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PROCESS CHANGES IN POLYPHENOLIC SUBSTANCES AFTER PROCESSING ARONIA INTO VARIOUS FOOD PRODUCTS

Andrea Mendelová[1], Ľubomír Mendel[2], Miriam Solgajová[1], Jozef Golian[1], Anna Kolesárová[1]

Address(es): doc. Ing. Andrea Mendelová, PhD.
[1] Institute of Food Sciences, Faculty of Biotechnology and Food Sciences, Slovak University of Agriculture, Tr. A. Hlinku 2, 949 76 Nitra, Slovak Republic.
[2] National Agricultural and Food Centre, Research Institute of Plant Production, Bratislavská cesta 122, 921 68 Piešťany, Slovak Republic.

*Corresponding author: andrea.mendelova@uniag.sk

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ABSTRACT

The chokeberry is a plant with interesting biological potential and versatile uses. The most nutritionally valuable are the fruits, which are characterised by their high content of procyanidins, anthocyanins, flavonoids and phenolic acids. The aim of this work was to evaluate selected parameters of the composition of the fruits of the chokeberry varieties Nero and Galicjanka and to compare chokeberry products such as pasteurized chokeberry juice and puree, chokeberry jam, jelly and reduced sucrose jam, dried fruit and dried puree and baked chokeberry tea in terms of the stability of the total content of polyphenols and anthocyanins. Infrared spectroscopy was used to determine soluble solids, sugars, organic acids and pH. Determination of total polyphenols was carried out spectrophotometrically using Folin-Ciocalteu reagent. Determination of anthocyanin dye content was also performed spectrophotometrically by the pH differential method. Results were evaluated using one-way analysis of variance (ANOVA) followed by post hoc analysis of statistically significant differences between chokeberry products using the LSD multiple range test (Statistica 12, Statsoft). Fresh chokeberry fruits were high in soluble solids (22.8%), which is mainly composed of carbohydrates (19.71 $g.100\ g^{-1}$). The average glucose, fructose and total organic acid contents of the fruit were 5.85 $g.100\ g^{-1}$ FW, 4.89 $g.100\ g^{-1}$ FW and 1.02 $g.100\ g^{-1}$ FW, respectively. The fruits were characterised by a high content of total polyphenols (6.89 g GAE.100 g^{-1} DM), of which almost 45% were anthocyanin dyes with an average content of 3.05 g CGE.100 g^{-1} DM. The content of total polyphenols and anthocyanins decreased in the prepared products due to processing and heat treatment. The content of total polyphenols in the prepared products ranged from 3.32 to 5.53 g GAE.100 g^{-1} DM and the content of total anthocyanins from 1.14 to 2.40 g CGE.100 g^{-1} DM. Statistically significant ($p<0.05$) the highest content of total polyphenols was retained in the pasteurized chokeberry juice and the lowest content in the roasted chokeberry tea. The highest content of total anthocyanins remained statistically significant ($p<0.05$) in pasteurized chokeberry juice and chokeberry puree and statistically significant ($p<0.05$) lowest in roasted chokeberry tea. Despite the decrease in the polyphenolic content of products prepared from chokeberry, these products are characterised by a high content of bioactive substances and chokeberry is a raw material suitable for the production of value-added foods.

Keywords: chokeberry, chokeberry products, total polyphenols, anthocyanins

INTRODUCTION

Aronia (*Aronia melanocarpa* [Michx] Elliot) is a perennial shrub native to North America from where it has spread throughout the world, but especially to countries in Central and Southeastern Europe such as Croatia, Serbia, Bulgaria, Romania, Poland and Germany, and also to Southeast Asia **(Gerasimov *et al.*, 2023; Negreanu-Pirjol *et al.*, 2023)**. Studies on the healthy effects of chokeberries fit in with current nutrition trends and increased consumer interest in healthy diets and lifestyles. Black chokeberry fruits have high antioxidant potential and often outperform other fruit species with which they are compared in scientific papers **(Strugała *et al.*, 2016)**. Compared to other fruits, chokeberry contains relatively small amounts of vitamin C, but is rich in polyphenols **(Danielczuk, 2003)**. As consistently reported by **Oszmiański & Lachowicz (2016)** and **Tolić *et al.* (2015)** the determining compounds of high biological potential of chokeberry are polyphenols, especially proanthocyanidins, anthocyanins, flavonoids, and phenolic acids. Proanthocyanidins, also called condensed tannins or tannins, are represented in chokeberry by dimers of catechins and epicatechins, form the main group of phenolic compounds of chokeberry, and are responsible for the astringent flavor of chokeberry, which gradually disappears during fruit ripening **(Naruszewicz *et al.*, 2007; Kokotkiewicz *et al.*, 2010)**. The dark blue colour of the chokeberry fruit is due to the presence of anthocyanins, which represent 25-41% of the total polyphenols. Cyanidin-3-galactoside has been cited as the main anthocyanin of chokeberries. In addition to it, cyanidin-3-arabinoside, cyanidin-3-glucoside and cyanidin-3-xyloside are found in fruits **(Šavikin *et al.*, 2014; Veberic *et al.*, 2015; Jurikova *et al.*, 2017)**. Among phenolic acids, neochlorogenic acid, chlorogenic acid dominate, caffeic acid and its derivatives and ellagic acid are represented in smaller amounts. Phenolic acids are present in the fruits of chokeberry in an average amount of 96 $mg.kg^{-1}$ **(Mattila *et al.*, 2006; Jakobek *et al.*, 2012; Oszmiański & Lachowicz, 2016)**. Flavonols of black chokeberry belong to a broad group of compounds that mainly consist of quercetin derivatives, namely quercetin-3-rutinoside, quercetin-3-galactoside and quercetin-3-glucoside. However, their content in fruits is low compared to phenolic acids and anthocyanins **(Oszmiański & Wojdylo, 2005; Kulling & Rawel, 2009; Tian *et al.*, 2017)**. In addition to polyphenols, chokeberries contain other bioactive compounds including vitamins, carotenoids, tannins, pectins, organic acids, proteins, carbohydrates and minerals. The most important of these are vitamins (C and E), carotenoids and minerals (iodine, potassium, calcium and magnesium). Aronia berries also contain fibre. Aronia seed oil is rich in phospholipids, sterols and tocopherol fractions **(Skupień, 2007; Borowska & Brzóska, 2016)**.
Already Native Americans used different parts of the chokecherry plant to prepare a tea, which was used to treat colds, or the bark, which is characterized by its astringent effects **(Kulling & Rawel 2009; Kokotkiewicz *et al.*, 2010)**. In the 20th century, the popularity of chokeberry increased due to numerous scientific studies that confirmed its beneficial effects on health. The medicinal and therapeutic effects include hypoglycemic, hepatoprotective, antioxidant and anti-inflammatory effects. Aronia helps in the treatment of varicose veins and hemorrhoids and alleviates symptoms of the aging process **(Kokotkiewicz *et al.*, 2010; Lupascu *et al.*, 2019)**. Aronia berries have been shown to exhibit antimutagenic properties, contributing to reducing the risk of cardiovascular disease **(Kokotkiewcz *et al.*, 2010; Gao *et al.*, 2024)**. Consumption of chokeberries has also been correlated with positive effects on problems related to elevated cholesterol and triglycerides in the blood **(Valcheva-Kuzmanova *et al.*, 2007)**. Other studies have demonstrated the antidiabetic properties of the berries and have been recommended in the prevention and even control of diabetes **(Simeonov *et al.*, 2001)**. Phenolic compounds present in chokeberry fruits show antimutagenic activity **(Gasiorowski *et al.*, 1997)**, several studies have shown antiproliferative effect against various tumor cells **(Bermúdez-Soto *et al.*, 2007)**, hepatoprotective effects have been confirmed in animal experiments **(Valcheva-Kuzmanova *et al.*, 2007)**. Aronia fruit juice shows bacteriostatic activity against various microbial strains such as *Staphylococcus aureus* or *Escherichia coli* **(Valcheva-Kuzmanova *et al.*, 2007)**.

