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COMPARISON OF THE INFLUENCE OF DIFFERENT FRUIT DRYING METHODS ON THE CONTENT OF SELECTED BIOACTIVE SUBSTANCES

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ABSTRACT

The aim of the work was to evaluate the effect of hot air and infrared drying on the content of total polyphenols and anthocyanin dyes in selected types of small fruits. In the work we used chokeberry (*Aronia melanocarpa* Michx.) variety Nero, elderberry (*Sambucus nigra* L.) variety Haschberg, sour cherry (*Prunus cerasus* L.) variety Fanal, red currant (*Ribes rubrum* L.) variety Lake, black currant (*Ribes nigrum* L.) variety Triton, cherry elaeagnus (*Elaeagnus multiflora* Thunb), raspberry (*Rubus idaeus* L.) variety Heritage and blueberry (*Vaccinium corymbosum* L.*)* variety Bluecrop. Drying was performed in a Concept S1060 hot air dryer and a Yden CI IR D5 infrared dryer. The analysis of the content of anthocyanin dyes was performed by the pH differential method, the determination of the total content of polyphenols was performed by the Folin - Ciocalteu method. By analyzing fresh fruits, we found the highest content of anthocyanin dyes in the fruits of chokeberry (3036.97 mg.100 g^{-1} DM) and the lowest in the fruits of cherry elaeagnus (83.86 mg.100 g^{-1} DM). The total polyphenol content ranged from 726.07 mg GAE.100 g^{-1} dry matter (cherry elaeagnus) to 7895.61 mg GAE.100 g^{-1} DM (chokeberry). After drying in a hot air dryer, the content of anthocyanin dyes decreased by 62.20% (in elderberry) to 72.52% (in cherry elaeagnus) and the content of total polyphenols by 45.16% (in chokeberry) to 53.34% (in red currant). After drying in an infrared dryer, the decrease in the content of anthocyanin dyes was 50.41% (in elderberry) to 71.22% (in cherry elaeagnus) and total polyphenols 41.05% (in chokeberry) to 47.89% (in sour cherry).

Keywords: drying, small fruits, total polyphenols, anthocyanin dyes

INTRODUCTION

The fruits of so-called small fruits species are characterized by a valuable nutritional composition and a high potential for use in the food industry. Fruit drying is one of the oldest ways of canning food. Drying products are consumed directly or used for further processing in the food industry (**Sánchez *et al.*, 2020, Meléndez-Martinez, 2021).** Hot air drying is one of the simplest methods used to dry fruit, especially because of its affordability **(Zhang, 2019**). However, this method of drying has and negative effect on the nutritional quality of the final product due to the degradation of thermolabile substances. An alternative to hot air drying is infrared drying, which is characterized by better process energy efficiency (**Okamoto *et al.*, 2012, Orikasa *et al.*, 2018, Roslan, 2020**). The infrared dryer works on the principle that the radiation energy is transferred from the radiation source to the surface of the product without heating the environmental air, which heats the material faster and more evenly. Energy penetrates the material and is converted into heat. Infrared drying is characterized by lower energy consumption, shorter drying time and consequently higher nutritional and sensory quality of the final product (**Guiné, 2018, Hasan *et al.*, 2019, Wu *et al.*, 2019**).
Chokeberry (*Aronia melanocarpa* Michx.) is one of the richest natural sources of polyphenols with confirmed health benefits, thanks to which its popularity and use in the food industry is constantly increasing. The fruits are used for the production of fruit spreads, juices, wines, liqueurs and for the production of natural dyes (**Vagiri, Jensen, 2017**). The main polyphenols in aronia are anthocyanins, procyanidins, flavonols and phenolic acids (**Sueiro *et al.*, 2006, Kokotkiewicz *et al.*, 2010, Rugina *et al***., **2012**). Black chokeberry extracts have shown many health benefits in vitro and in vivo, including antioxidant, antimutagenic, anticancer, cardioprotective, hepatoprotective, gastroprotective, antidiabetic, antiinflammatory, antibacterial, antiviral, radioprotective and immunomodulatory effects (**Kokotiewicz *et al.*, 2010, Zhang *et al.*, 2021**).
The fruits of the elderberry (*Sambucus nigra* L.) are also characterized by a high content of phenolic compounds. The main polyphenols found in fruits include chlorogenic acid, quercetin and campferol, anthocyanins. In addition, elderberry berries contain small amounts of tannins with a low degree of condensation, such as procyanidins, epicatechin, and catechin (**Mlynarczyk *et al.*, 2018**). The antinutritional substances of elderberry are sambunigrin and prunasin. Sambunigrin is hydrolyzed to hydrogen cyanide in the gastrointestinal tract. However, heat treatment of the fruit eliminates it, which increases the safety of fruit consumption (**Senica *et al.*, 2016**). The fruits of the elderberry have a wide range of food uses, they are used for the production of fruit spreads, wine, liqueurs and food coloring (**Miraj, 2016**). Elderberry flower extracts have diuretic effects, a beneficial effect on vascular flexibility. Extracts are effective as antipiretics. In alternative medicine, the base is used as a diuretic, laxative and anti-inflammatory agent (**Sidor, Gramza-Michalowska, 2015**).
Black cherry (*Prunus cerasus* L.) is one of the traditional fruits, popular for its refreshing delicate sour taste. The fruits are interesting in their content of organic acids, anthocyanin dyes, flavonoids, vitamins, minerals, fiber and also melatonin, which acts against insomnia and at the same time reduces the risk of stroke. The fruits are consumed fresh or canned into compotes, spreads, soft drinks and alcoholic beverages (**Serradilla *et al.*, 2016, Hussain *et al.*, 2021, Motyleva *et al.*, 2021**).
Currants (*Ribes rubra* L., *Ribes nigrum*, L.) are highly valued fruit species for versatile use in the food industry, high nutritional value and content of healthy substances (**Mikulic-Petkovsek *et al.*, 2016**). The most valuable compounds in berries are phenolic compounds, ascorbic acid, flavonols, flavanols, hydrocinnamic acids and anthocyanins (**Zdunić *et al.*, 2016**). Fruits are significant in their routine content with anti-inflammatory and neuroprotective effects (**Frum *et al.*, 2017**). Of the vitamins, vitamin C, B complex and vitamin E are present in higher concentrations in the fruits (**Pieszka *et al.*, 2015, Cao *et al.*, 2021, Golovenko *et al.*, 2021**).
Blackberry (*Rubus idaeus* L.) fruits are widely used not only in the food industry, but also in traditional and alternative medicine. Berries and leaves have been used in the past to treat digestive problems, the cardiovascular system, kidney disease and flu. Raspberry leaf extract is said to work against muscle cramps. In addition, they are characterized by antimicrobial and anti-inflammatory effects (**Hummer, 2010, Veljković *et al.*, 2019**). The fruit is eaten fresh, frozen and dried or processed into compotes, jams, syrups, wines or liqueurs. Of the biologically valuable substances, the presence of vitamins C, E, K, B vitamins and provitamin A is interesting in the fruits. Mineral substances are dominated by manganese, potassium, calcium, magnesium and phosphorus (**Rao and Snyder, 2010; Bobinaité *et al.*, 2016**).
The fruits of *Eleagnum multiflora* Thunb. contain a number of chemical compounds that have a positive effect on human health. These are mainly phenolic acids, flavonoids, lipids, carotenoids, ascorbic acid and lycopene (**Patel, 2015, Nowak *et al.*, 2021**). In fresh or processed form, the fruits have antioxidant, anti-

