson N (2000). The effects of fertilizer rate on vegetative growth, yield and fruit quality, with special respect to pigments, in black chokeberry (*Aronia melanocarpa*) cv. Viking'. *Scientia Horticulturae* 83(2):127-137. [https://doi.org/10.1016/S0304-4238\(99\)00070-9](https://doi.org/10.1016/S0304-4238(99)00070-9).
- Jeppsson N, Johansson R (2000). Changes in fruit quality in black chokeberry (*Aronia melanocarpa*) during maturation. *Journal of Horticultural Science and Biotechnology* 75(3):340-345. <https://doi.org/10.1080/14620316.2000.11511247>.
- Jurendic T, Sctar M (2021). *Aronia melanocarpa* products and by-products for health and nutrition: A review. *Antioxidants* 10(7):1052. <https://doi.org/10.3390/antiox10071052>.
- Jurikova T, Mlcek J, Skrovankova S, Sumczynski D, Sochor J, Hlavacova I, Orsavova J (2017). Fruits of black chokeberry *Aronia melanocarpa* in the prevention of chronic diseases. *Molecules* 22(6):944. <https://doi.org/10.3390/molecules22060944>

- Kaličanin B, Velimirović D, Nešić I (2022). A study on mineral composition of *Aronia melanocarpa* as a functional food with potential therapeutic properties. *Journal of Food and Nutrition Research* 61(1):53-60.
- King ES, Bolling BW (2020). Composition, polyphenol bioavailability, and health benefits of aronia berry: A review. *Journal of Food Bioactives* 11. <https://doi.org/10.31665/JFB.2020.11235>.
- Kulling SE Rawel HM (2008). Chokeberry (*Aronia melanocarpa*) - A review on the characteristic components and potential health effects. *Planta medica* 74(13):1625-1634.
- Lee SC, Prosky L, Vries JWD (1992). Determination of total, soluble, and insoluble dietary fiber in foods - Enzymatic-gravimetric method, MES-TRIS buffer: Collaborative study. *Journal of AOAC International* 75(3):395-416.
- Meng L, Zhu J, Ma Y, Sun X, Li D, Li L, Bai H, Xin G, Meng X (2019). Composition and antioxidant activity of anthocyanins from *Aronia melanocarpa* cultivated in Haicheng, Liaoning, China. *Food Bioscience* 30:100413. <https://doi.org/10.1016/j.fbio.2019.100413>.
- Merrill AL, Watt BK (1973). Energy value of foods: basis and derivation. *Agriculture Handbook No. 74*. Washington, DC, ARS United States Department of Agriculture.
- Negreanu-Pirjol BS, Oprea OC, Negreanu-Pirjol T, Roncea FN, Prelipcean AM, Craciunescu O, Popoviciu DR (2023). Health benefits of antioxidant bioactive compounds in the fruits and leaves of *Lonicera caerulea* L. and *Aronia melanocarpa* (Michx.) Elliot. *Antioxidants* 12(4):951. <https://doi.org/10.3390/antiox12040951>.
- Nicola C, Florea A, Chițu E, Butac M (2020). Evaluation of the biochemical quality of *Aronia melanocarpa* fruits in the conditions of southern Romania, under the influence of fertilization. *Scientific Papers Series B Horticulture* 64(1):147-154.
- Nielsen SS (2010). Phenol-sulfuric acid method for total carbohydrates. In: Nielsen SS (Ed). *Food Analysis Laboratory Manual*. Food Science Texts Series. Springer, Boston, MA. https://doi.org/10.1007/978-1-4419-1463-7_6.
- Ochmian ID, Grajkowski J, Smolik M (2012). Comparison of some morphological features, quality, and chemical content of four cultivars of chokeberry fruits (*Aronia melanocarpa*). *Notulae Botanicae Horti Agrobotanici Cluj-Napoca* 40(1):253-260. <https://doi.org/10.15835/nbba4017181>.
- Oszmiński J, Wojdyło A (2005). *Aronia melanocarpa* phenolics and their antioxidant activity. *European Food Research and Technology* 221(6):809-813. <https://doi.org/10.1007/s00217-005-0002-5>.
- Paunović SM, Mašković P, Milinković M (2022). Optimization of primary metabolites and antimicrobial activity in aronia berries as affected by soil cultivation systems. *Erwerbs-Obstbau* 64(4):581-589. <https://doi.org/10.1007/s10341-022-00744-0>.