Due to its high content of health-promoting substances, chokeberry is currently used as a functional food and processed into various forms. Fresh, unprocessed chokeberry fruits are rarely consumed due to their astringent taste, but are processed in the food industry into juices, nectars, syrups, jams, wines, fruit teas and dietary supplements **(Vagiri & Jensen, 2017; Bednarska & Janiszewska-Turak, 2020; Zhang *et al*., 2021; Kaloudi *et al*., 2022)**. Traditional foods such as honey, dairy products, confectionery, tea but also coffee are fortified with aronia. The pomace, as a recoverable waste, can be incorporated into products of the food or pharmaceutical industry **(Kitryté *et al*., 2020)**. **Raczkowska *et al.* (2022)** conducted a study in which they added dried chokeberry pomace at 10, 30 and 50% to shortbread. **Cacak-Pietrzak *et al.* (2023)** in their experiment enriched wheat bread with black chokeberry pomace at 1-6% and evaluated the physicochemical and sensory properties of the bread.

Arslan *et al.* (2015) report that anthocyanins are stable compounds under normal conditions, their stability is enhanced by acidic pH, but during processing and storage they decompose to colourless compounds and subsequently to insoluble brown pigments. **Demirdöven *et al.* (2016)** report that temperature is the most important factor that causes the decomposition of anthocyanins. **Castaneda-Ovando *et al.* (2009)** found that anthocyanin pigments are rapidly degraded during heat processing, which can have a dramatic effect on the colour quality and nutritional properties of the product. There are several studies dealing with the effect of heat processing on the colour content of fruits. **Zorenc *et al.* (2017)** report that the degradation of anthocyanins occurs when the ambient temperature exceeds 50°C. Due to instability, anthocyanins are broken down into the sugar component and anthocyanidin, which can lead to a dark colour of the product. **Wu *et al.* (2018)** report that the degradation of anthocyanins is influenced by the pH of the environment along with the temperature. The degradation of anthocyanins increases as the pH of the environment increases. Overall, it is clear that thermal processing affects the stability of polyphenols in aronia, making it important to optimize processing conditions to preserve as many of these valuable compounds as possible. The choice of processing method and its parameters, such as temperature, time, and pH, plays a crucial role in maintaining the antioxidant properties of aronia in final products.

The aim of the work was to compare the quality of fruits of black chokeberry varieties Nero and Galicjanka, which are the most widespread widespread planted in Slovakia, and to prepare different canned products from chokeberry and evaluate them in terms of the content and retention of the total content of polyphenols and anthocyanin dyes.

MATERIAL AND METHODS

Plant material and growing locations

In this work we used the Galicjanka and Nero varieties. The variety Galicjanka was grown on the plantations in Giraltovce. The variety is characterised by large malvica and outperforms the traditional variety Nero in yield by 20%. The surface of the juicy malvicais finely shaded. It is a suitable variety for mechanised harvesting because of its even ripening. The Giraltovce area is situated in the southern part of the Low Beskid Mountains, in the north-east of Slovakia, at the confluence of the Topľa and Radomka rivers. The altitude of the area is 370 m above sea level, the surface of the area is flat in the western part and slightly undulating to rugged in the eastern part. The average temperature during the year is around 8°C and the annual rainfall is 600-700 mm. The soil in the area is derived from Tertiary flysch (sandstones and claystones) and Quaternary alluvial deposits of sand, gravel, clay and slope clay. The variety Nero was grown in the Research Institute of Fruit and Ornamental Trees in Bojnice. The fruits of this variety are smaller, up to 10 mm in size and arranged in dense clusters. The flesh of the fruit is juicy with a bitter-sweet taste and a relatively thick skin. The fruit is characterised by a long shelf life, lasting up to 2 months fresh after harvesting. The juice of the fruit is crimson red in colour. The town of Bojnice is situated in the central part of the Hornonitrian Basin at the foot of the Malá Magura Mountains, on the right bank of the Nitra River at an altitude of 291 m above sea level. Average annual temperatures range from 8-9.5°C, while average annual rainfall ranges from 613-718 mm. Soil types in the area are dominated by loamy, sandy loam and, locally, sandy loam and clay loam.

Aronia processing

Fruits harvested at full maturity were analysed fresh for soluble solids, total sugars, glucose, fructose, total acids and pH. The content of total polyphenols and anthocyanin dyes in the fruits was determined spectrophotometrically. The fruits of the Galicjanka variety were subsequently processed into various products, namely pasteurized chokeberry juice, chokeberry puree, chokeberry jam and jelly, chokeberry jam with reduced sucrose content, dried chokeberry fruit, dried chokeberry puree and roasted chokeberry tea.

The fruits intended for the production of products were washed and stripped of their stems and bunches. Part of the fruit was pressed on a table hydraulic press NEREZ - HYDRAULIC 18L/2t. After pressing, the juice was left to drain in a static way and the clean drained juice was used for evaluation and further production. The aronia juice was pasteurized at 82°C for 3 minutes. The unpasteurised juice was used as a semi-finished product for the production of aronia jelly. The heat-treated fruit was used for the production of aronia puree. The heat treatment was carried out in a water bath at 100°C for 3 minutes after reaching the desired temperature. The fruits were poured into boiling water, cooled with cold water after reaching the desired temperature and heat endurance, and then passaged on a ROBOT CUBE C80 passer with a 0.5 mm mesh opening. Aronia puree was the final product and also a semi-finished product for the production of aronia jams and dried aronia puree. To produce roasted chokecherry tea, we used whole fruit, striped of the remaining stems and bunches.

Chokeberry spreads - chokeberry jam and chokeberry jelly were prepared in accordance with Decree 44/2012 of the Ministry of Agriculture and Rural Development of the Slovak Republic on fruit jams, jellies, marmalades and sweetened chestnut puree in the quality class Extra jam. Decree 44/2012 lays down the minimum refractometric dry matter of the finished product (min. 60%), the acid content is not laid down in the standard, the addition of acids is determined on the basis of a sensory evaluation of the finished product. The proportion of fruit in 'extra' quality spreads must be at least 350 g in 1 kg of finished product. We have used puree of the fruit to make chokeberry jam and chokeberry juice to make chokeberry jelly. The other raw materials used for the spread were sucrose and citric acid. We calculated the recipes of the spreads as a mass balance of the dry matter of the raw materials used in the production. For the production of chokeberry jam we used 520 g of chokeberry puree, 480 g of sucrose and 10 g of citric acid. For the production of reduced sucrose choke we used 750 g of choke puree and 350 g of sucrose and 10 g of citric acid. For the production of the chokeberry jelly we used 520 g of chokeberry juice, 480 g of sucrose and 10 g of citric acid.

For drying, we washed the fruits, chopped them and spread them in a thin layer on the drying sieves. A professional drying oven BIOSEC PRO was used for drying, the drying was carried out at a temperature of 40°C until the product reached an adjusted moisture content of 15±1%. The total drying time was 5 hours. We also used a BIOSEC PRO dryer to produce dried chokeberry puree, also known as chokeberry skin. The purée was applied in a 3 mm thick layer to a silicone drying mat and then to the dryer screens. The drying process was carried out at 40°C for 3 hours and the drying time was 16 hours in the open chamber of the dryer.

For the production of the roasted chokeberry tea, we used fresh black chokeberry fruit, which we partially chopped. The fruit, 1000 g, was then poured onto a sack, covered with 300 mL of water, sprinkled with 1 kg of sugar, and 10 cloves spices, 1 cinnamon bark slice 5 cm long and 2 pieces of star anise were added. The container was covered with aluminium foil to eliminate evaporation of water from the product. The heat treatment process was carried out in an electric hot-air oven at 150°C for 60 minutes.