inflammatory and antiproliferative effects. They are used in supportive care against diarrhea, gastrointestinal disorders and even colon cancer (**Abdalla, 2019**). In the food industry, it is used to make juices, jams, jellies and compotes and they are part of tea blends (**Lachowicz *et al.*, 2020**). According to **Lachowicz-Wiśniewska *et al.* (2021)** the main group of polyphenols found in fruit pulp and seeds are procyanidins, which are important components of nutraceuticals.

Blueberry (*Vaccinium corymbosum* L.) has spherical fruits weighing 1-5.5 grams, with a waxy coating on the surface, characterized by a sweet taste and a juicy flesh without coloring properties (**Medvecký, Daniel, 2019**). In the food industry, they are widely used for the production of overpressures, spreads, alcoholic and non-alcoholic beverages (**Orella-Palma *et al.*, 2017**). Blueberries are a rich source of valuable compounds. In addition to sugars, vitamins, minerals and organic acids, they contain flavonoids (**Lavefve *et al.*, 2020**), anthocyanins (**Kuntz *et al.*, 2017, Huang *et al.*, 2018, Zhou *et al.*, 2020**) and procyanidins (**Silva *et al.*, 2020**).

The aim of the work was to compare the effect of hot air drying and infrared drying on the content of total polyphenols and anthocyanin dyes in the dried fruits of selected types of small fruits.

MATERIAL AND METHODS

In this work we used small fruits that are characterized by the presence of anthocyanin dyes. These were the following species and varieties - black-fruited chokeberry (*Aronia melanocarpa* Michx.) variety Nero, elderberry (*Sambucus nigra* L.) variety Haschberg, sour cherry (*Prunus cerasus* L.) variety Fanal, red currant (*Ribes rubrum* L.) variety Lake, black currant (*Ribes nigrum* L.) variety Triton, cherry elaeagnus (*Elaeagnus multiflora* Thunb), raspberry (*Rubus idaeus* L.) variety Heritage and blueberry (*Vaccinium corymbosum* L.*)* variety Bluecrop. We harvested the fruits in full consumption maturity, after reaching the characteristic sensory properties. We analyzed the fruit fresh and after drying. We dried the fruit in two types of dryers, in the concept S1060 hot air dryer at 60 °C and in the Yden CI IR D5 infrared dryer at a wavelength of 750-3000 nm. The drying time is given in Table 1. Drying was performed until the moisture content of the product was less than 13-15%. The final moisture content was monitored at moisture analyzer KERN MRS 120-3.

Table 1 Drying time of individual fruits

Spieces	Hot air drying (hours)	Infrared drying (hours)
chokeberry	24	16
elderberry	16	10
sour cherry	24	16
red currant	36	24
black currant	36	24
cherry elaeagnus	16	10
raspberry	16	10
blueberry	16	10

The determination of total polyphenols was performed by the Folin-Ciocalteau method of **Lachman *et al.* (2003).** The method is based on the reaction of Folin-Ciocalteu reagent with polyphenols present in the analyzed sample to produce a blue color product. Sample preparation for polyphenol analysis consisted of homogenization and extraction in 80% ethanol at HEIDOLPH GSL 3006 shaker at 150 rpm for 24 hours. For the standard preparation, exactly 100 mg gallic acid were weighed (Analytical balance Sartorius TE214S-0CE, Sartorius Lab Instruments GmbH & Co. KG, Göttingen, Germany) and diluted with demineralized water up to 100 mL volume to prepare a stock solution. One mL of the stock solution was diluted with distilled water up to 200 mL volume. The calibration curve was prepared in range of 5–200 mg. L^{-1} of gallic acid. The blank contained Folin–Ciocalteu reagent and distilled water, without the standard or extract. The correlation coefficient of the calibration curve reached R = 0.996.

For the samples preparation, 50 µL were pipetted into 50 mL volumetric flasks; subsequently, 2.5 mL of Folin-Ciocalteu reagent diluted with distilled water (1:2 v/v) were added. Next, 5 mL of Na_2CO_3 (20% water solution) was added. Following this, flasks were filled with distilled water. In this form, the samples were left for 2 h at a room temperature to develop the blue complex. The measurement wavelength was set to 765 nm. For the measurement a double-beam UV-VIS spectrophotometer (Jenway 6405 UV/VIS) was used.

The measurement of the total anthocyanins content was carried out in accordance with **Lapornik *et al.* (2005)**. One milliliter of extract was pipetted into two tubes. One mL of 0.01% HCl solution in 95% ethanol was added into each tube. Next, (A1) 10 mL of 2% aqueous HCl solution were added into the first tube, and into another tube we added (A2) 10 mL of solution with pH = 3.5 (prepared from 0.2 M Na_2HPO_4 and 0.1 M citric acid). The absorbances of both samples were measured at 520 nm against a blank sample (water). The total anthocyanin content was calculated as follows, where "f" is constant (396.598). For the measurement a double-beam UV-VIS spectrophotometer (Jenway 6405 UV/VIS) was used.

Content of Total Anthocyanins (mg.kg^{-1}) = (A1−A2) × f

The data were evaluated using one-way analysis of variance (ANOVA) followed by post hoc analysis using LSD multiple range test (Statistica v.12, Statsoft, USA), assuming that differences were statistically significant at α=0.05.

RESULTS AND DISCUSSION

By analyzing fresh fruits, we found that the content of total polyphenols in fruit samples ranged from 726.07-7895.61 mg GAE.100 g^{-1} DM. By multiple comparison of averages using the LSD test, the species were arranged into 8 homogeneous groups and statistically significant differences ($p<0.05$) in the content of total polyphenols were found for all 28 pairs of fruits.

We found a statistically significant ($p<0.05$) the highest content of total polyphenols in the fruits of black chokeberry and the lowest in the fruits of the cherry elaeagnus.

The content of total anthocyanins in the studied fruit species was in the range of 156.21-3036.97 mg.100 g^{-1} DM. Based on the results of the LSD test, the species were organized into 6 homogeneous groups according to the content of anthocyanins. We confirmed the highest content of anthocyanins in black chokeberry and the lowest in cherry elaeagnus. We did not find a statistically significant difference ($p>0.05$) between raspberry, blackberry and blueberry, which together formed a separate homogeneous group (cd). Likewise, we did not detect a difference between sour cherry and raspberry, sour cherry and blueberry, elderberry and blueberry also elderberry and raspberry (Table 2).

