Rocz Panstw Zakl Hig 2024;75(2)
https://roczniki.pzh.gov.pl/ https://doi.org/10.32394/rpzh.2024.0298

ORIGINAL ARTICLE

EVALUATION OF PHENOLIC CONTENT IN SELECTED RED FRUIT JUICES

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ABSTRACT

Background. Red fruits are characterised by a particularly high content of bioactive compounds, e.g. anthocyanins, tannins, pectins, vitamins and minerals. Dietary supply of proper amounts of antioxidants is essential to reduce oxidative stress, and thus is an important element in the prevention of lifestyle diseases.
Objective. The aim of the study was to evaluate and compare the content of polyphenols in selected red fruit juices (chokeberry, elderberry, pomegranate, cranberry), as well as to assess the impact of storage time on the content of these compounds in the analysed samples.
Material and methods. The research material consisted of 17 juices (100%): 3 chokeberry juices, 4 elderberry juices, 5 pomegranate juices and 5 cranberry juices, which differed in terms of the manufacturer, type, price range, country of origin and production method. The total polyphenol content was measured by spectrophotometry using the Folin-Ciocalteu reagent. The procedure was based on a modified method described by Waterhouse. Active acidity (pH) was measured with the potentiometric method using a pH-meter and the sucrose content was measured using a refractometer.
Results. The highest mean content of polyphenolic compounds was found in chokeberry and elderberry juices. Juice storage time did not reduce the mean content of polyphenolic compounds. The highest sucrose content was found in chokeberry juices and the lowest in cranberry juice.
Conclusions. Chokeberry and elderberry juices had the highest content of polyphenols among the tested products. Juices stored after opening in accordance with the manufacturer's instructions (at 4°C) do not lose their nutritional properties.

Keywords: *polyphenols, fruit juices, chokeberry, elderberry, pomegranate, cranberry*

STRESZCZENIE

Wprowadzenie. Czerwone owoce charakteryzują się szczególnie wysoką zawartością związków bioaktywnych m.in. antocyjanów, garbników, pektyn, witamin oraz składników mineralnych. Dostarczenie wraz z codzienną dietą odpowiedniej ilości przeciwutleniaczy jest niezbędne w celu redukcji stresu oksydacyjnego, a tym samym stanowi istotny element w prewencji chorób cywilizacyjnych.
Cel badań. Celem prowadzonych badań była ocena i porównanie zawartości związków polifenolowych w wybranych sokach z czerwonych owoców (aronia, czarny bez, granat, żurawina), a także zbadanie wpływu przechowywania na zawartość ww. związków w badanym materiale. Ocenie podlegały także inne parametry fizykochemiczne: kwasowość aktywna (pH), zawartość sacharozy oraz zawartość suchej masy.
Materiał i Metody. Materiał badawczy stanowiło 17 soków (100%): 3 soki z aronii, 4 soki z czarnego bzu, 5 soków z granatu, 5 soków z żurawiny, zróżnicowanych pod względem: producenta, rodzaju, przedziału cenowego, kraju pochodzenia oraz sposobu produkcji. Oznaczenie całkowitej zawartości polifenoli było prowadzone metodą spektrofotometryczną z wykorzystaniem odczynnika Folin-Ciocalteu`a. Procedura opierała się na zmodyfikowanej metodzie opisanej przez Waterhouse`a. Kwasowość aktywną (pH) oznaczono metodą potencjometryczną przy pomocy pH-metru, a zawartość sacharozy oznaczono przy użyciu refraktometru.
Wyniki. Największą średnią zawartość związków polifenolowych oznaczono w soku z aronii i czarnego bzu. Przechowywanie soków nie wpłynęło na zmniejszenie średniej zawartości związków polifenolowych. Zawartość sacharozy w badanych produktach była największa w sokach z aronii, a najmniejsza w soku z żurawiny.

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Publisher: National Institute of Public Health NIH - National Research Institute

Wnioski. Soki z aronii i czarnego bzu charakteryzowały się największą zawartością polifenoli wśród badanych produktów. Soki przechowywane po otwarciu zgodnie z zaleceniami producenta (w temperaturze 4°C) nie tracą swoich właściwości odżywczych.

Słowa kluczowe: *polifenole, soki owocowe, aronia, czarny bez, granat, żurawina*

INTRODUCTION

Fruit and vegetables are products rich in health-supporting ingredients. However, the group of red or dark-coloured fruits, which are characterised by a high content of, among other things, polyphenolic compounds, including anthocyanins, tannins, pectins, carotenoids, vitamins and minerals, is particularly noteworthy [15]. Dietary supply of proper amounts of antioxidants is essential to reduce oxidative stress, and thus is an important element in the prevention of lifestyle diseases [16].