Chemical analysis

Infrared spectroscopy was used to determine soluble solids, sugars, organic acids and pH. The determination was carried out using an ALPHA analyser from Bruker Optik GMBH. The ALPHA analyzer is used for the rapid analysis of wines, ciders and fruit and vegetable juices. For the analysis we used a calibration for juices, filtered and centrifuged chokeberry juice, which was applied to the measuring head of the analyzer using an applicator, where the sample was tempered to 40°C and then analyzed.

Determination of total polyphenols was carried out spectrophotometrically using Folin-Ciocalteu reagent. The principle of the method is based on the reaction of Folin-Ciocalteu reagent with polyphenols contained in the analyzed sample to form a blue complex. The intensity of the blue colour is directly proportional to the polyphenol content. The evaluation of the total polyphenol content is carried out using a spectrophotometer, at a wavelength of 700 nm **(Singleton *et al*., 1999)**. The workflow involved the preparation of extracts from fresh fruits and chokeberry products, which consisted of thorough homogenization of 25 g of sample followed by extraction on a shaker at 150 min^{-1} for 20 h in 50 mL of distilled water. For the determination of total polyphenols, 0.5 ml of the extract was pipetted into a 50 ml volumetric flask, 0.5 ml of Folin- Ciocalteu reagent and 5 mL of 20% Na_2CO_3 solution were added. Subsequently, we made up the volume of the flask with distilled water. After thorough stirring and stabilization in a dark room for 15 minutes, we measured the absorbance at 700 nm against the blank. We calculated the content of total polyphenols from the gallic acid calibration curve.

Determination of anthocyanin dye content was also performed spectrophotometrically by the pH differential method. The principle of the method for the determination of anthocyanin dyes is to reduce the pH of the extract to between 0.5 and 0.8 which is associated with the transformation of all anthocyanins to the red colored flavin cation **(Lee *et al*., 2005)**. We used the same extract for the determination as for the determination of total polyphenols. We pipetted 1 ml of extract and 1 ml of 0.01% HCl in 80% ethanol into two test tubes. We then added 10 ml of a 2 % aqueous HCl solution to the first tube and 10 mL of a buffer solution at pH 4.5 (c (0.2 $mol.dm^{-3}$) Na_2HPO_4 and c (0.1 $mol.dm^{-3}$) citric acid) to the second tube. The absorbance of the samples was measured spectrophotometrically at wavelengths of 520 and 700 nm and then the total anthocyanin content was calculated according to the formula TA = (A. MW.Df.10^3) / (ε. l) (mg cyanidin-3-glucoside equivanets. g^{-1}), where A- absorbance = ($A_{520\ nm}$ - $A_{700\ nm}$)pH 1.0 - ($A_{520\ nm}$ - $A_{700\ nm}$)pH 4.5; MW- molecular weight (449.2 g mol^{-1} for cyanidin-3-glucoside;

Df- is the dilution factor, 10^3 - conversion factor from g to mg; l - length of the cuvette; ε - molar extinction coefficient (26,900 $l.mol^{-1}.cm^{-1}$).

Statistical analysis

The experiment was conducted in three repetitions. Data were evaluated using one-way analysis of variance (ANOVA) followed by post hoc analysis of statistically significant differences between chokeberry products using LSD multiple range test **(Statistica 12, Statsoft)**, assuming that differences were statistically significant at α=0.05

RESULTS AND DISCUSSION

The chemical composition of chokeberry fruit is influenced by several agroclimatic factors, including growing location, soil, climatic conditions such as temperature and rainfall, but also fruit maturity and storage conditions or processing method **(Tolić *et al*., 2015; Kulling & Rawel, 2009)**. In this work, we used the Galicjanka and Nero varieties for fruit analysis. The results are presented in Table 1.

Table 1 Composition of the fruits of the black chokeberry varieties Galicjanka and Nero

varieties	total dry matter (%)	soluble solids (°Brix)	total sugars ($g.100\ g^{-1}$)	glucose ($g.100\ g^{-1}$)	fructose ($g.100\ g^{-1}$)	pH	total acids ($g.100\ g^{-1}$)	total polyphenols (g GAE.100 g^{-1} FW)	total anthocyanins (g CGE.100 g^{-1} FW)
Galicjanka	22.38a	21.84a	19.29a	5.47a	4.82a	3.18a	1.11b	1.23a	0.54a
Nero	24.63b	23.76b	20.13b	6.23b	4.97b	3.26a	0.93a	1.82b	0.80b

FW - fresh matter, GAE - gallic acid equivalent, CGE - cyanidin-3-glucoside equivalent

The dry matter of the chokeberry fruit was 22.38% in the Galicjanka variety and 24.63% in the Nero variety. The Nero variety had statistically significantly ($p<0.05$) higher values than the Galicjanka variety in other monitored parameters, with the exception of total acid content.The total dry matter content of the fruit has been studied by several authors, who report values of total dry matter content ranging from 15.30% to 30.76%. The location and growing conditions of aronia may also influence the given fact. The planting of the Nero variety is located at a lower altitude and in a warmer area. **Ochmian *et al*. (2012)** focused their work on the comparison of 4 chokeberry varieties, namely Galicjanka, Hugin, Nero and Viking, grown at the University of Szczecin, Poland. The authors found that the lowest dry matter content was achieved by the Viking variety (15.3%) and the highest by the Hugin variety (19.5%). The dry matter content of the Nero variety was 15.7% and that of the Galicjanka variety 17.8 %, which are lower than the values found in our research. **Andrzejewska *et al.* (2015)** studied the dry matter content in the Galicjanka cultivar, evaluating the effect of bush age on fruit quality parameters. In their work, the authors found fruit dry matter content ranging from 23.2% to 26.0%, showing that fruit from older bushes (16-17 years old) had statistically significantly higher dry matter content than fruit from bushes aged 6-7 and 11-12 years. The reported dry matter values of chokeberry fruits by **Andrzejewska *et al.* (2015)** agree with our values. **Skupien *et al.* (2008)** focused on foliar fertilization of chokeberry with fertilizer containing N, K, Si and Mn and in their work they showed an increase in fruit dry matter content after fertilization to values of 18.92-20.14%. However, the authors state that climatic conditions of a given year, especially the amount of rainfall, have a more significant effect on dry matter content than fertilization. **Trenka *et al.* (2020)** compared the quality of fruit of the Galicjanka variety from conventional and organic farming and, in the case of total dry matter content, the authors also point out that climatic conditions have a greater influence on dry matter content than the effect of cultivation. The dry matter content of fruit grown in the Kraków area was 23.8-26.5%, which is comparable to our results.

The soluble solids content of the fruits in our work was found to be 21.84% and 23.76% in the Galicjanka and Nero varieties, respectively. The soluble solids content was monitored by **Ochmian *et al.* (2009)**, who in their work compared the quality of red fruits of different fruit types. In their experiment, they used black chokeberry, black elderberry, cranberry and chocholate blueberry, ground elderberry and black raspberry. The dissolved solids content of the species ranged from 7.4% (blackberry) to 16.0% (chokeberry), but this was lower than the dissolved solids content in our experiment. The soluble solids in the work of **Ochmian *et al.* (2012)** ranged from 14.2% to 18.7%. The authors report a soluble solids content of 16.6% in the Galicjanka variety and 14.4% in the Nero variety, in both cases lower than the values in our research. **King *et al.* (2021)** monitored changes in soluble solids content during fruit ripening and found that dry matter content increased from 13.0 to 21.0% during the 6 weeks of monitoring. **Tolić *et al.* (2015)** investigated the soluble solids content of chokeberry juice as a soft drink. Samples of commercially available juices were from Germany, Serbia, Croatia, Bulgaria and Poland and ranged in soluble solids content from 13.42 to 21.54%. The product from Croatia had the highest soluble solids content, followed by the juice from Bulgaria (19.98 %)