Table 2 Means and homogeneous groups for the total polyphenols and total antocyanins treatment based on multiple comparison from the LSD test

Spieces	**Dry matter (%)**	**Total polyphenols (mg GAE.100 g^{-1} DM)**	**Total anthocyanins (mg.100 g^{-1} DM)**
chokeberry	24.38	7895.61 h	3036.97 f
elderberry	16.42	4232.91 g	428.83 d
sour cherry	14.32	1202.49 c	351.75 c
red currant	11.86	980.64 b	156.21 b
black currant	16.26	3108.75 f	582.55 e
cherry elaeagnus	16.79	726.07 a	83.86 a
raspberry	13.81	1436.37 d	390.97 cd
blueberry	14.14	2572.21 e	405.14 cd

different letters at mean represent statistically significant differences among treatments ($p<0.05$)

Damar and Eksi (2012) monitored the content of total polyphenols and anthocyanin pigments in sour cherry juice from different regions of Turkey. The authors found the content of total polyphenols in the amount of 1510-2297 mg. L^{-1} and the content of total anthocyanins in the amount of 195.8-437.9 mg.L^{-1}. The determination of the content of polyphenols in elderberries was dealt with by **Kiprowski *et al.* (2021)**. The Wild, Haschberg and Ljubostinja varieties grown in Serbia were used for the evaluation. They found that chlorogenic acid and caffeic acid derivatives with a content of almost 4000 mg.100 g^{-1} predominate in black elderberry fruits. **Pentallidis *et al.* (2007)** monitored the content of total polyphenols and anthocyanins in raspberry and red currant fruits originating from Greece. The content of anthocyanins in the fruits was analyzed by the pH differential method and the authors found a content of 1.3-7.8 mg.100 g^{-1} FW in red currants and 104-198 mg.100 g^{-1} FW in raspberry fruits. After converting to fruit dry matter (DM), it represented 657-1193 mg. 100 g^{-1} DM in currants and in raspberries 1137-2112 mg.100 g^{-1} DM. These values are comparable with our results. **Lachowicz *et al.* (2000)** determined the content of total polyphenols in two varieties of mullein grown in Poland. The content of total polyphenols in the fruits of the Sweet Scarlet variety was 1268.90 mg.100 g^{-1} DM and in the fruits of the Jahidka variety 904.65 mg.100 g^{-1} DM. In our work, we analyzed lower concentrations of polyphenols in the fruits of the gorse. The content of total polyphenols in blueberry fruits grown in Florida was monitored by **Das *et al.* (2022)**. The authors determined polyphenolic compounds using the Folin-Ciocalteu method and report that the total content of polyphenols ranged from 42.2 to 122.6 mg GAE.g^{-1}. Compared to our results, these values are higher. Authors **Domínguez *et al.* (2020)** monitored the content of total polyphenols in black elderberries from Spain. The analysis was carried out using the Folin-Ciocalteu reagent and the content of polyphenols in the fruits ranged from 2524 to 3157 mg GAE. 100 g^{-1} dry matter. The authors state that the most represented polyphenols in elderberries were flavonoids, namely rutin and quercentin. In our analysis, the content of total polyphenols in fresh elderberry fruits was found in average amounts of 4232.91 mg GAE.100 g^{-1} DM, which is a value only slightly higher.

According to **Paunović *et al.* (2017)** more than 70% of the antioxidant capacity of black currants comes from anthocyanins. The authors report that there are four main types of anthocyanins in the fruit, which they detected by liquid chromatography. In the highest concentration, they proved the presence of delphinidin-3-rutinoside, cyanidin-3-O-rutinoside, delphinidin-3-O-glucoside and cyanidin-3-O-glucoside. **Kula *et al.* (2016)** report the presence of cyanidin and pelargonidin derivatives in raspberry blackberry, with cyanidin derivatives being dominant and constituting approximately 20 mg.kg^{-1} of fresh weight. Pelargonidin derivatives make up less than a tenth of the total anthocyanins. The content of anthocyanin dyes by the pH differential method in the fruits of red and four varieties of black currants was evaluated by **Orsavová *et al.* (2019)**. Red currant fruits originating from the Czech Republic contained 60.34 mg.100 g^{-1} DM of total anthocyanins. They evaluated black currants in a wider varietal composition and found a higher average content of anthocyanins (140.71-186.12 mg.100 g^{-1} DM). The highest content in the work of **Orsavová *et al.* (2019)** was observed in variety Ben Gairn originally from Scotland. The authors state that the differences in the content of dyes in individual types of black currants are influenced by factors such as the date of harvest, genotype and location of cultivation. In our work, we measured the concentrations of anthocyanin dyes in the fruits of red currants and black currants in higher amounts, namely 156.21 mg.100 g^{-1} DM (red currants) and 582.55 mg.100 g^{-1} DM (black currants). The content of anthocyanins in elderberries was quantified by **Domínguez *et al.* (2020)** by the spectrophotometric method and their content ranged from 287.8 to 645.7 mg.100 g^{-1} of dry matter, which are results comparable to ours. Total anthocyanin content by **Toshima *et al.* (2021)** analyzed in the blackberry variety Indian Summer, which is grown in Japan. In their study, the authors report that the fruits contain an average of 27.09 mg.100 g^{-1} FW of anthocyanins, which is a lower amount compared to our results.

Table 3 Content of total polyphenols (mg GAE.100 g^{-1} dry matter) in fruits after different drying methods

Species	Hot air drying	Decrease (%)	Infrared drying	Decrease (%)
chokeberry	4329.56	45.16	4654.49	41.05
elderberry	2181.06	48.47	2352.94	44.41
sour cherry	588.85	51.03	626.59	47.89
red currant	457.60	53.34	519.18	47.06
black currant	1630.81	47.54	1802.57	42.02
cherry elaeagnus	339.53	53.24	387.81	46.59
raspberry	764.60	46.77	801.65	44.19
blueberry	1344.83	47.72	1425.81	44.57