Chokeberry (*Aronia melanocarpa*) is a plant whose fruits are particularly rich in polyphenolic compounds, including flavonoids, anthocyanins, flavan-3-ols and phenolic acids. The content of phenolic compounds depends on the cultivar, degree of maturity, growing environment, post-harvest storage conditions and processing techniques [2, 16]. Chokeberry is particularly recommended in the prevention of cardiovascular diseases due to its anti-atherosclerotic, antihypertensive and anti-platelet properties. Polyphenolic compounds found in its fruits reduce blood cholesterol (LDL) and triglycerides [5]. Furthermore, chokeberry fruits show gastroprotective, hepatoprotective and antiproliferative effects, and are also used in the prevention and treatment of diabetes and other lifestyle diseases [13, 4]. Due to their tart taste, they are most often consumed in processed form (jams, tea or juices). The latter are increasingly popular among consumers due to their wide assortment, including sugar-free, preservative or dye-free products, which is increasingly important for the wide range of consumers [33].

Elderberry (*Sambucus nigra* L.) is a shrub or a small tree belonging to Adoxaceae, commonly known as the moschatel family. Fruit and flowers are most often used for medicinal, cosmetic and food purposes. The plant was used in traditional medicine for respiratory diseases, common colds, flu, burns, swelling, wounds, joint sprains and dislocations, skin problems, insect bites and stings, rheumatic problems, dental pain, nephrological disorders, gastrointestinal and eye diseases. Elderberry infusions, extracts, and syrups are currently recommended for colds, rhinitis, and as a diaphoretic, diuretic, laxative and anti-inflammatory agent. The use of elderberry in these conditions is associated with its antiviral and antibacterial action, as well as its ability to boost the immune system [31]. The health-supporting properties of elderberry are related primarily to its high content of antioxidants, anthocyanins, flavonols (quercetin, kaempferol) and phenolic acids in particular [6]. These compounds neutralize oxidative stress, which produces beneficial effects in the form of cardiovascular support, reduced glycaemia, immune system stimulation, anti-cancer effects, as well as increased activity of antioxidant plasma enzymes, including glutathione, and reduced uric acid levels [31]. Elderberry fruits are most often used for juices, jams, marmalades, jellies, desserts, candies, syrups, teas, wines and as colourants for ice cream, yoghurts, candies and cakes. Raw fruits are poisonous, but toxic substances are decomposed by heat treatment [17].

In terms of botanical classification, large-fruited cranberry (*Vaccinium macrocarpon* L.) belongs to the Ericaceae family. Its fruits are spherical red berries with thin, smooth skin. Cranberries are a source of valuable ingredients for the body. They contain vitamins (A, C, E), minerals (potassium, sodium, selenium), as well as lutein and β-carotene. Polyphenols, i.e. flavonoids, phenolic acids and stilbenes, are the most important group of compounds contained in cranberry fruits [21]. Cranberry is very popular among consumers not only due to its taste, but also because of its multiple health-supporting properties. It is most often available in the form of fresh and dried fruit, but it is also used to produce juices, sauces, preserves and jellies [34].

Its beneficial properties include, among others, anti-cancer, anti-inflammatory and antimicrobial effects. Studies have shown that cranberry reduces LDL cholesterol and glucose levels in patients with metabolic syndrome. This is due to the presence of proanthocyanins, flavonoids and a high content of vitamin C, all of which have strong antioxidant properties [25, 29]. Active substances contained in cranberry, such as citric acid and benzoic acid, help prevent urolithiasis and support the treatment of bladder inflammation. Furthermore, the high content of ascorbic acid acidifies the urine, which hinders the growth of bacteria, and the proanthocyanidins prevent uropathogenic *E. coli* from adhering to the urinary epithelial mucosa, therefore cranberries are recommended in the prevention of genitourinary conditions [10].

Pomegranate (*Punica granatum* L.) was known for its health-supporting properties already in antiquity, when the juice made of this fruit was recommended against diarrhoea, caries, ulcers, and pharyngitis. Pomegranate and its products are a very rich source of vitamins A, C, E, and B, as well as minerals, proteins, folic acid, fibre, beta-carotene and polyphenols, in particular ellagitannins (punicalagin), anthocyanins and hydrolysable tannins [1]. The latter components contribute to multiple health-supporting properties of pomegranate. These include, among others, cardioprotective, blood pressure lowering and LDL lowering action. The active substances present in the pomegranate help neutralise oxidative stress and alleviate inflammation [30, 36]. There is also scientific evidence for antimicrobial, antifungal and antiviral effects of this fruit. However, the anti-proliferative and anti-cancer effects of pomegranate (prostate, colon, oral and breast cancer) are particularly noteworthy [1].

Regular consumption of food products rich in, among others, polyphenolic compounds contributes to maintaining proper health, as well as helps prevent and treat many diseases. It is important that the consumed products have a low degree of processing to minimise the loss of beneficial components. 100% fruit juices widely available all year round, regardless of the season, are an example of this type of product.

The aim of the study was to estimate and compare the content of polyphenols in selected red fruit juices (chokeberry, elderberry, pomegranate, cranberry), as well as to assess the impact of storage time on the content of these compounds in the tested samples. Other physical and chemical parameters, such as active acidity (pH), sucrose content and dry matter content, were also assessed.