Kulling & Rawel (2009) reported that sorbitol, glucose and fructose are the predominant carbohydrates in chokeberry fruit. In their study, the authors report that the total carbohydrate content of chokeberry fruit is 6.21-20.92%, sorbitol 8.56%, fructose 1.38-4.71%, glucose 1.09-5.70%. In our research we found total sugars content of 19.29 $g.100\ g^{-1}$ (Galicia) and 20.13 $g.100\ g^{-1}$ (Nero). In terms of glucose and fructose content, we found higher glucose content. Our results are comparable with those of **Kulling & Rawel (2009)**. The carbohydrate content of chokeberry fruit was also evaluated by **Nawirska-Olszańska *et al.* (2020)** and found sorbitol (11.51%) as the dominant carbohydrate in fresh chokeberry fruit, followed by glucose (7.10%) and fructose (5.78%). The authors found non-detectable amounts of sucrose in the fruits. **Andrzejewska *et al.* (2015)** in their work reported a reducing carbohydrate content of 8.0-8.8% in the Galicjanka cultivar. **Ochmian *et al.* (2012)** found the content of total sugars in chokeberry in the values of 9.1-13.79%, the highest content was found in the Hugin variety. They found a content of 12.92% and 10.25% in the variety Galicjanka and Nero, respectively, which are lower than the values found in our research. **Sasmaz *et al.* (2024)** investigated the carbohydrate content of chokeberry fruits of Nero and Viking cultivars grown in the Turkish provinces of Bursa, Trabzon, Kırşehir Viking and Kirklareli. They found glucose and fructose contents of the fruits ranging from 2.3-6.21 $g.100\ g^{-1}$ and 3.11-5.23 $g.100\ g^{-1}$, respectively. Low values of total sugars were detected in the Trabzon area (9.89 $g.100\ g^{-1}$), while the highest values were reached by fruits grown in the Bursa (18.62 $g.100\ g^{-1}$) and Kirsehir (18.96 $g.100\ g^{-1}$) areas. The observed values are comparable with our results.

The pH of the chokeberry juice in our research was 3.18 in the Galicjanka variety and 3.26 in the Nero variety. The organic acid content was 0.93 $g.100\ g^{-1}$ in the Nero variety and 1.11 $g.100\ g^{-1}$ in the Galicjanka variety. **Tolić *et al.* (2015)** found pH values of 3.54-3.92 in commercially available juices, which are higher than in our research. The organic acid content in the work of **Tolić *et al.* (2015)** ranged from 0.29-1.32%, which are values lower than in our research. The highest content of organic acids in the work of **Tolić *et al.* (2015)** was in juice originating from Croatia, which was characterized by the highest soluble solids content. **Ochmian *et al.* (2009)** reported an organic acid content of 1.42% in chokeberry, a value comparable to that of *Vaccinium myrtillus* from the authors' research. In the work of **Trenka *et al.* (2020)**, the organic acid content reached values of 0.93-1.29%, with statistically significantly higher values of organic acids in samples grown in organic farming. **Ochmian *et al.* (2012)** report an organic acid content of 0.75% in the Galicjanka sample and 0.8% in the Nero variety, values slightly lower than in our experiment. **King *et al.* (2021)** monitored changes in pH and organic acids during fruit ripening and found that pH values increased from an initial value of 3.2 to 3.33 and organic acid content decreased from an initial value of 1.75 to 1.59%.

According to several authors, the fruits of chokeberries are interesting in particular for the presence of a wide range of biologically active substances, the most important of which are polyphenolic substances, including anthocyanin dyes. In our work, we evaluated the content of total polyphenols, which was lower in the Galicjanka variety than in the Nero variety. The content of total polyphenols was 1.23 g GAE.100 g^{-1} FW in the Galicjanka cultivar and 1.82 g GAE.100 g^{-1} FW in the Nero cultivar. The anthocyanin content was 0.64 g CGE.100 g^{-1} FW in Galicjanka and 0.8 g CGE.100 g^{-1} FW in Nero. The analysis of total polyphenol content was also carried out by **Jakobek *et al.* (2012)** and by comparing Galicjanka, Nero, Viking and Wild varieties, they found the highest total polyphenol content in Wild variety (1.44 g GAE.100 g^{-1} FW). In the Nero cultivar the authors report a total polyphenol content of 1.37 g GAE.100 g^{-1} FW and in the Galicjanka cultivar 1.04 g GAE.100 g^{-1} FW, which are lower values than in our research, but comparable to the results of **Jakobek *et al.* (2012)**. The content of total anthocyanins in the work of **Jakobek *et al.* (2012)** ranged from 0.14 g CGE.100 g^{-1} FW in the Galicjanka cultivar to 0.27 g CGE.100 g^{-1} FW in the Wild cultivar. In the variety Nero, the authors report a total anthocyanin content of 0.22 g CGE.100 g^{-1} FW. The values reported by the authors are significantly lower than our values. The analysis of the total anthocyanin content of chokeberry fruits was also carried out by **Andrzejewska *et al.* (2015)** and they detected a content of 0.63-0.77 g CGE.100 g^{-1} FW in fruits of the Galicjanka cultivar, which are values comparable to our findings. Similarly, **Ochmian *et al.* (2009)** investigated the content of total polyphenols and anthocyanins in chokeberry and other dark fruits and found the highest content of total polyphenols in chokeberry (0.67 g GAE.100 g^{-1} FW) and the second highest content of total anthocyanins (0.53 g CGE.100 g^{-1} FW), which are, however, values lower than in our work. In the work of **Ochmian *et al.* (2012)**, the authors compared the quality of 4 black chokeberry cultivars reporting total polyphenol contents of 1.85 g GAE.100 g^{-1} FW in the Viking cultivar to 2.34 g GAE.100 g^{-1} FW in the Hugin cultivar. In the variety Nero the authors report a content of 1.95 g GAE.100 g^{-1} FW and in the variety Galicjanka 2.19 g GAE.100 g^{-1} FW, which, especially in the case of the variety Galicjanka, is higher than the value we found in our research. **King *et al.* (2021)** report a gradual increase in both total polyphenols and anthocyanins during fruit ripening. The content of total polyphenols increased from 1.59 g GAE.100 g^{-1} FW to 1.95 g GAE.100 g^{-1} FW in the fruit during 6 weeks, an increase of 22.6%. The content of total anthocyanins increased from 0.18 g CGE.100 g^{-1} FW to 0.23 g CGE.100 g^{-1} FW, an increase of 27.8 %. **Trenka *et al.* (2020)** report a total polyphenol content of 2.29-2.6 g GAE.100 g^{-1} FW in chokeberries, with statistically significantly higher content in fruits from organic farming. **Oszmianski & Wojdylo (2005)** in their study monitored the contribution of anthocyanin content to the total polyphenol content and reported that this contribution was 66%. In our research, the average proportion of total anthocyanins to total polyphenols content was 44.3%, which is lower than the value reported by the authors.

In the second part of the research, we focused on the processing of chokeberry fruit and the evaluation of the stability and loss of total anthocyanins and polyphenols content that occurs during processing. Heat treatment was used in the production of all products. Aronia juice was pasteurised at 82°C, berries for puree production were heat treated at 100°C, fruit spreads reached a temperature of 103°C during the boiling of the products, baked tea was prepared at 150°C and dried products were dried at a temperature of 40-50°C.