The results of the analyzes of the dried fruit show that the highest amount of total polyphenols after both types of drying was found in the fruits of chokeberry, such as 4329.56 mg GAE.100 g^{-1} DM (warm air) and 4654.49 mg GAE.100 g^{-1} DM (infrared). In chokeberry, the content of polyphenols decreased by 45.16% after hot air drying and by 41.05% after infrared drying. The lowest content of polyphenols in fresh fruits, as well as after the application of two different types of drying, was found in the many-flowered gorse, such as 339.53 mg GAE.100 g^{-1} DM after hot air drying and 387.81 mg GAE.100 g^{-1} DM after infrared drying. In this case, drying in an infrared oven caused a decrease in the content of polyphenols by 46.59% and in an infrared oven by 53.24%.
The highest decrease in total polyphenols after hot air occurred in red currant fruits (53.34%) and the lowest in black chokeberry fruits (45.16%). In the fruits dried by an infrared dryer, the percentage decrease of polyphenols ranged from 41.05% in chokeberry to 47.89% in sour cherry fruits.
Based on the achieved results, we assume that the infrared method of drying fruits has a less destructive effect on the total content of polyphenols contained in the examined fruit samples.
Wojdylo *et al.* (2013) investigated changes in the content of polyphenols in sour cherry fruits after three drying methods. They used hot air drying at 60 °C, vacuum-microwave drying and lyophilization. The initial value of polyphenols in fresh fruits was 7905.77 mg.kg^{-1} DM, which is a value lower than in our case. After hot air drying, the content of polyphenols decreased to 4885.95 mg.kg^{-1} DM, after lyophilization to 6538.35 mg.kg^{-1} DM, and after vacuum-microwave drying at 240 W to 7510.27 mg.kg^{-1} dry matter. The authors mention lyophilization as the best drying method. Black chokeberry berries from Serbia after drying at a temperature of 40 °C were evaluated in terms of anthocyanin content and total polyphenols by the authors **Ćujić *et al.* (2018)**. In their study, the authors performed the analysis in triplicate and report that the total polyphenol content of the dried fruits was 55.2 mg GAE.g^{-1}, which is slightly higher than our results. The authors of **Horuz *et al.* (2017)** used a combined microwave-hot air drying method to dry sour cherries. The analysis of the content of total polyphenols was carried out at a temperature of 50 °C, 60 °C and 70 °C and three types of microwave power 120 W, 150 W and 180 W. In their results, the authors state that the content of total polyphenols in dried cherries ranged from 285.56 to 385.85 mg GAE.100 g^{-1}. In our experiment, in the fruits dried with an infrared dryer, the content of total polyphenols of sour cherry ranged in an average amount of 626.59 mg GAE.100 g^{-1} DM. Based on these data, we can say that the loss of polyphenol content when drying fruit with an infrared dryer is almost half less than with combined microwave-conventional drying.
We evaluated the results of the content of total polyphenols in dried fruits by two-factor analysis of variance and observed whether drying with an infrared dryer is statistically significantly ($p<0.05$) more favorable in terms of retention of polyphenols. Based on the comparison of the results, we can conclude that infrared drying is statistically significantly ($p<0.05$) better than hot air drying in terms of retention of total polyphenols (Figure 1).

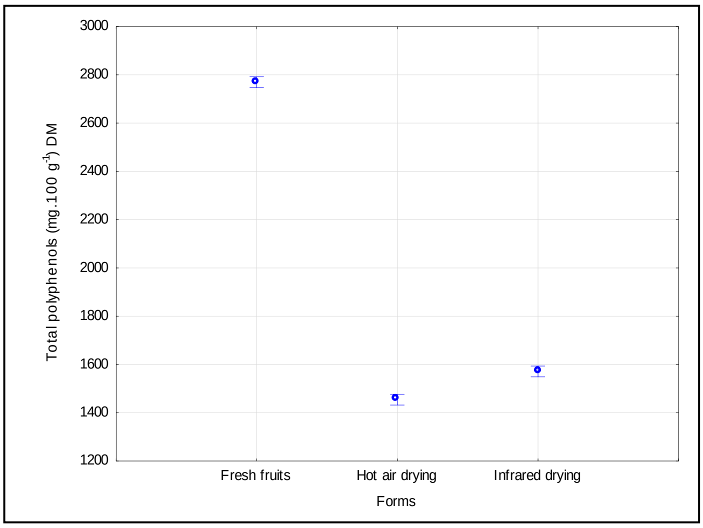

Figure 1 Comparison of the content of total polyphenols (mg GAE.100 g^{-1} DM) in fresh fruits and fruits dried by hot air and infrared dryers

However, if we evaluate the changes in the content of polyphenols for individual types of fruit and methods of drying, we must state that drying with an infrared dryer was statistically more advantageous in the case of chokeberry, elderberry and black currant. In the case of the other species, there is an overlap of the marginal averages of the content of total polyphenols during hot air and infrared drying, and therefore we cannot confirm statistically significant differences (Figure 2).

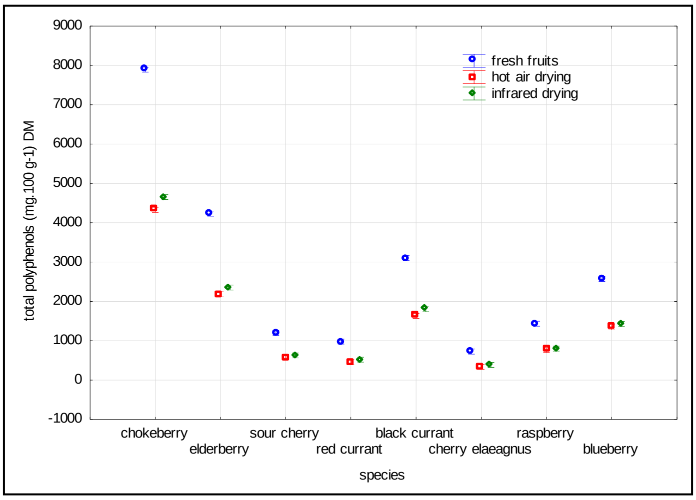

Figure 2 Marginal averages of the content of total polyphenols in individual types of fresh and dried fruit (mg GAE.100 g^{-1} DM)

Table 4 Content of anthocyanin dyes (mg.100 g^{-1} DM) in fruits after different methods of drying

Species	Hot air drying	Decrease (%)	Infrared drying	Decrease (%)
chokeberry	979.13	67.76	1363.72	55.10
elderberry	162.12	62.20	212.64	50.41
sour cherry	113.82	67.64	127.80	63.67
red currant	55.21	64.65	61.43	60.68
black currant	176.64	69.68	200.32	65.61
cherry elaeagnus	23.04	72.52	24.13	71.22
raspberry	142.03	63.67	168.58	56.88
blueberry	118.02	70.87	155.04	61.73