MATERIALS AND METHODS

The study included 17 juices (100%) from the following red fruits: chokeberry (n=4 products), elderberry (n=3 products), pomegranate (n=5 products) and cranberry (n=5 products); a total of 68 samples were tested. Juices was differed in terms of the manufacturer, type, price range, country of origin (Poland, European Union countries or outside the EU – Turkey, Canada), and production method (directly squeezed from fruit or obtained from concentrated juice). Each of the products of a given type of juice was represented by various manufacturers. Four juices of each manufacturer from different batches were analysed to obtain the most representative results.

The tested juices were purchased in generally accessible grocery stores, health food stores and pharmacies. The selected juices did not contain added sugar or preservatives and were packed in dark glass (except for pomegranate juices). A detailed description of the tested juices is shown in Figure 1.

Each of the juices was assessed for the content of polyphenolic compounds immediately after opening, as well as for the impact of storage on the content of the above-mentioned compounds in the tested material. Other physical and chemical parameters, such as active acidity (pH), sucrose content and dry matter content, were also assessed (Figure 2). Measurements were performed on the day of the opening of the product, 24 and 48 hours after opening, and then 1, 2, 3 weeks after opening. After opening, the juices were stored according to the manufacturer's instructions, i.e. in a refrigerator at 4°C.

Total polyphenol content

The total polyphenol content was measured by spectrophotometry using the Folin-Ciocalteu reagent. The procedure was based on a modified method described by Waterhouse [37]. Before the analysis, the

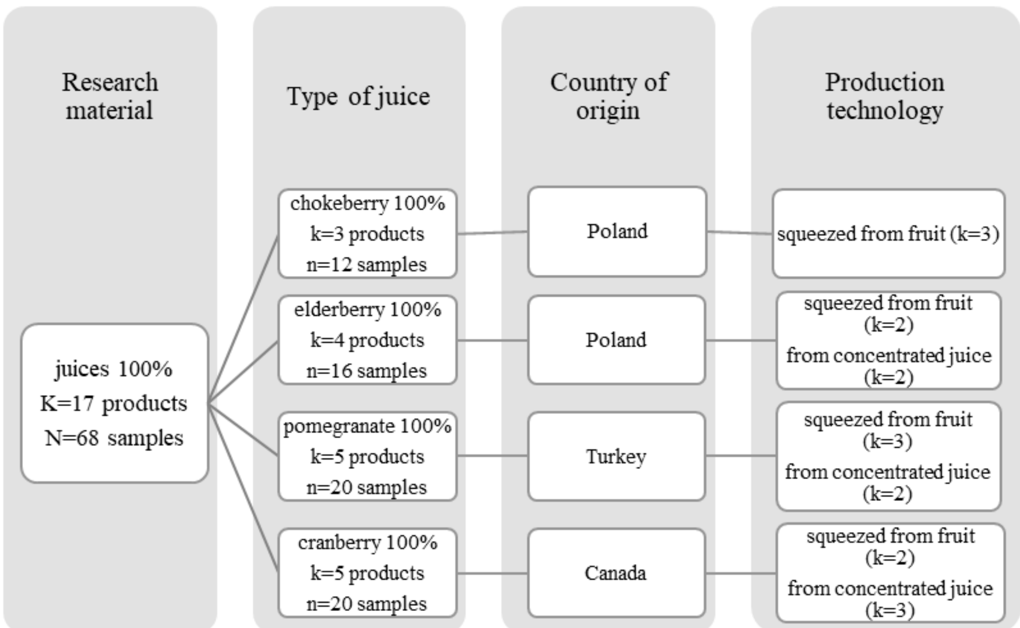

Figure 1. Characteristics of the research material

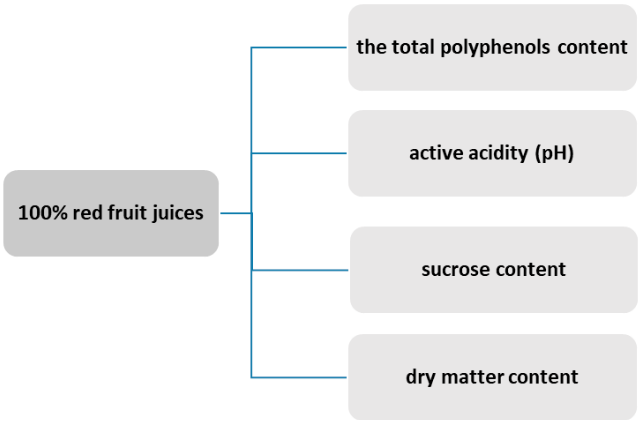

Figure 2. Physicochemical parameters determined in the tested 100% red fruit juices