Sadilova *et al.* (2006) reported that degradation of black elder anthocyanins at a treatment temperature of 95°C resulted in a loss of up to 50%. Similar degradation of anthocyanins in blueberry juice was found by **Kechinski *et al.* (2010)**. **Brownmiller *et al.* (2008)** monitored changes in anthocyanins in blueberry puree treated with pasteurization temperatures and found a 43% loss of pigments. **Patras *et al.* (2009)** reported that treatment at 70°C significantly affected cyanidin-3-glucoside and pelargonidin-3-glucoside in blackberry and strawberry puree. **Szalóki-Dorkó *et al.* (2015)** investigated the changes of cyanidin-3-glucosyl-rutinoside and cyanidin-3-rutinoside content in sour cherry juice during heat treatment at treatment temperatures of 70, 80 and 90°C. The authors found the greatest loss of anthocyanins at 90°C, while treatments at 80 and 70°C caused less thermal degradation. The loss of anthocyanins in the juice of the Kántorjánosi variety was up to 46% at 90°C. The experiment also showed that cyanidin-3-rutinoside was more resistant to heat than cyanidin-3-glucosyl-rutinoside. **Yildiz *et al.* (2022)** compared the effect of heat and microwave treatment on cherry juice. In their work, they used treatment temperatures of 70-75°C, 90-95°C and microwave treatment at 2450 MHz, 400 W power. The authors found that all treatments caused changes in juice quality, but these were not statistically significant for anthocyanin content and antioxidant activity; changes were only evident for total polyphenol content. The authors concluded that the bioactive components are significantly better preserved in home-made cherry juice produced in the microwave, and there is also a lower production of hydroxymethylfurfural, resulting in a higher quality product from a food safety point of view.

Table 2 Evaluation of the content of total polyphenols and anthocyanins in chokeberry products

product	total dry matter (%)	total anthocyanins		total polyphenols	
		g CGE.100 g^{-1} FW	g CGE.100 g^{-1} DM	g GAE.100 g^{-1} FW	g GAE.100 g^{-1} DM
fresh chokeberry	24.36	0.81	3.32±0.11f	1.78	7.29±0.05f
chokeberry juice	22.38	0.54	2.40±0.12e	1.23	5.53±0.07e
chokeberry puree	23.52	0.55	2.35±0.09e	1.24	5.27±0.16d
chokeberry jam	64.21	1.02	1.59±0.01bc	2.22	3.46±0.05b
reduced sucrose choke jam	64.23	0.97	1.51±0.07ab	2.24	3.49±0.06b
chokeberry jelly	63.69	1.00	1.58±0.15bc	2.24	3.56±0.12b
dried chokeberry	84.48	1.48	1.75±0.08d	3.28	3.88±0.06c
dried chokeberry purée (skin)	80.24	1.35	1.68±0.08cd	3.12	3.89±0.09c
roasted chokeberry tea	48.78	0.69	1.41±0.01a	1.62	3.32±0.04a

FW - fresh matter, DM - dry matter, GAE - gallic acid equivalent, CGE - cyanidin-3-glucoside equivalent, ± standard deviation, a-f homogeneous group, different letters at mean represent statistically significant differences among treatments (p<0.05)

The processing of chokeberry into chokeberry products resulted in the degradation of anthocyanins and polyphenols in all products, which we perceived through the reduction of the values of total anthocyanins and total polyphenols. Table 2 shows the content of total anthocyanins and total polyphenols. In the case of the chokeberry spread and the baked fruit tea, the content is converted to 100% of the fruit component. Statistically significant ($p<0.05$) the highest content of total polyphenols was retained in pasteurised chokeberry juice. Statistically significant ($p<0.05$) the highest content of total anthocyanins was retained in pasteurised chokeberry juice and chokeberry puree. In the case of these products, a short heat treatment of maximum 3 minutes at 82-100°C was used. In the aronia juice, 72.4% of the total anthocyanins and 70.9% of the total polyphenols were retained; in the aronia puree, 70.9% of the total anthocyanins and 72.3% of the total polyphenols were retained.

A decrease in the content of total polyphenols and anthocyanins of about 50% was observed in the production of dried chokeberry and chokeberry skin. The temperature used was 50°C and the exposure time was 5 hours for dried chokeberry and 3 hours for chokeberry skin and 16 hours for drying under normal atmosphere conditions. The content of total polyphenols in these products decreased on average by 46.75% and the content of total anthocyanins by 48.2%. No statistically significant ($p>0.05$) differences in total polyphenols and anthocyanins were found between dried chokeberry fruit and dried chokeberry puree.

On average, 47% of the total anthocyanins and also of the total polyphenols were preserved in the prepared chokeberry spreads. The content of total anthocyanins in the chokeberry jam and jelly at a fruit component content of 52% was 0.83 g CGE.100 g^{-1} DM and 0.82 g CGE.100 g^{-1} DM, respectively. In the sucrose-reduced chokeberry jam at 75% fruit component, the total anthocyanin content was 1.13 CGE g.100 g^{-1} DM. The content of total polyphenols was 1.80 g GAE.100 g^{-1} DM and 2.51 g GAE.100 g^{-1} DM in the sucrose-reduced chokeberry jam and 1.85 g GAE.100 g^{-1} DM in the aronia jelly. For statistical comparisons, we used values converted to 100% fruit component. In terms of total polyphenol content, the chokeberry spread samples formed a separate homogeneous group and we did not find a statistically significant difference between the spreads ($p>0.05$). A similar situation occurred in terms of the content of total anthocyanins in the chokeberry spreads, where no statistically significant difference was confirmed between the samples ($p>0.05$). Statistically significant ($p<0.05$) the lowest content of total anthocyanins (1.41 CGE g.100 g^{-1} DM) and total polyphenols (3.32 g GAE.100 g^{-1} DM) was found in roasted chokeberry tea, in which 42.5% of total anthocyanins and 45.6% of total polyphenols were retained. The study confirmed that, in terms of preserving the content of biologically valuable polyphenols and anthocyanins in aronia products, it is advisable to use a short heat treatment. Prolonged heat treatment during the production of aronia jams, dried aronia, and baked aronia tea resulted in higher degradation of total polyphenols and anthocyanins. For this reason, we suggest that, if the production technology allows, only quick heat treatment should be used during processing.

The evaluation of the content of total polyphenols and anthocyanins in commercially available juices and dried fruits of chokeberry was conducted by **Tolić *et al.* (2015)**. In their work, the authors found the content of total polyphenols in chokeberry juice ranging from 3.0 g GAE.100 g^{-1} DM to 6.64 g GAE.100 g^{-1} DM. The lowest content was found in juice originating from Croatia and the highest in juice originating from Serbia, which also reached the highest organic acid content. In the case of anthocyanin content, the authors found a wider range of values, such as 0.15-1.23 g CGE.100 g^{-1} DM. The authors found the highest total anthocyanin content in juice from Germany, which, however, was among the samples with lower total polyphenol content. Compared with our study, the authors found lower total polyphenols and anthocyanins in chokeberry juices, but they do not report the processing method of the fruit or the length and storage conditions of the product. In dried fruit, the authors found an average content of 2.2 g GAE.100 g^{-1} DM of total polyphenols and 0.14 g GAE.100 g^{-1} DM of total anthocyanins, which are lower than the values found in our research. **Bo *et al.* (2018)** prepared a chokeberry puree and treated the product by gassing, applying high pressures from 200 to 600 MPa. Chokeberry fruits were frozen but not heat treated before processing. The authors even found an increase in the content of total polyphenols and anthocyanins in the puree treated in this way. In the untreated control sample they found a total polyphenol content of 0.92 g GAE.100 g^{-1} FW and in the puree treated with 400 MPa pressure for 5 min a content of 1.4 g GAE.100 g^{-1} FW. There was also an increase in the content of total anthocyanins, where the initial content in the control sample (0.32 g CGE.100 g^{-1} FW) increased to 0.38 g CGE.100 g^{-1} FW with the same treatment method. Pascalisation is considered as an alternative method to pasteurisation and has the advantage that it does not expose the fruit to heat, thus eliminating the degradation of bioactive compounds. **Banaś *et al.* (2018)** prepared gooseberry jams enriched with raw materials of high biological value where, among others, they used aronia in the amount of 15%. The authors found that gooseberry jams enriched with chokeberry had the highest content of total polyphenols and anthocyanins compared to jams with the addition of elderberry, quince or linseed. These values were 330 mg GAE.100 g^{-1} FW and 35 mg CGE. 100 g^{-1} FW. The authors also monitored changes in the composition of the jams during storage and found that anthocyanins were the most sensitive constituents. The authors' results are lower than we found in our research, the reason being the combination of aronia with gooseberry. A similar study was also conducted by **Wojdylo *et al.* (2013)**, the authors enriched chokeberry jam with chokeberry and their aim was to increase both the colour attractiveness and the biological value of the jams. **Catana *et al.* (2017)** reported that due to the nutritional potential of chokeberry fruit and its short availability during the year, it is important to process chokeberry fruit into a variety of products. In their work, the fruits were frozen, dried and made into jam and compote. The authors found a total polyphenol content of 1.46 g GAE.100 g^{-1} FW in fresh chokeberry fruit, and a similar content of 1.31 g GAE.100 g^{-1} FW in frozen fruit. The highest content of total polyphenols, also due to the high dry matter content, was found in dried fruits at 4.02 g GAE.100 g^{-1} FW, this value is lower but comparable to our results. The authors found the lowest content of total polyphenols in the aronia compote with 55% fruit content, 0.6 g GAE.100 g^{-1} FW. **Samoticha *et al.* (2016)** conducted a study in which they investigated the changes in anthocyanin content in chokeberry fruit after different drying methods. Based on the analyses, the authors reported that conventional drying of fruits at 60°C resulted in a decrease in anthocyanin dyes from 3.92 g CGE.100 g^{-1} DM to 0.78 g CGE.100 g^{-1} DM. After vacuum drying, the dyes decreased to 1.82 g CGE.100 g^{-1} DM and after freeze-drying to 2.23 g CGE.100 g^{-1} DM. The authors report that drying leads to a loss of anthocyanins ranging from 43-80% depending on the drying method. In our research, we found a 48% reduction in total anthocyanin content