The highest content of anthocyanin dyes after the use of both types of driers, similar to the content of total polyphenols, was found in chokeberry fruits, in the amount of 979.13 mg.100 g^{-1} DM (warm air) and 1363.72 mg.100 g^{-1} DM (infrared). After drying chokeberry fruits in an infrared oven, higher amounts of dyes were preserved (decrease by 55.10%) than during hot air drying (decrease by 67.76%).
After hot air drying, the content of anthocyanins in dried fruits decreased by 62.20-72.52%. The decrease of anthocyanin dyes after infrared drying was 50.41-71.22%.
Hot-air drying of the fruits caused the most significant degradation of anthocyanin dyes in the fruits of the cherry elaeagnus. The content decreased from the original 83.86 mg.100 g^{-1} DM to 23.04 mg.100 g^{-1} DM, which represents a decrease of 72.52%. On the other hand, the drying temperature of 60 °C had a gentler impact

on the anthocyanin content of elderberry fruits, in which the anthocyanin content varied in the amount of 428.83 mg.100 g^{-1} DM in fresh fruits and 162.12 mg.100 g^{-1} DM dried fruits, which represented a decrease of 62.20%.
We found the smallest decrease in the content of anthocyanin dyes after the application of infrared drying in the fruits of the elderberry, the largest decrease was in the fruits of the cherry elaeagnus.
Dried fruits of black elderberry and chokeberry grown in Poland were evaluated by **Kowalska *et al.* (2021).** The analysis was carried out by preparing the extract by mixing the dried sample and the solvent - glycerol + water + ethanol in a certain ratio. The authors report that the total content of anthocyanins in black chokeberry fruits ranged from 32.24 to 131.95 $mg.L^{-1}$, while extracts from black elder fruits contained from 11.76 $mg.L^{-1}$ to 35.59 $mg.L^{-1}$ of anthocyanins. The authors **Hui *et al.* (2021)** determined the content of anthocyanins in freeze-dried fruits of black currants and blueberries from New Zealand. The authors reported that the average content of anthocyanins in black currant powder was 36.27 mg.100 g^{-1} DM and in blueberries 14.96 mg.100 g^{-1} DM, which are values lower than in our work. **Samoticha *et al.* (2016)** monitored the representation of anthocyanins in black chokeberry fruits after different methods of drying. Based on the analyses, the authors state that during hot air drying of fruits at 60 °C, the anthocyanin dyes decreased from 3917 mg.100 g^{-1} DM to 781 mg.100 g^{-1} DM, after vacuum drying the dyes decreased to 1821 mg.100 g^{-1} DM and after lyophilization to 2227 mg.100 g^{-1} DM. Based on measurements, the authors state that drying leads to a loss of anthocyanins ranging from 43-80%, depending on the drying method. Based on the results, the largest loss was after hot air drying at 60 °C and the smallest after lyophilization. In our work, we found a smaller loss of anthocyanins during hot air drying than reported by the authors. **Wojdylo *et al.* (2013)** reported that the content of anthocyanins in sour cherries grown in Poland was in fresh fruits 2923.85 $mg.kg^{-1}$ DM. After drying the fruits by hot air drying at a temperature of 60 °C, the anthocyanin content in this study decreased to the value of 1617.92 $mg.kg^{-1}$ DM. The authors results are comparable to our results. **Piccolo *et al.* (2020)** determined the content of anthocyanins in fresh and dried raspberries. For drying, they used a hot air dryer and dried at a temperature of 65 °C. In the study, they reported that the total content of anthocyanin dyes in fresh fruits was 1.18 $mg.g^{-1}$ DM. After drying at a temperature of 65 °C, the content of anthocyanin dyes decreased to a value of 0.78 $mg.g^{-1}$ of dry matter. In comparison, the decrease in anthocyanin pigments in the study by **Piccolo *et al.* (2020)** was 33.9%, while in our experiment it was up to 70.87%. The content of anthocyanin dyes in chokeberry after drying at a temperature of 40 °C was determined in an average amount of 20.6 $mg.g^{-1}$ DM **Ćujić *et al.* (2018)**. Compared to our results, it is 2 times higher content than after drying the fruits at 60 °C.
Based on the results of the analysis, we found that the decrease of anthocyanin pigments during infrared drying was lower than after hot air drying, based on which we assume that infrared drying of fruits has less destructive effects on the content of anthocyanins than hot air drying.
We verified our assumption with a two-factor analysis of variance. Based on the comparison of the results of the content of anthocyanin dyes from hot air and infrared drying for all monitored species, we found that infrared drying is statistically significantly (p<0.05) more favorable than hot air drying (Figure 3).

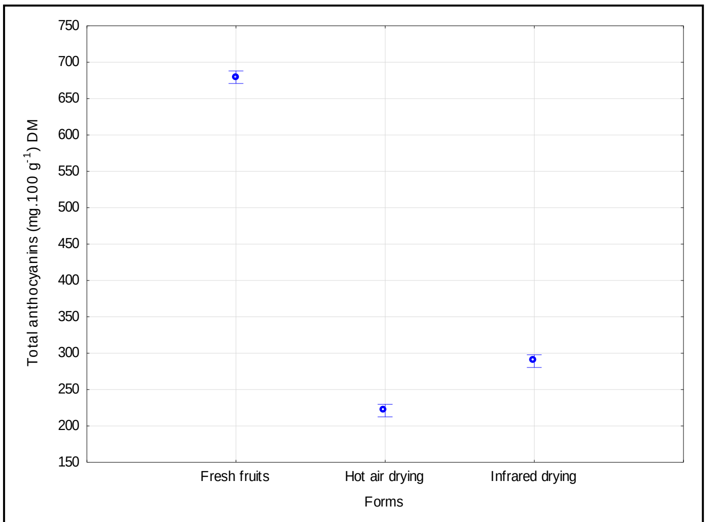

Figure 3 Comparison of anthocyanins (mg.100 g^{-1} DM) content in fresh fruits and fruits dried by hot air and infrared dryers

Similar to the case of total polyphenols and in the case of anthocyanin dyes, we must state that when comparing the effect of drying on individual species, the statistically positive effect of infrared drying on the retention of anthocyanin dyes was confirmed only in the case of chokeberry, elderberry and blackcurrant (Figure 4).

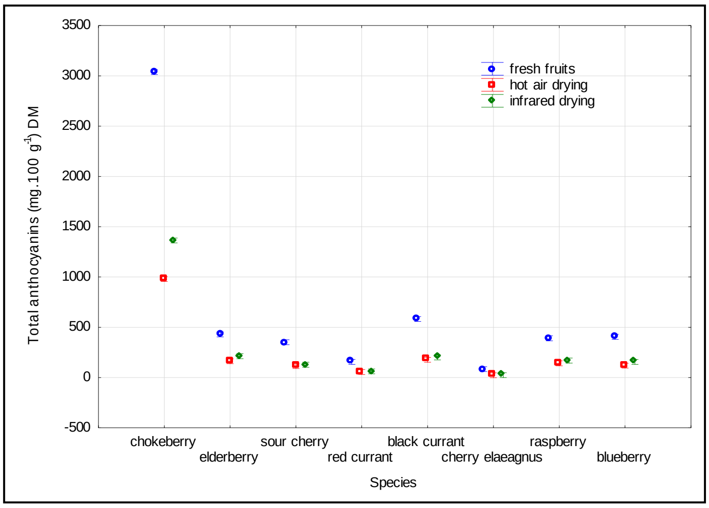

Figure 4 Marginal averages of the content of anthocyanin dyes (mg.100 g^{-1} DM) in individual types of fresh and dried fruit

CONCLUSION

Small fruits are among the most nutritionally valuable fruits with high biological potential in human nutrition and in the processing industry. One of the possibilities of processing not only small fruits is drying. Food drying is in the constant focus of technological practice and research from the point of view of optimization of key parameters of the process, especially with the aim of protecting nutritionally important thermolabile substances. The aim of our work was to compare the influence of hot air and infrared drying on the content of polyphenols and anthocyanins in selected types of small fruits. In our work, we found that after drying, degradation of polyphenols and anthocyanin dyes occurred in all types, the intensity of which was different depending on the drying method and the type of fruit. A statistically significant (p<0.05) more favorable drying method is infrared drying. By comparing the species, we found that the highest content of total polyphenols and anthocyanin dyes in both fresh and dried fruits is found in chokeberry. At the same time, this species belongs to species with good stability of the observed components after drying.