juices were thoroughly stirred, samples were collected and diluted with demineralised water (10 x dilution for chokeberry and elderberry juices, 10 x dilution for pomegranate and cranberry juices), and then filtered through a soft quantitative filter. To determine the total polyphenol content, 0.1 mL of a diluted and filtered juice sample was transferred into a 10 mL flask, and then 5 mL of distilled water was added. Next, 0.5 mL of Folin-Ciocalteu's reagent was added and mixed. Finally, 1.5 mL of 20% sodium carbonate (Na_2CO_3) was added, and the sample was made up to the mark with distilled water and thoroughly mixed. The samples prepared in this way were placed in an incubator (Incucell/V111, Memmert) at 40°C for 30 minutes. After the pre-set time, the samples were removed from the incubator and transferred successively to glass cuvettes with an optical path length of 10 mm. The absorbance of the samples was then measured using a UV/VIS spectrophotometer (HALO SB-10 Spectrophotometer, Biogenet) at a wavelength of 765 nm against blank. The measurements were performed in quadruple. In parallel with the tested samples, the absorbance was measured for a series of gallic acid standards (0-500 µg/mL). Each standard was measured in triplicate. Based on the obtained results, a curve y=0.0009x+0.0015 was plotted; R2=0.9995, which was used to estimate the total content of polyphenols in the tested samples. The result was expressed in gallic acid equivalents (mg GAE/100 mL of the product).

Active acidity (pH)

Active acidity (pH) was measured with the potentiometric method using a pH-meter (pH-meter CPC-505, Elmetron). Before starting the measurements, the device was calibrated in buffering solutions (pH values: 4, 7 and 9). The measurements were performed at room temperature.

Sucrose content

The sucrose content was measured using a refractometer (HI 96801 portable digital sucrose refractometer, HANNA Instruments), with the result given in Brix (°Bx) corresponding to % sucrose (g/100mL of product). Before the measurements, the device was calibrated using distilled water. The measurements were performed at room temperature.

Dry mass

Dry matter content was measured with moisture analyser (MB23, Ohaus). Samples of 3 g of each juice were collected, spread on tissue paper and placed in a moisture analyser at 105°C. The results were then read: water content (%), dry matter content (%) and dry matter content (g). The measurements were performed in triplets for each juice.

Statistical analysis

MS Excel 2013 and Statistica v.13.3 (StatSoft Polska) software were used for statistical data processing. Measurable data are presented as mean and standard deviation – X±S, along with the median and interquartile range expressed by the lower and upper quartile – M ($Q_{0.25}$-$Q_{0.75}$). The Shapiro-Wilk test was used to assess the normality of the distribution. Differences in the distributions in two unrelated groups, due to the asymmetry, were assessed using the Mann-Whitney U test. The significance of the differences in distributions for multiple related measurements (separate time units) was assessed with the Friedman ANOVA test. Spearman rank correlation coefficient with its significance test was used for the assessment of the dependence of measurable variables. Significance level was set at p=0.05.

RESULTS

The content of polyphenols

When analysing the content of polyphenols (expressed in gallic acid equivalents [mg GAE/100 mL]) in individual types of juice, their significant differentiation over time was observed in the case of chokeberry, pomegranate and cranberry juice. In the case of chokeberry juice, there was a decrease in the mean polyphenol content the day after opening, followed by a significant increase in its levels. However, it should be noted that the minimum content of polyphenols immediately after opening the juice (on the first day) was the highest compared to subsequent measurements. The average content of polyphenols in elderberry juice remained stable, except for the second day after opening the juice, when it increased at the border of statistical significance (p=0.05). On the other hand, the analysis of pomegranate juices showed a significant variation over time, with a significant decrease in the mean content of gallic acid over 3 weeks: from 382.2 mg GAE/100mL to 349.2 mg GAE/100mL (p<0.0001). In the case of cranberry juice, the average polyphenol content remained constant, except for the measurement performed one week after opening the juices. This value significantly increased (by about 15%) compared to measurements at other time points ($p<0.0001$) (Table 1). There was no analysis of differences in the content of polyphenols in different juices of the same fruit. However, an additional statistical analysis was performed between individual types of juices (chokeberry, elderberry, pomegranate and cranberry juice) and their average gallic acid content values on the opening day ($p=0.0001$), after 24 h ($p=0.001$), after 48 h ($p=0.001$), after 1 week ($p=0.0001$), after 2 weeks ($p=0.0001$) and after 3 weeks ($p=0.0001$).

The technology of juice production (directly squeezed from fruit or produced from concentrated juice) was also taken into account in the analyses. It was only in the case of cranberry juices that significant differences in the mean content of polyphenols were observed in the period from the opening day to two weeks after opening. Higher polyphenol levels were found in products made from concentrated juice (Table 2).

From the juices analysed in the present study, the highest mean content of polyphenols was found in chokeberry juices (491.2-663.15 mg GAE/100 mL), and the lowest in cranberry juices (79.38-185.49 mg GAE/100 mL). Elderberry juices contained from 401.16 to 571.30 mg GAE/100 mL, and pomegranate juices from 253.36 to 420.60 mg GAE/100 mL. In the case of chokeberry and elderberry juice, it was observed that juices from organic crops (bio farming) contain on average 100 to 200 mg GAE/100mL more polyphenols compared to juices from conventional sources. No such correlation was found for pomegranate and cranberry juices.