Ćujić *et al.* (2018) in their study demonstrated a beneficial effect of consumption of dried chokeberry extract on cardiovascular health. Subjects consumed an extract prepared from fruits dried at 40°C for 48 h, which contained 2.6 g CGE.100 g^{-1} DM of total anthocyanins and 5.52 g GAE.100 g^{-1} DM of total polyphenols.

CONCLUSION

The aim of the work was to evaluate the quality of fresh fruits of chokeberry varieties Galicjanka and Nero and to assess the stability of total polyphenols and anthocyanins content in chokeberry products such as chokeberry juice, puree, jam, jelly, jam with reduced sucrose content, dried chokeberry, dried puree and baked tea. The average dry matter content of the chokeberry fruit was 23.8 °Brix, the dry matter of the fruit was mainly composed of carbohydrates, the average content of which in the samples studied was 19.7%, of which the glucose content was 5.85 g.100 g^{-1} and the fructose content was 4.89 g.100 g^{-1}. Polyphenols, including anthocyanin dyes, are important antioxidant components of chokeberry. The total content of polyphenols and anthocyanins was higher in the Nero variety, reaching values of 7.4 g GAE.100 g^{-1} and 3.25 g CGE.100 g^{-1}. After processing of the fruits into chokeberry products, due to the effect of the applied heat treatment, there was a statistically significant ($p<0.05$) degradation of the content of polyphenols and anthocyanins. The content of total polyphenols in chokeberry products ranged from 3.32 to 5.29 g GAE.100 g^{-1} DM and the content of total anthocyanins ranged from 1.41 to 2.40 g CGE.100 g^{-1} DM. Statistically significant ($p<0.05$) the highest content of total polyphenols was retained in pasteurized chokeberry juice and statistically significant ($p<0.05$) the highest content of anthocyanins was retained in pasteurized chokeberry juice and chokeberry puree. Statistically significant ($p<0.05$) the lowest content of the studied components was in roasted chokeberry tea. Lower losses of both studied components, at the level of 24.8-27.7% of the content of total polyphenols and 27.6-29.1% of total anthocyanins, were observed in chokeberry juice and chokeberry puree during production. In the chokeberry spread, 51.7-52.6 % of the anthocyanin content and 51.2-54.4% of the total polyphenols were degraded. In the dried products, the content of total polyphenols decreased on average by 46.75% and the content of total anthocyanins by 48.2%. Despite these losses in total polyphenols and anthocyanins, black chokeberry products are characterised by a high content of bioactive components, making chokeberries a very important raw material for the production of healthful foods.

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REFERENCES

Andrzejewska, J., Sadowska, K., Klóska, Ł., Rogowski, L. 2015. The effect of plant age and harvest time on the content of chosen components and antioxidative potential of black chokeberry fruit. *Acta Scientarium Polonorum. Hortorum Cultus*, *14*(4), 105-114. ISSN 1644-0692

Arslan, D. 2015. Effects of degradation preventive agents on storage stability of anthocyanins in sour cherry concentrate. *Agronomy Research, 13*(4), 892-899. ISSN 1406-894X

Banaś, A., Korus, A., Tabaszewska, M. 2018. Quality assessment of low-sugar jams enriched with plant raw materials exhibiting health-promoting properties. Journal of Food Science and Technology, *55*(1), 408-417. https://doi.org/10.1007/s13197-017-2952-6

Bednarska, M.-A., Janiszewska-Turak, E. 2020. The influence of spray drying parameters and carrier material on the physico-chemical properties and quality of chokeberry juice powder. *Journal of Food Science and Technology*, *57*(1), 564-577. https://doi.org/10.1007/s13197-019-04088-8

Bermúdez-Soto, M. J., Larrosa, M., Garcia-Cantalejo, J. M., Espín, J. C., Tomás-Barberan, F. A., García-Conesa, M. T. 2007. Up-regulation of tumor suppressor carcinoembryonic antigenelated cell adhesion molecule 1 in human colon cancer Caco-2 cells following repetitive exposure to dietary levels of a polyphenol-rich chokeberry juice. *Journal of Nutritional-biochemistry*, *18*, 259-271. https://doi.org/10.1016/j.jnutbio.2006.05.003

Bo, Y., Mary-Grace, C. Danao M.-G., C., Stratton, J. E., Weier, S. A., Curtis L. Weller, C. L., Lu, M. 2018. High pressure processing (HPP) of aronia berry purée: Effects on physicochemical properties, microbial counts, bioactive compounds, and antioxidant capacities. *Innovative Food Science & Emerging Technologies*, *47*, 249-255. https://doi.org/10.1016/j.ifset.2018.03.009

Borowska S., Brzóska M. M. 2016. Chokeberries (*Aronia melanocarpa*) and Their Products as a Possible Means for the Prevention and Treatment of Noncommunicable Diseases and Unfavorable Health Effects Due to Exposure to Xenobiotics. *Comprehensive Reviews in Food Science and Food Safety*, *15*(6), 982-1017. https://doi.org/10.1111/1541-4337.12221

Bräunlich, M., Slimestad, R., Wangensteen, H., Brede, C., Malterud, K. E., Barsett, H. 2013. Extracts, anthocyanins and procyanidins from *Aronia melanocarpa* as radical scavengers and enzyme inhibitors. *Nutriens*, *5*(3), 663-678. https://doi.org/10.3390/nu5030663

Brownmiller, C., Howard, L., Prior, R. L. 2008. Processing and storage effects on monomeric anthocyanins, percent polymeric colour, and antioxidant capacity of processed blueberry products. *Journal of Food Science*; *73*(5), 72-79. http://doi.org/10.1111/j.1750-3841.2008.00761.x

Cacak-Pietrzak, G., Dziki, D., Gawlik-Dziki, U., Parol-Nadłonek, N., Kalisz, S., Krajewska, A., Stepniewska, S. 2023. Wheat Bread Enriched with Black Chokeberry (*Aronia melanocarpa* L.) Pomace: Physicochemical Properties and Sensory Evaluation. *Applied Sciences*, *13*(2), 6936. https://doi.org/10.3390/app13126936

Castaneda-Ovando, A., Pacheco-Hernandez, M. L., Paez-Hernandez, M. E., Rodriguez, J.A., Galan-Vidal, C. A. 2009. Chemical stability of anthocyanins: a review. *Food Chemistry*, *113*, 859-871. http://doi.org/10.1016/j.foodchem.2008.09.001

Catana, L., Catana, M., Iorga, E., Asanica, A. C., Lazar, A. G., Lazar, M. A., Belc, N. 2017. Vitamin C and total polyphenol content and antioxidant capacity of fresh and processed fruits of aronia melanocarpa. S*cientific papers-Series B-Horticulture*, *61*, 433-440, eISSN 2286-1580

Ćujić, N., Savikin, K., Miloradovic, Z., Ivanov, M., Vajic, U. J., Karanovic, D., Grujic-Milanovic, J. G., Jovovic, D., Mihailovic-Stanojevic, N. 2018. Characterization of dried chokeberry fruit extract and its chronic effects on blood pressure and oxidative stress in spontaneously hypertensive rats. *Journal of Functional Foods,* 44, 330-339. https://doi.org/10.1016/j.jff.2018.02.027.