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REFERENCES

Abdalla T. E. 2019. Some Wild *Elaeagnus* Species: Overview, Description, Biochemistry, and Utilization. *Wild Fruits: Composition, Nutritional Value and Products*. 507-521. https://doi.org/10.1007/978-3-030-31885-7_38

Bobinaité, R., Viškelis, P., Venskutonis, P. R. 2016. Chapter 29 - Chemical Composition of Raspberry (*Rubus* spp.) Cultivars. *Nutritional Composition of Fruit Cultivars, 74*(7), 713-731. https://doi.org/10.1016/B978-0-12-408117-8.00029-5

Cao, L., Park, Y., Lee, S., Kim, D.O. 2021. Extraction, Identification, and Health Benefits of Anthocyanins in Blackcurrants (*Ribes nigrum* L.). *Applied Sciences*, *11*(4). https://doi.org/10.3390/app11041863

Ćujić, N., Savikin, K., Miloradovic, Z., Ivanov, M., Vajic, U. J., Karanovic, D., Grujic-Milanovic, J., Gjovovic, 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.

Damar, I.; Eksi, A. 2012. Antioxidant capacity and anthocyanin profile of sour cherry (*Prunus cerasus* L.) juice. *Food Chemistry*, *135*(4), 2910-2914. https://doi.org/10.1016/j.foodchem.2012.07.032

Das, R.P., Darwish, A.G., Ismail, A., Haikal, A.R., Gajjar, P., Balasubramani, S.P., Sheikh, M.B., Tsolova, V., Soliman, K.F.A., Sherif, S.M., El-Sharkawy, I. 2022. Diversity in blueberry genotypes and developmental stages enables discrepancy in the bioactive compounds, metabolites, and cytotoxicity. *Food Chemistry*, 374. https://doi.org/10.1016/j.foodchem.2021.131632

Domínguez, R., Zhang, L., Rocchetti, G., Lucini, L., Pateiro, M., Munekata, P.E.S., Lorenzo, M.S. 2020. Elderberry (*Sambucus nigra* L.) as potential source of antioxidants. Characterization, optimization of extraction parameters and bioactive properties. *Food Chemistry*, 330, https://doi.org/10.1016/j.foodchem.2020.127266

Frum, A., Cecilia, G., Gligor, F., Dobrea, C.M., Ovidiu, T. 2017. Identification and Quantification of Phenolic Compounds from Red Currant (*Ribes rubrum* L.) and Raspberries (*Rubus idaeus* L.). *International Journal of Pharmacology*, *Phytochemistry and Ethnomedicine*, 6, 30-37. https://doi.org/10.18052/www.scipress.com/IJPPE.6.30.

Golovenko, E., Lyashenko, S., Akimova, S., Mitina, L., Mulenkova, E., Belarbi, E.L., Guil-Guerrero, J. L. 2021. Gamma-linolenic Acid from Fifty-seven *Ribes* Species and Cultivars. *Plant Foods for Human Nutrition*, 76, 385-393. https://doi.org/10.1007/s11130-021-00913-8.

Guiné, R. P. F. 2018. The Drying of Foods and Its Effect on the Physical-Chemical, Sensorial and Nutritional Properties. In *International Journal of Food Engineering*, *4*(2), 93-100. https://doi.org/10.18178/ijfe.4.2.93-100

Hasan, M. U., Malik, A., U., Ali, S., Imtiaz, A., Munir, A., Amjad, W., Anwar, R. 2019. Modern drying techniques in fruits and vegetables to overcome postharvest losses: a review. *Journal of Food Processing and Preservation*, *43*(12), 1-15. https://doi.org/10.1111/jfpp.14280.

Horuz, E., Bozkurt, H., Karats, H., Maskan, M. 2017. Effects of hybrid (microwave-convectional) and convectional drying on drying kinetics, total phenolics, antioxidant capacity, vitamin C, color and rehydration capacity of sour cherries. *Food Chemistry*, 230, 295-305. https://doi.org/10.1016/j.foodchem.2017.03.046

Huang, W.Y., Yan, Z., Li, M., Ma, Y., Zhou, J., Sui, Z. 2018. Antioxidant and anti-inflammatory effects of blueberry anthocyanins on high glucose-induced human retinal capillary endothelial cells. *Oxidative Medicine and Cellular Longevity*, 10, https://doi.org/10.1155/2018/1862462

Hui, X., Wu, G., Han, D., Gong, X., Stipkovits, L., Wu, X., Tang, S., Brennan, M. A., Brennan, C. S. 2021. Bioactive compounds from blueberry and blackcurrant powder alter the physicochemical and hypoglycaemic properties of oat bran paste. *LWT*, 143, https://doi.org/10.1016/j.lwt.2021.111167

Hummer, K. E. 2010. *Rubus* pharmacology: antiquity to the present. *Horticultural Science*, *45*(11), 1587-1591. https://doi.org/10.21273/HORTSCI.45.11.1587

Hussain, S. Z., Naseer, B., Qadri, T., Fatima, T. Bhat, T. A. 2021. Cherries *(Prunus Cerasus)* – Morphology, Taxonomy, Composition and Health Benefits. *Fruits Grown in Highland Regions of the Himalayas*, 63-75. https://doi.org/10.1007/978-3-030-75502-7

Kiprowski, B., Malenčić, D., Ljubojević, M., Ognjanov, V., Veberic, R., Hudina, M., Mikulic-Petkovsek. 2021. Quality parameters change during ripening in leaves and fruits of wild growing and cultivated elderberry (*Sambucus nigra*) genotypes. *Scientia Horticulturae*, 277. https://doi.org/10.1016/j.scienta.2020.109792

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*(20), 255–269. https://doi.org/10.1089/jmf.2009.0062

Kowalska, G., Wyrostek, J., Kowalski, R., Pankiewicz, U. 2021. Evaluation of glycerol usage for the extraction of anthocyanins from black chokeberry and elderberry fruits. *Journal of Applied Research on Medicinal and Aromatic Plant*, 22. https://doi.org/10.1016/j.jarmap.2021.100296