Active acidity (pH)

In addition to the total content of polyphenols, we also measured the active acidity (pH) of the juices – starting from the baseline (opening) and continuing for the 3-week storage period. Cranberry juices had the lowest pH (from 1.82 to 1.94), whereas elderberry juices had the highest pH (from 3.51 to 4.28). Active acidity ranged from 3.2 to 3.54 for chokeberry juices, and from 2.39 to 3.19 for pomegranate juices. No significant pH changes were observed for elderberry and chokeberry juices, considering the measurement on the day of opening the juice and one week afterwards. The increase in pH occurred in the second week after opening and continued until the end of the experiment. In pomegranate juices, the pH decreased in the first week after opening, and then it remained at the baseline level until week 3 after opening.

Water and dry matter content

The tested juices were also assessed for water and dry matter content. The highest dry matter content was found in chokeberry (14.78–20.35%) and elderberry juices (12.33–16.58%). Dry matter content ranged from 11.73 to 14.7% for pomegranate juice, and from 5.75 to 6.75% for cranberry juice. A significantly lower water content was found for pomegranate and elderberry products obtained from direct pressing, which was also associated with a significantly higher dry matter content (Table 3).

Sucrose content

The highest sucrose content was found in chokeberry juices (14.05–17.1 °Brix). The other juices had a sucrose content of 14–16.1 °Brix (pomegranate), 7.03-10.15 °Brix (black elderberry), and 7.23–8.05 °Brix (cranberry). We observed a significant positive

Table 1. Average content of gallic acid in the tested juices depending on the time from opening by the type of juice

Gallic acid content [mg GAE/100 mL]							
	Time from opening						p-value
	Opening day	24 hours	48 hours	1 week	2 weeks	3 weeks	
Chokeberry n=12	623.5±89 640 (542.2-691.7)	569±104 590 (477.2-654.4)	578.6±77.9 616.7 (493.9-642.8)	600±76 626.1 (511.1-666.1)	595.8±77.1 634.4 (518.3-642.8)	610.4±96.8 666.7 (485.6-681.7)	p=0.005
Elderberry n=16	513.1±88.7 539.4 (448.9-570.6)	501±86.1 533.9 (441.7-556.7)	572.6±58.3 559.4 (531.1-615.6)	509.9±96.1 557.2 (441.1-566.7)	490.7±81.8 512.2 (392.8-565)	520.9±88.6 553.9 (471.1-581.1)	p=0.05
Pomegranate n=20	364.9±75.3 382.2 (283.6-426.1)	371.9±77.6 404.7 (307.2-429.2)	326.1±78.3 343.6 (246.7-361.4)	338.6±82.1 363.3 (260.8-420)	342.5±63 356.7 (283.9-373.6)	320±60.7 349.2 (243.1-369.4)	p<0.0001
Cranberry n=20	123.2±48.5 104.4 (81.4-175.3)	123.7±41.1 107.2 (89.7-158.9)	114.6±42.5 93.6 (80-163.6)	132.3±44.6 121.9 (90.3-175)	119.8±39.6 105.8 (82.2-161.7)	129.8±79.3 105.3 (82.8-153.3)	p<0.0001

Measurable data are presented as mean and standard deviation (X±S), along with the median and interquartile range expressed by the lower and upper quartile – M ($Q_{0.25}$-$Q_{0.75}$); p-value – Friedman ANOVA results with repeated measures

Table 2. Average content of gallic acid depending on the production technology by the type of juice and opening time

Gallic acid content [mg GAE/ 100 mL]	Production technology	Time from opening					
		Opening day	24 hours	48 hours	1 week	2 weeks	3 weeks
Chokeberry n=12	squeezed from fruit	623.5±89 640 (542.2-691.7)	569±104 590 (477.2-654.4)	578.6±77.9 616.7 (493.9-642.8)	600±76 626.1 (511.1-666.1)	595.8±77.1 634.4 (518.3-642.8)	610.4±96.8 666.7 (485.6-681.7)
Elderberry n=16	squeezed from fruit	461.7±96.4 457.8 (371.7-551.7)	457.2±104.9 441.7 (362.2-555.6)	549.4±49.4 538.9 (523.3-563.3)	458.1±113.8 457.2 (352.8-564.4)	461±88.2 456.7 (373.3-544.4)	488.2±119 498.3 (377.2-597.8)
	from concentrated juice	564.6±39.2 562.8 (530.6-601.7)	544.9±21.6 540 (533.9-556.7)	595.8±60.1 576.1 (559.4-654.4)	561.8±25.8 558.3 (543.9-580)	520.4±67.3 541.7 (495.6-567.8)	553.6±14.7 553.9 (542.2-564.4)
	p-value	p=0.046	p=0.13	p=0.08	p=0.25	p=0.21	p=0.96
Pomegranate n=20	squeezed from fruit	378.8±77.7 411.7 (286.7-431.4)	361.5±80 404.7 (255.6-420.8)	314.3±56.5 343.6 (241.7-358.9)	335.2±89.6 372.8 (240.6-420)	333.4±45.4 356.7 (296.9-362.5)	319.4±59.5 349.2 (243.1-361.1)
	from concentrated juice	343.9±71.2 334.2 283.6-382.2)	387.5±76.4 384.7 (315-461.4)	343.8±105 327.8 (248.1-430.8)	343.8±75.2 325.8 (281.1-407.5)	356.1±84.8 358.9 (276.9-435)	321±66.7 323.1 (262.2-382.5)
	p-value	p=0.33	p=0.23	p=0.23	p=0.62	p=0.56	p=0.64
Cranberry n=20	squeezed from fruit	88.8±19.1 91.7 (68.9-104.4)	95.5±13.1 96.4 (84.2-107.2)	82.8±13.2 81.7 (72.5-93.6)	103.1±18.4 98.1 (86.4-121.9)	93.1±14.7 95 (78.3-105.8)	93.7±15.2 89.7 (81.7-105.3)
	from concentrated juice	146.1±49 171.9 (88.9-181.4)	142.5±43 151.9 (92.5-177.8)	135.8±42.3 151.4 (82.2-173.1)	151.9±46.7 172.5 (92.5-181.1)	137.5±41.3 160.3 (85.3-165.6)	153.8±95.6 151.4 (84.4-160.3)
	p-value	p=0.03	p=0.02	p=0.02	p=0.03	p=0.04	p=0.06