Danielczuk, J. 2003. Aronia w przetworstwie spozywczym- własciwosci i kierunki wykorzystania. *Przemysł Fermentacyjny i Owocowo- warzywny*, *47*(12), 26-28. ISSN 0137-2645

Demirdöven, A., Erceyes, E., Erceyes, Ö. 2016. Vişne suyu konsantresi antioksidanlarinin üretim ve depolama süresince değişimleri, Gida, *41*(4), 213-220. https://doi.org/10.15237/gida.GD15069.

Gao, N., Shua, Ch., Wang, Y., Tian, J., Lang, Y., Jin, Ch., Cui, X., Jiang, H., Liu, S., Li, Z., Chen, W., Xu, H., Li, B. 2024. Polyphenol components in black chokeberry (*Aronia melanocarpa*) as clinically proven diseases control factors—an overview. *Food Science and Human Wellness*, *13*, 1152-1167. http://doi.org/10.26599/FSHW.2022.9250096

Gasiorowski, K., Szyba, K., Brokos, B., Kolaczynska, B. B., Wlodarczyk, M. J., Oszmianski, J. 1997. Antimutagenic activity of anthocyanins isolated from Aronia melanocarpa fruits. *Cancer Lett*. *119*(97), 37–46. https://doi.org/10.1016/S0304-3835

Gerasimov, M. A., Perova, I. B., Eller, K. I., Akimov, M. Y., Sukhanova, A. M., Rodionova, G. M., Ramenskaya, G. V. 2023. Investigation of Polyphenolic Compounds in Different Varieties of Black Chokeberry *Aronia melanocarpa*. *Molecules*. *2*(10), 4101. https://doi.org/10.3390/molecules28104101

Jakobek, L., Drenjančević, M., Jukić, V., Šeruga, M. 2012. Phenolic acids, flavonols, anthocyanins and antiradical activity of “Nero”, “Viking”, “Galicianka” and wild chokeberries. Scientia Horticulturae, *147*, 56-63. [online]. [cit. 2018-04-04]. https://doi.org/10.1016/j.scienta.2012.09.006

Jurikova, T., Mlcek, J., Skrovankova, S., Sumczynski, D., Sochor, J., Hlavacova, I., Snopek, L., Orsavova. J. 2017. Fruits of Black Chokeberry Aronia melanocarpa in the Prevention of Chronic Diseases. *Molecules*, *22*(3), 944. https://doi.org/10.3390/molecules22060944

Kaloudi, T., Tsimogiannis, D., Oreopoulou, V. 2022. *Aronia Melanocarpa*: Identification and Exploitation of Its Phenolic Components. *Molecules*. *27*(14), 4375. https://doi.org/10.3390/molecules27144375

Kechinski, C. P., Ramos Guimaraes, P. V., Zapata Norena, C. P., Tessaro, I. C., Ferreira Marczak, L. D. 2010. Degradation Kinetics of Anthocyanin in Blueberry Juice during Thermal Treatment. *JFC: Food Chemistry*, *75*(2), 173-176. https://doi.org/10.1111/j.1750-3841.2009.01479.x

King, E. S., Cho, J., Li,H., Jiang, X., Madler, A. K., Weishair, M. K., Glenn, S., Brand, M. H., Xu, Ch., Bolling, B. W. 2021. Time of harvest affects United States-grown Aronia mitschurinii berry polyphenols, °Brix, and acidity. *Journal of Agriculture and Food Research*, *6*, p. 100248. https://doi.org/10.1016/j.jafr.2021.100248

Kitrytė, V., Laurinaviciene, A., Syrpas, M., Pukalskas, A., Venskutonis, P. R. 2020. Modeling and optimization of supercritical carbon dioxide extraction for isolation of valuable lipophilic constituents from elderberry (*Sambucus nigra L.*) pomace.