Kula, M., Majdan, M. Glod, D. 2016. Phenolic composition of fruits from different cultivars of red and black raspberries grown in Poland. *Journal of Food Composition and Analysis*, 52, 74-82. https://doi.org/10.1016/j.jfca.2016.08.003

Kuntz, S., Kunz, C., Rudloff, S. 2017. Inhibition of pancreatic cancer cell migration by plasma anthocyanins isolated from healthy volunteers receiving an anthocyanin-rich berry juice. *European Journal of Nutrition*, *56*(1), 203-214. https://doi.org/10.1007/s00394-015-1070-3

Lachowicz, S., Kapusta, I., Świeca, M., Stinca, C. M., Meléndez-Martínez, A., Bienik, A. 2020. In Vitro Biological Activities of Fruits and Leaves of *Elaeagnus multiflora Thunb.* and Their Isoprenoids and Polyphenolics Profile. *Antioxidants (Basel)*, *9*(5), pp. 436. https://doi.org/10.3390/antiox9050436.

Lachowicz-Wiśniewska, S., Kapusta, I., Stinca, M.C., Meléndez-Martínez, J.L., Bienik, A., Ochmian, I., Gil, Z. 2021. Distribution of Polyphenolic and Isoprenoid Compounds and Biological Activity Differences between in the Fruit Skin + Pulp, Seeds, and Leaves of New Biotypes of *Elaeagnus multiflora Thunb*. *Antioxidants*, *10*(6), 849. https://doi.org/10.3390/antiox10060849.

Lachman, J., Proněk, D., Hejtmánková, A., Pivec, V., Faitová, K. 2003. Total polyphenol and main flavonoid antioxidants in different onion (*Allium cepa L.*) varieties. *Scientia Horticulturae*, *30*, 142-147. https://doi.org/10.17221/3876-HORTSCI

Lapornik, B., Prošek, M., Wondra, A. G. 2005. Comparison of extracts prepared from plant by-products using different solvents and extraction time. *Journal of Food Engineering*, 71, 214-222. https://doi.org/10.1016/j.jfoodeng.2004.10.036

Lavefve, L., Howard, L. R., Carbonero, F. 2020. Berry polyphenols metabolism and impact on human gut microbiota and health. *Food & Function*, *11*(1), 45-65. https://doi.org/10.1039/c9fo01634a.

Medvecký, M., Daniel, J. 2017. *Pestovanie brusnice vysokej* (*Vaccinium corymbosum L.*) *a obsah bioaktívnych látok v plodoch tohto ovocia v podmienkach severného Slovenska*. Metodická príručka. Národné poľnohospodárske a potravinárske centrum. ISBN 978-80-89800-15-5. Dostupné z: http://vutphp.sk/wp-content/uploads/Pestovanie-brusnice-vysokej.pdf

Meléndez-Martínez, A.J., Bohm, V., Borge, G. I. A., Cano, M. P., Fikselová, M., Gruskiene, R., Lavelli, V., Loizzo, M. R., Mandić, A. I., Brahm, P. M., Mišan, A. Č., Pintea, A. M., Sereikaité, J. 2021. Carotenoids: Considerations for Their Use in Functional Foods, Nutraceuticals, Nutricosmetics, Supplements, Botanicals, and Novel Foods in the Context of Sustainability, Circular Economy, and Climate Change. *Annual Review of Food Science Technology*, 12, 433-460. https://doi.org/10.1146/annurev-food-062220-013218.

Mikulic-Petkovsek, M., Koron, D., Veberic, R. 2016. Quality parameters of currant berries from three different cluster positions. *Scientia Horticulturae*, *21*, 188–196. https://doi.org/10.1016/j.scienta.2016.07.030.

Miraj, S. 2016. Chemical composition and pharmacological effects of *Sambacus nigra*. *Der Pharma Chemica*, vol. 8, no. 13, pp. 231-234.

Mlynarczyk, K., Walkowiak-Tomoczak, D., Lysiak, G. P. 2018. Bioactive properties of *Sambucus nigra* L. as a functional ingredient for food and pharmaceutical industry. *Journal of Functional Foods*, 40, 377-390. https://doi.org/10.1016/j.jff.2017.11.025.

Motyleva, S., Upadysheva, G. Tumaeva, T. 2021. The mineral composition of cherry (*Prunus cerasus Mill.*) fruits depending on the scion-stock combination. In *Potravinarstvo Slovak Journal of Food Sciences*. https://doi.org/10.5219/1454

Nowak, K. C., Mielnik, P., Sieda, M., Staniszewska, I., Bienik, A. 2021. The effect of ultrasound treatment on the extraction of lycopene and β-carotene from cherry silverberry fruits. *Agricultre and Food*, *6*(1), 247-254. https://doi.org/10.3934/agrfood.2021016

Okamoto, S., Orikasa, T., Kuwajima, G., Komoda, T., Saito, J., Yano, T., Muramatsu, Y., Koide, S., Shiina, T., Tagawa, A. 2012. Application of far-infrared for drying of Komatsuna. *Journal of the Japanese Society for Food Science and Technology*, *59*(9), 465-472. https://doi.org/10.3136/nskkk.59.465

Orellana-Palma, P., Petzold, G., Gauerra-Valle, M., Astudillo-Lagos, M. 2017. Impact of block cryoconcentration on polyphenol retention in blueberry juice. *Food Bioscience*, 20, 149-158. https://doi.org/10.1016/j.fbio.2017.10.006.

Orikasa, T., Ono, N., Watanabe, T., Ando, Y., Shiina, T., Koide, S. 2018. Impact of blanching pretreatment on the drying rate and energy consumption during far-infrared drying of Paprika (*Capsicum annuum* L.). *Food Quality and Safety*, *2*(2), 97-103. https://doi.org/10.1093/fqsafe/fyy006.

Orsavová, J., Hlaváčová, I., Mlček, J., Snopek, L., Mišuričová, L. 2019. Contribution of phenolic compounds, ascorbic acid and vitamin E to antioxidant activity of currant (*Ribes* L.) and gooseberry (*Ribes uva-crispa* L.) fruits. *Food Chemistry*, *284*, 323-333. https://doi.org/10.1016/j.foodchem.2019.01.072.

Patel, S. 2015. Plant genus Elaeagnus: underutilized lycopene and linoleic acid reserve with permaculture potentia. *Fruits*, *70*(4), 191–199. https://doi.org/10.1051/fruits/2015014

Paunović, S. M., Mašković, P., Nikolić, M., Miletić, R. 2017. Bioactive Compounds and Antimicrobial Activity of Black Currant (*Ribes nigrum* L.) Berries and Leaves Extract Obtained by Different Soil Management System. *Scientia Horticulturae*, 222, 69-75. https://doi.org/10.1016/j.scienta.2017.05.015

Pentallidis, G. E., Vasilakakis, M., Manganaris, G. A., Diamantidis, G. 2007. Antioxidant capacity, phenol, anthocyanin and ascorbic acid contents in raspberries, blackberries, red currants, gooseberries and Cornelian cherries. *Food Chemistry*, *102*, 777-783. DOI: https://doi.org/10.1016/j.foodchem.2006.06.021.