Measurable data are presented as mean and standard deviation (X±S), along with the median and interquartile range expressed by the lower and upper quartile – M ($Q_{0.25}$-$Q_{0.75}$); p-value – U Mann-Whitney test result

effect of the sucrose level on gallic acid content in elderberry, pomegranate and cranberry juices. In the case of chokeberry juices, the correlation was moderate, but not statistically significant (Table 4).

DISCUSSION

The antioxidant capacity of fruit juices was also assessed by Nowak et al. [26], who investigated both self-prepared juices and those produced on an industrial scale. Chokeberry, apple, blackberry and blackcurrant juices came from Polish plantations, whereas sea buckthorn and pomegranate juices were imported from Georgia, and orange juices from Spain. The juices were produced using traditional or organic methods. The pH values ranged between 3.03 and 3.74. Sea buckthorn juice had the lowest pH, whereas the highest pH was found for apple nectar. The total content of polyphenols in chokeberry juice was about 550 mg GAE/100 mL, which corresponded to our findings. Other authors confirm a similar total polyphenol content (approximately 500-600 mg GAE/100 mL) in chokeberry juices [15, 9]. The content of polyphenols in individual parts of this plant can range from 3.73 g/100 g dry matter in juice, through 7.85 g/100 g dry matter in fruits to 10.58 g/100 g dry matter in pomace [38]. Other authors report that the total polyphenol content in chokeberry juice can range from 690 to 2560 mg GAE/100 g fresh matter. The content of polyphenols in the juice obtained from this fruit is 2 to 8 times higher than that in blackberry, blueberry, raspberry or red currant juices [14].

Oszmiański and Lachowicz [28] assessed, among other things, antioxidant activity, the content of bioactive compounds, water and dry matter in juices from crushed and uncrushed chokeberry fruits. The dry matter content was 16.87% for uncrushed fruit and 15.46% for crushed fruit. In our study, chokeberry juices had a dry matter content of 15–19%.

Tolić et al. [33] assessed 22 products made of chokeberry (juices, powders, capsules, fruit teas, dried fruits) for their physicochemical properties, phenolic content and antioxidant properties. The active acidity of the tested juices ranged from 3.54 to 3.94; dry matter content from 13.42 to 21.54%, and total polyphenol content from 300.2 to 663.9 mg GAE/100 mL. These