- Pavlovic AN, Brcanovic JM, Veljkovic JN, Mitic SS, Tosic SB, Kalicanin BM, Kostic DA, Dordevi MS, Velimirovic DS (2015). Characterization of commercially available products of aronia according to their metal content. *Fruits* 70(6):385-393. <https://doi.org/10.1051/fruits/2015038>.
- Pop L, Costa R, Asănică A, Tudoreanu L (2022). Mineral nutritional value of products containing aronia fruits and juices: a review. *Scientific Papers Series B Horticulture* 66(1):846-856.
- Skupien K, Oszmiński J (2007). The effect of mineral fertilization on nutritive value and biological activity of chokeberry fruit. *Agricultural and Food Science* 16(1):46-55. <https://doi.org/10.2137/145960607781635822>.
- Snebergrova J, Cízková H, Neradova E, Kapci B, Rajchl A, Voldrich M (2014). Variability of characteristic components of aronia. *Czech Journal of Food Sciences* 32(1):25-30.
- Sosnowska D, Kajszyk D, Podśędek A (2022). The effect of different growth stages of black chokeberry fruits on phytonutrients, anti-lipase activity, and antioxidant capacity. *Molecules* 27(22):8031. <https://doi.org/10.3390/molecules27228031>.
- Tanaka T, Tanaka A (2001). Chemical components and characteristics of black chokeberry. *Journal of Japan Society of Nutrition and Food Sciences* 48:606-610.
- Tolic MT, Krbavcic IP, Vujevic P, Milinovic B, Jurcevic IL, Vahcic N (2017). Effects of weather conditions on phenolic content and antioxidant capacity in juice of chokeberries (*Aronia melanocarpa* L.). *Polish Journal of Food and Nutrition Sciences* 67(1):67-74. <https://doi.org/10.1515/pjfn-2016-0009>
- Yang H, Kim YJ, Shin Y (2019). Influence of ripening stage and cultivar on physicochemical properties and antioxidant compositions of aronia grown in South Korea. *Foods* 8(12):598. <https://doi.org/10.3390/foods8120598>.
- Zhang Y, Zhao Y, Liu X, Chen X, Ding C, Dong L, Zhang J, Sun S, Ding Q, Khatoom S, Cheng Z, Liu W, Shen L, Xiao F (2021). Chokeberry (*Aronia melanocarpa*) as a new functional food relationship with health: an overview. *Journal of Future Foods* 1(2):168-178. <https://doi.org/10.1016/j.jfutfo.2022.01.006>.



The journal offers free, immediate, and unrestricted access to peer-reviewed research and scholarly work. Users are allowed to read, download, copy, distribute, print, search, or link to the full texts of the articles, or use them for any other lawful purpose, without asking prior permission from the publisher or the author.



License - Articles published in *Notulae Botanicae Horti Agrobotanici Cluj-Napoca* are Open-Access, distributed under the terms and conditions of the Creative Commons Attribution (CC BY 4.0) License.

© Articles by the authors; Licensee UASVM and SHST, Cluj-Napoca, Romania. The journal allows the author(s) to hold the copyright/to retain publishing rights without restriction.

Notes:

- **Material disclaimer:** The authors are fully responsible for their work and they hold sole responsibility for the articles published in the journal.
- **Maps and affiliations:** The publisher stay neutral with regard to jurisdictional claims in published maps and institutional affiliations.
- **Responsibilities:** The editors, editorial board and publisher do not assume any responsibility for the article's contents and for the authors' views expressed in their contributions. The statements and opinions published represent the views of the authors or persons to whom they are credited. Publication of research information does not constitute a recommendation or endorsement of products involved.