Journal of CO_2 Utilization, *35*, 225-235. https://doi.org/10.1016/j.jcou.2019.09.020
Kokotkiewicz, A., Jaremicz, Z., Luczkiewicz, M. 2010. Aronia Plants: A Review of Traditional Use, Biological Activities, and Perspectives for Modern Medicine. *Journal of Medicinal Food*, *13*(2). https://doi.org/10.1089/jmf.2009.0062
Kulling, S., Rawel, H. 2009. Chokeberry (*Aronia melanocarpa*) – A Review on the Characteristic Components and Potential Health Effects. *Planta Medica, 74*(13), 1625-34. https://doi.org/10.1055/s-0028-1088306
Lee, J., Durst, R. W., Wrolstad, R. E., Eisele, T., Giusti, M. M., Hach, J., Hofsommer, H., Koswig, S., Krueger, D. A., Kupina, S., Martin, S. K., Martinsen, B. K., Miller, T. C., Paquette, F., Ryabkova, A., Skrede, G., Trenn, U., Wightman, J. D. 2005. Determination of total monomeric anthocyanin pigment content of fruit juices, beverages, natural colorants, and wines by the pH differential method: collaborative study. *Journal of AOAC International*, *88*(5), 1269-1278, https://doi.org/10.1093/jaoac/88.5.1269
Lupascu, N., Cadar, E., Cherim, M., Erimia , C. L., Sîrbu, R. 2019. Research Concerning the Efficiency of Aronia Melanocarpa for Pharmaceutical Purpos. *European Journal of Interdisciplinary Studies,* *4*(1), 115. https://doi.org/10.26417/ejis.v4i1.p115-121
Mattila, P., Hellström, J., Törrönen, R. 2006. Phenolic Acids in Berries, Fruits, and Beverages. *Journal of Agricultural and Food Chemistry*, 54(19), 7193-9. https://doi.org/10.1021/jf0615247
Naruszewicz, M., Łaniewska, I., Millo, B., Dłużniewski, M. 2007. Combination therapy of statin with flavonoids rich extract from chokeberry fruits enhanced reduction in cardiovascular risk markers in patients after myocardial infraction (MI). *Atherosclerosis,* *194*(2), 179-184. https://doi.org/10.1016/j.atherosclerosis.*2006.12.032*
Nawirska-Olszańska, A., Pasławska, M., Stepień, B., Oziembłowski, M., Sala, K., Smorowska, A. 2020. Effect of Vacuum Impregnation with Apple-Pear Juice on Content of Bioactive Compounds and Antioxidant Activity of Dried Chokeberry Fruit. *Foods*. *9*(3), 108. https://doi.org/10.3390/foods9010108
Negreanu-Pirjol, B. G. S., Oprea, O. C., Negreanu-Pirjol, T., Roncea, F. N., Prelipcean, A.-M., Craciunescu, O., Iosageanu, A., Artem, V., Ranca, A., Motelica, L., Lepadatu, A.-C., Cosma, M., Popoviciu, D. R. 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
Ochmian, I., Grajkowski, J., Smolik, M. 2012. Comparsion 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/nbha4017181
Ochmian, I., Oszmiański, J., Skupień, K. 2009. Chemical composition, phenolics and firmness of small black fruis. *Journal of Applied Botany and Food Quality*, *83*(1), 64-69. e ISSN 1439-040X
Oszmiański, J., Lachowicz, S. 2016. Effect of the Production of Dried Fruits and Juice from Chokeberry (*Aronia melanocarpa* L.) on the Content and Antioxidative Activity of Bioactive Compounds, *Molecules*, *21*(8), 1098. https://doi.org/10.3390/molecules21081098
Oszmiański, J., Wojdylo, 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
Patras, A., Brunton, N. P., Da Pieve, S., Butler, F. 2009. Impact of high pressure processing on total antioxidant activity, phenolic, ascorbic acid, anthocyanin content and colour of strawberry and blackberry purées. *Innovative Food Science and Emerging Technologies*, *10*(3), 308-313. https://doi.org/10.1016/j.ifset.2008.12.004
Raczkowska, E., Nowicka, P., Wodylo, A., Styczyńska, M. Lazar, Z. 2022. Chokeberry Pomace as a Component Shaping the Content of Bioactive Compounds and Nutritional, Health-Promoting (Anti-Diabetic and Antioxidant) and Sensory Properties of Shortcrust Pastries Sweetened with Sucrose and Erythritol. *Antioxidants*. *11*(2), pp. 190. https://doi.org/10.3390%2Fantiox11020190
Sadilova, E., Stintzing, F. C., Carle, R. 2006. Thermal degradation of acylated and nonacylated anthocyanins. *Journal of Food Science*, *71*(8), 504-512. http://dx.doi.org/10.1111/j.1750-3841.2006.00148.x
Samoticha, J., Wojdylo, A., Lech, K. 2016. The influence of different the drying methods on chemical composition and antioxidant activity in chokeberries. *LWT-Food Science and Technology*, *66*, 484-489. https://doi.org/10.1016/j.lwt.2015.10.073
Sasmaz, H. K., Kilic-Buyukkurt, O., Selli, S., Bouaziz, M., Kelebek, H. 2024. Antioxidant Capacity, Sugar Content, and Tandem HPLC−DAD−ESI/MS Profiling of Phenolic Compounds from Aronia melanocarpa Fruits and Leaves (Nero and Viking Cultivars). *ACS Omega*, *9*, 14963-14976. https://doi.org/10.1021/acsomega.3c09040
Simeonov, S., Botushanov, N., Karahanian, E., Pavlova, Husianitis, H., Troev, D. 2001. Effects of *Aronia melanocarpa* juice as part of the dietary regimen in patients with diabetes mellitus. *Folia Medica*, *44*(3), 20-23. PMID: 12580526
Singleton, V. L., Orthofer, R., Lamuela-Raventos, R. M. 1999. Analysis of total phenols and other oxidation substrates and antioxidants by means of Folin-Ciocalteu reagent. *Methods in Enzymology,* 299, 152-178, https://doi.org/10.1016/s0076-6879(99)99017-1
Skupien, K. 2007. The effect of mineral fertilization on nutritive value and biological activity of chokeberry fruit. *Agricultural and Food Science*, *16*, 46-55. https://doi.org/10.2137/145960607781635822
Skupień, K., Ochmian, I., Grajkowski, J. 2008. Influence of mineral fertilization on selected physical features and chemical composition of aronia fruit. *Acta Agrophysica*, *11*(1), 213-226. eISSN: 2300-6730
StatSoft, Inc. (2013). Statistica (data analysis software system), version 12. Tulsa, Oklahoma, USA http://www.statsoft.com
Strugała, P., Gładkowski, W., Kucharska, A. Z., Sokół-Łętowska, A., Gabrielska, J. 2016. Antioxidant activity and anti-inflammatory effect of fruit extracts from blackcurrant, chokeberry, hawthorn, and rosehip, and their mixture with linseed oil on a model lipid membrane. *European Journal of Lipid Science and Technology*, *118*, 461-474. https://doi.org/10.1002/ejlt.201500001
Szalóki-Dorkó, L., Végvári, G., Ladányi, M., Ficzek, G., Stéger-Máté, M. 2015. Degradation of Anthocyanin Content in Sour Cherry Juice During Heat Treatment. Food Technology and Biotechnology, *53*(3), 354-360. https://doi.org/10.17113/ftb.53.03.15.3931
Šavikin, K., Zdunić, G., Janković, T., Gođevac, D., Stanojković, T., Pljevljakušić, D. 2014. Berry fruit teas: Phenolic composition and cytotoxic activity. *Food Research International*, *62*, 677-683. https://doi.org/10.1016/j.foodres.2014.04.017
Tian, Y., Liimatainen, J., Alanne, A. L., Lindstedt, A., Liu, P., Sinkkonen, J., Kallio, H. Yang, B. 2017. Phenolic compounds extracted by acidic aqueous ethanol from berries and leaves of different berry plants. *Food Chemistry*, *220*, 266-281. https://doi.org/10.1016/j.foodchem.2016.09.145
Trenka, M., Navirska-Olszańska, A., Oziemblowski, M. 2020. Analysis of Selected Properties of Fruits of Black Chokeberry (*Aronia melanocarpa* L.) from Organic and Conventional Cultivation. *Applied Sciences*, *10*(24), 9096. https://doi.org/10.3390/app10249096
Tolić, M.-T., Landeka Jurčević, I., Panjkota Krbavčić, I., Marković, K., Vahčić, N. 2015. Phenolic Content, Antioxidant Capacity and Quality of Chokeberry (*Aronia Melanocarpa*) Products. *Food Technology and Biotechnology*, *53*(2). https://doi.org/10.17113/ftb.53.02.15.3833
Vagiri, M., Jensen, M. 2017. Influence of juice processing factors on quality of black chokeberry pomace as a future resource for colour extraction. *Food Chemistry*, *217*,409-417. https://doi.org/10.1016/j.foodchem.2016.08.121
Valcheva-Kuzmanova, K., Kuzmanov, V., Mihova, I., Krasnaliev, P., Borisova, A., Belcheva, A. 2007. Antihyperlipidemic effect of Aronia melanocarpa fruit juice in rats fed a high-cholesterol diet. *Plant Foods for Human Nutrition*, *62*, 19-24. https://doi.org/10.1007/s11130-006-0036-2
Veberic, R., Slatnar, A., Bizjak, J., Stampar, F., Mikulic-Petkovsek, M. 2015. Anthocyanin composition of different wild and cultivated berry species. *LWT-Food Science and Technology*, *60*, 509-517. https://doi.org/10.1016/j.lwt.2014.08.033
Wojdylo, A., Oszmianski, J., Teleszko, M., Sokol-Letowska, A. 2013. Composition and quantification of major polyphenolic compounds, antioxidant activity and colour properties of quince and mixed quince jams. *International Journal of Food Sciences and Nutrition*, *64*(6), 749-756, https://doi.org/10.3109/09637486.2013.793297
Wu, H.-Y., Yang, K.-M., Chiang, P-Y. 2018. Roselle Anthocyanins: Antioxidant Properties and Stability to Heat and pH. *Molecules*, *23*, 1357. https://doi.org/10.3390/molecules23061357
Yildiz, D., Gürel, D. B., Çagindi, O., Kayaardi, S. 2022. Heat treatment and microwave applications on homemade sour cherry juice: The effect on anthocyanin content and some physicochemical properties. *Current Plant Biology*, 29, 100242. https://doi.org/10.1016/j.cpb.2022.100242
Zorenc, Z., Veberic, R., Stampar, F., Koron, D., Mikulic-Petkovsek, M. 2017. Thermal stability of primary and secondary metabolites in highbush blueberry (*Vaccinium corymbosum* L.) purees. *LWT - Food Science and Technology*, *76*, 79-86. https://doi.org/10.1016/j.lwt.2016.10.048
Zhang, Y., Zhao, Y., Liu, X., Chen, X., Ding, Ch., 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/10.106/jfutfo.2022.01.006