Table 3. Water and dry matter content in the tested juices

Type of juice	Production technology	Water content [%]	Water content [g]	Dry matter content [%]	Dry matter content [g]
Chokeberry n=12	overall	82±3.3 82.3 (80.8-84.6)	2.5±0.1 2.5 (2.4-2.5)	18.1±3.3 17.7 (15.4-19.4)	0.5±0.1 0.5 (0.5-0.6)
	squeezed from fruit	82±3.3 82.3 (80.8-84.6)	2.5±0.1 2.5 (2.4-2.5)	18.1±3.3 17.7 (15.4-19.4)	0.5±0.1 0.5 (0.5-0.6)
Elderberry n=16	overall	85.6±3.2 85 (83.4-88)	2.6±0.1 2.5 (2.5-2.6)	14.4±3.3 15.1 (12-16.7)	0.4±0.1 0.5 (0.4-0.5)
	squeezed from fruit	83.8±2.6 83.8 (82.2-84.6)	2.5±0.1 2.5 (2.46-2.54)	16.2±2.6 16.3 (15.4-17.9)	0.5±0.1 0.5 (0.46-0.55)
	from concentrated juice	87.5±2.9 87 (85.6-89.8)	2.6±0.1 2.6 (2.6-2.7)	12.6±2.9 13 (10.3-14.4)	0.4±0.1 0.4 (0.3-0.4)
	p-value	p=0.04	p=0.04	p=0.04	p=0.04
Pomegranate n=20	overall	86.6±1.2 86 (85.6-87.8)	2.7±0 2.7 (2.7-2.8)	13.4±1.3 14 (12.2-14.4)	0.3±0 0.3 (0.2-0.3)
	squeezed from fruit	85.7±0.3 85.7 (85.6-86)	2.7±0 2.7 (2.71-2.72)	14.3±0.6 14.4 (14-14.4)	0.3±0 0.3 (0.28-0.29)
	from concentrated juice	88±0.8 88.2 (87.5-88.4)	2.8±0 2.8 (2.8-2.8)	12.1±0.8 11.9 (11.6-12.5)	0.2±0 0.2 (0.2-0.3)
	p-value	p=0.0002	p=0.0002	p=0.0002	p=0.0002
Cranberry n=20	overall	94±0.4 94 (94-94.3)	2.9±0 2.9 (2.9-2.9)	6±0.4 6 (5.7-6)	0.1±0 0.1 (0.1-0.1)
	squeezed from fruit	94.2±0.3 94 (94-94.5)	2.9±0.01 2.88 (2.88-2.89)	5.8±0.3 6 (5.5-6)	0.1±0.01 0.1 (0.11-0.12)
	from concentrated juice	93.9±0.5 94 (93.5-94.1)	2.9±0.01 2.9 (2.87-2.88)	6.2±0.5 6(5.9-6.5)	0.1±0.01 0.1 (0.12-0.13)
	p-value	p=0.26	p=0.16	p=0.26	p=0.16

Measurable data are presented as mean and standard deviation (X±S), along with the median and interquartile range expressed by the lower and upper quartile – M ($Q_{0.25}$-$Q_{0.75}$); p-value – U Mann-Whitney test result

Table 4. Average content of gallic acid depending on the average content of sucrose on the opening day of the tested products by to the type of juice

Type of juice	Measurement on the opening day		Spearman rank correlation coefficient p-value
	gallic acid content [mg GAE/100 mL]	sucrose content [°Brix]	
Chokeberry n=12	623.5±89 640 (542.2-691.7)	15.8±1.4 16.3 (14.2-17.1)	0.5 p=0.1
Elderberry n=16	513.1±88.7 539.4 (448.9-570.6)	9.1±1.3 9.6 (8.2-10)	0.66 p=0.005
Pomegranate n=20	364.9±75.3 382.2 (283.6-426.1)	15.2±0.7 15.1 (14.9-15.7)	0.62 p=0.003
Cranberry n=20	123.2±48.5 104.4 (81.4-175.3)	7.8±0.3 7.8 (7.7-8)	0.47 p=0.03

Measurable data are presented as mean and standard deviation (X±S), along with the median and interquartile range expressed by the lower and upper quartile – M (Q0.25-Q0.75); p-value – the result of the significance test of the R Spearman correlation coefficient

findings are similar to those obtained in our study. Similar pH values were also reported by other authors. Bolling et al. [3], reported that the pH of chokeberry juice ranged from 3.15 to 3.45 pH, depending on the harvest week. The authors also measured the content of polyphenols in chokeberry juices, which ranged from 400 to 500 mg GAE/100 mL. The value for refractometric extract in the analysed juices fluctuated depending on the harvest week (from 10.5 °Brix in week 1, through 7.8 in week 2 and increasing up to week 7 to 14.3 °Brix). Jeszka-Skowron et al. [11] evaluated the antioxidant activity of methanol/water extracts of dried goji berries, dried cranberries and raisins. Food products came from organic and conventional cultivation in various parts of the world (China, USA, Poland, Canada, Turkey, Iran). The highest content of polyphenols was found in dried goji fruits (a mean of 11.5 mg GAE/g DM), while it was approximately 2.5 mg GAE/g dry matter for dried cranberries, and about 1.9 mg GAE/g dry matter for raisins. No correlation was found between the higher antioxidant activity of the fruit and its origin from organic farms.

Vu et al. [35] assessed the effects of heat treatment and exposure to light and oxygen on the stability of bioactive compounds in cranberry, and analysed whether cranberry extracts and juices could effectively inhibit the proliferation of colorectal cancer cells. It was shown that compared to thermal treatment, freezing is a better method to inhibit the drop in polyphenol levels in cranberries. The total phenolic content in three juices (raw, filtered and concentrated) was also assessed. It was on average from 1375 μg GAE/mL (pH 7) to 1681 μg GAE/mL of juice for unfiltered juices (pH 2.5), and from 1255 μg GAE/mL to 1595 μg GAE/mL of juice for filtered juices. The polyphenol content in concentrated juices was 2 to up to 6 times higher (from 2655 μg GAE/mL [pH 7] to 8648 μg GAE/mL [pH 2.5]). The above studies support the potential use of cranberry extracts or juices to aid cancer prevention and/or treatment.