Piccolo, E. L., Garcìa, L. M., Landi, M., Guidi, L., Massai, R., Remorin, D. 2020. Influences of Postharvest Storage and Processing Techniques on Antioxidant and Nutraceutical Properties of *Rubus idaeus* L.: A Mini-Review. *Horticulturae*, *6*(4). https://doi.org/10.3390/horticulturae6040105.

Pieszka, M., Migdal, W., Gasior, R., Rudzińska, M., Bederska-Lojewska, D., Pieszka, M., Szczurek, P. 2015. Native oils from apple, blackcurrant, raspberry, and strawberry seeds as a source of polyenoic fatty acids, tocochromanols, and phytosterols: A health implication. *Journal Chemistry*, 4, 1-8. https://doi.org/10.1155/2015/659541.

Rao, A.V., Snyder, D.M. 2010. Raspberries and human health: a review. *Journal of Agricultural and Food Chemistry*, *58*(7), 3872-3883. https://doi.org/10.1021/jf903484g.

Roslan, A.S. 2020. Effect of drying methods and parameters on the antioxidant properties of tea (*Camellia sinensis*) leaves. *Food Production, Processing and Nutrition*, *2*(8), p. 1-8. https://doi.org/10.1186/s43014-020-00022-0.

Rugina, D., Sconta, Z., Leopold, L., Pintea, A., Bunea, A., Socaciu, C. 2012. Antioxidant activities of chokeberry extracts and the cytotoxic action of their anthocyanin fraction on HeLa human cervical tumor cells. *Journal of Medicinal Food*, *15*(8), pp. 700–706. http://doi.org/10.1089/jmf.2011.0246

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

Sánchez, C.Á., Lipan, L., Cano-Lamadrid, M., Kharaghani, A., Masztalerz, K., Carbonell-Barrachina, Á.A., Figiel, A. 2020. Comparison of Traditional and Novel Drying Techniques and Its Effect on Quality of Fruits, Vegetables and Aromatic Herbs. *Foods*, *9*(9), 1261. https://doi.org/10.3390/foods9091261

Senica, M., Stampar, F., Veberic, R., Mikulic-Petkovsek, M. 2016. Processed elderberry (*Sambacus niga* L.) products: A beneficial or harmful food alternative?. *LWT – Food Science and Technology*, 72, 182-188. https://doi.org/10.1016/j.lwt.2016.04.056.

Serradilla, M. J., Hernández, A., López-Corrales, M., Ruiz-Moyano, S., de Guía Córdoba, M., Martín, A. 2016. Composition of the cherry (*Prunus avium L. and Prunus cerasus L.; Rosaceae*). *Nutritional composition of fruit cultivars*. Academic Press, pp.127-147. https://doi.org/10.1016/B978-0-12-408117-8.00006-4

Sidor, A., Gramza-Michalowska, A. 2015. Advanced research on the antioxidant and health benefit of elderberry (*Sambucus nigra*) in food- a review. *Journal of Functional Foods*, 18, 941-958. https://doi.org/10.1016/j.jff.2014.07.012

Silva, S., Costa, E.M., Veiga, M., Morais, R.M., Calhau, C., Pintado, M. 2020. Health promoting properties of blueberries: A review. Critical Reviews. *Food Science and Nutrition*, *60*(2), 181-200. https://doi.org/10.1080/10408398.2018.1518895.

Sokol-Letowska, A., Kucharska, A. Z., Hodun, G., Golba, M. 2020. Chemical Composition of 21 Cultivars of Sour Cherry (*Prunus cerasus*) Fruit Cultivated in Poland. *Moleculus*, *25*(19), 4587. https://doi.org/10.3390/molecules25194587

Sueiro, L., Yousef, G. G., Seigler, D., De Mejia, E. G., Grace, M. H., Lila, M. A. 2006. Chemopreventive potential of flavonoids extracts from plantation-bred and wild *Aronia melanocarpa* (Black Chokeberry) fruits. *Journal of Food Science*, *71*(8), 480-488. https://doi.org/10.1111/j.1750-3841.2006.00152.x

StatSoft, Inc. 2014. STATISTICA (data analysis software system), version 12

Toshima, K., Hirano, T., Kunitake, H. 2021. Comparison of anthocyanins, polyphenols, and antioxidant capacities among raspberry, blackberry, and Japanese wild *Rubus* species. *Scientia Horticulturae*, 285. https://doi.org/10.1016/j.scienta.2021.110204.

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.

Veljković, B., Jakovljević, V., Stanković, M., Dajić-Stevanović, Z. 2019. Phytochemical and Antioxidant Properties of Fresh Fruits and Some Traditional Products of Wild Grown Raspberry (*Rubus idaeus L.*). *Notulae Botanicae Horti Agrobotanici Cluj-Napoca*, *4*(3), 565-573. https://doi.org/10.15835/nbha47311465.

Wojdylo, A., Figiel, A., Lech, K., Nowicka, P., Oszmiański, J. 2013. Effect of Convective and Vacuum–Microwave Drying on the Bioactive Compounds, Color, and Antioxidant Capacity of Sour Cherries. *Food and Bioprocess Technology*, 7, 829-841. https://doi.org/10.1007/s11947-013-1130-8.

Wu, X., Zhang, M., Bhandari, B. 2019. A novel infrared freeze drying (IRFD) technology to lower the energy consumption and keep the quality of *Cordyceps militaris*. *Innovative Food Science & Emerging Technologies*, *54*, 34-42. https://doi.org/10.1016/j.ifset.2019.03.003.

Zdunić, G., Šavikin, K., Pljevljakušić, D., Djordjević, B. 2016. Black (*Ribes nigrum* L.) and Red Currant (*Ribes rubrum* L.) Cultivars. *Nutritional Composition of Fruit Cultivars*, 101-126. https://doi.org/10.1016/B978-0-12-408117-8.00005-2.

Zhang, L. 2019. Effects of Freeze Vacuum Drying Combined with Hot Air Drying on the Sensory Quality, Active Components, Moisture Mobility, Odors, and Microstructure of Kiwifruits. *Journal of Food Quality*, 11. https://doi.org/10.1155/2019/8709343.

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/10.1016/j.jfutfo.2022.01.006.

Zhou, L., Xie, M., Yang, F., Liu, J. 2020. Antioxidant activity of high purity blueberry anthocyanins and the effects on human intestinal microbiota. *LWT*, 117. https://doi.org/10.1016/j.lwt.2019.108621.