Results similar to those presented in this paper were obtained by Nowak et al. [27], who conducted a comparative analysis of phenolic compounds in organic chokeberry, elderberry, cranberry and pomegranate juices. The juices came from organic Polish (chokeberry and elderberry) and foreign (cranberry – Canada; pomegranate – Turkey) crop systems. The lowest and the highest pH was reported for cranberry (2.78) and elderberry (4.21), respectively, which corresponds to our findings. Pomegranate juice had a pH of 3.53, which was higher than in juices used in our research. Chokeberry juices, on the other hand, had a pH of 3.63–3.88, which corresponds to our findings. All analysed juices were a rich source of phenolic compounds. Chokeberry juices were characterised by the highest total polyphenols (up to 790 mg GAE/100 mL). Lower values were reported for pomegranate and elderberry juices: 356 mg GAE/100 mL and 324 mg GAE/100 mL, respectively. The lowest content of polyphenols (163 mg GAE/100 mL) was found in cranberry juice. The total polyphenol content in the tested juices was also very similar to the results obtained in our research.

Narwojsz et al. [24] compared, among other things, polyphenol content in cranberry fruits differing in terms of variety and place of cultivation. The mean total content of polyphenols in the tested material ranged from 163 to 315 mg GAE/100 g fresh matter.

Sidor and Gramza-Michałowska [31] performed a review of research on the antioxidant properties of elderberry. The fruits of this plant contain an average of 371 mg to 583 mg GAE/100 g fresh matter. Pliszka [23] showed that the mean content of polyphenols in elderberry fruits ranged from about 600 to 1000 mg GAE per 100 g of fresh matter. Johnson et al. [12] measured the total content of polyphenols and anthocyanins in 3 genotypically different elderberries (different geographic origins). The estimations were performed immediately after harvest and during the period of 3, 6, 9 months of storage of frozen fruit. There were differences in polyphenol content between fruits from plants of different genotypes: 570 mg GAE/100 mL for Adams II, 800 mg GAE/100 mL for Bob Gordon and 680 mg GAE/100 mL for Wyldewood. The greatest drop in the content of polyphenols was observed after a 3-month storage period (by about 50-200 mg GAE/100 mL of juice). Nine months after opening, the content of polyphenols in fruit juices of individual varieties was 450, 600 and 490 mg GAE/100 mL, respectively, which was not less than 72% of the baseline polyphenol content in the tested material.

In our study, the content of polyphenols in pomegranate juices was on the average level, i.e. from 278.1 to 420.6 mg GAE/100 mL. The results reported by other authors indicate a very large variation in the content of polyphenols in the juice of this fruit. Mahdavi R. et al. [20] showed that the mean total polyphenol content was 421.42 mg GAE/100 mL in fresh pomegranate juices and 381.73 mg GAE/100 mL in commercial pomegranate juices. Other researchers reported a total polyphenol content of 146.94 mg GAE/100 g (Fu et al. [8]) or 115.77 mg GAE/100 g (Kościuk et al. [18]). Esposto et al. [7] assessed polyphenol content and antioxidant activity, and performed a sensory analysis in pomegranate juices from conventional and organic crops, as well as from concentrate-based and freshly squeezed juices. The average content of polyphenols was from 1379.9 to 3748.8 mg GAE/L in concentrate juices, and from 1632.0 to 2736 GAE/L in freshly squeezed juices. The varied content of polyphenols in pomegranate juices is not only due to the production method or type of cultivation, but it also depends on the type of fruit and the place of cultivation. One study compared the content of polyphenols in juices made of "Wonderful" cultivars from Spain, where the average polyphenol content ranged widely from 1562 to 4500 mg GAE/L (Mena et al. [22]). Turkish pomegranate juices contained between 2,602 and 10,086 mg GAE/L

(Tezcan et al. [32]). Labbe et al. [19] compared the content of polyphenols in pomegranate juices at different stages of fruit ripeness and between different cultivars. Their findings indicate that the fruit species plays a decisive role in the content of polyphenols in juices.

CONCLUSIONS

Chokeberry and elderberry juices had the highest content of polyphenols among the tested products. Differences between juices from the same type of fruit may result from different places of origin, growing conditions (exposure to sunshine), degree of ripeness at harvest, species variety, as well as the technology for juice production and storage. The average content of polyphenols in all tested juices remained at a similar level from the moment of opening to the end of the 3-week storage period. Juices stored after opening in accordance with the manufacturer's instructions (at 4°C) do not lose their nutritional properties. All analysed juices were acidic, with the lowest pH in cranberry juices and the highest pH in elderberry juices. The acidity of the juices persisted from the moment of opening to the end of the 3-week storage period. Chokeberry and elderberry juices had the highest dry matter content, while cranberry juice had the lowest dry matter content. The highest sucrose content was found for chokeberry and pomegranate juices, and the lowest in cranberry juices.

Disclosure conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Received: 18.01.2024
Revised: 12.04.2024
Accepted: 16.04.2024