Influence of variety and production system on selected chemical parameters of beetroot juices prepared from seven beetroot varieties

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Summary

Beetroots and beetroot juices become more interesting for consumers because of their widely reported health benefits. The aim of this research was to evaluate the nutritional composition of beetroot juices depending on the agricultural production system and the variety used for juice production. The research material consisted of juices produced from 7 varieties of certified organic and 7 non-organic beetroots. Concentrations of betalains, phenolic acids, flavonoids, organic acids, sugars and vitamin C in the juices were estimated. Most of the results did not confirm the assumption that increased synthesis of polyphenolic compounds would be observed when organic production practices were used. Only the concentration of betanin, the primary pigment of beetroots, confirmed this assumption. Significant differences were observed in the concentrations of certain components of the juices made from individual varieties of beetroots. Thus, the use of the varieties richest in beneficial compounds in terms of their health-promoting properties can be fundamentally important for the development of the production of juices or dietary supplements from beetroots.

Keywords

organic production; conventional production; variety; beetroot juices; bioactive compounds

The increased consumer interest in beetroots (*Beta vulgaris* ssp. *vulgaris* var. *conditiva*) is related to their high content of polyphenolic bioactive compounds, especially betalain, flavonoids and phenolic acids [1, 2]. Due to the antioxidant properties of these components, beetroots could promote health and well-being of consumers [3, 4]. According to ŽITŇANOVÁ et al. [5], beetroots belong to vegetables with the highest antioxidant activity. The consumption of natural products rich in antioxidants may help restore the balance between the production of reactive oxygen and nitrogen species and endogenous protection when the body undergoes oxidative stress. According to many studies, betalains and other polyphenols reduce the oxidative damage to lipids and improve the antioxidant status of the organism, consequently preventing many diseases, such as cancer and cardiovascular diseases [6, 7].

One of the main motivators for purchasing organic food is consumers' belief in its high quality. Therefore, the demand for organically produced food is rapidly increasing. According to SHASHI et al. [8], the most important personal values for consumers of organic food are health benefits, natural composition, taste and quality, which includes the absence of pesticide residues and other toxic compounds. Environmental protection, animal welfare, waste reduction and preservation of biodiversity are primary factors that inspire food customers to search for organic products.

To confirm beliefs about the values attributed to organic foods by consumers, it is necessary to consider the aspects of food quality that have a direct impact on the nutritional and biological value of food, including safety aspects. The latest meta-analysis by BARAŃSKI et al. [9] showed clear significant differences in the chemical composition of raw materials from organically and conventionally produced foods. It was found that the content of

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many antioxidants, such as polyphenols, is much higher in organic plant products than in their conventional counterparts. At the same time, significantly lower cadmium content and four-fold lower incidence of pesticide residues was determined in organic vs conventional products. It was found that the differences in the composition of organic and non-organic plant products are the result of production practices recommended in organic farming systems.

Consumers buying food in stores have no knowledge of the circumstances under which it was produced. However, it is very important for consumers to determine whether organic food could potentially have more health-promoting benefits than non-organic food. The range of products offered in stores comes from real farms and real producers on the market and not from controlled experimental studies. Therefore, the factors that can have a significant impact on the final composition of foods are associated not only with the production system but also with the varieties used in the production, the location of the farms in which the raw materials were produced, weather, applied transport facilities and the storage method [10, 11]. From the consumer point of view, it is very important to use plant varieties that are characterized by high contents of bioactive components with health-promoting activities [12]. Therefore, the aim of our work was to study the composition of juices prepared from seven different popular varieties of beetroots grown under organic and conventional conditions. We focused on the concentrations of betacyanins, sugars, organic acids, phenolic acids, flavonoids and vitamin C.

MATERIALS AND METHODS

Beetroot varieties used for juice production

Seven most popular and commercially available beetroot varieties in Polish (Czerwona Kula, Okrągły Ciemnoczerwony, Opolski, Rywal, Boro) and Spanish (Belushi, Monty) markets were selected for the experiment. Beetroots were collected in retail outlets (3 kg for each variety from both organic and conventional production systems). We ensured that organic and conventional vegetables were represented by the same varieties. The origin of the beetroots from organic production facilities was confirmed by certificates issued by certification bodies in accordance with the requirements of EU Council Regulation (EC) No 834/2007. Samples of beetroots were purchased from local organic and conventional shops in Warsaw, Poland (10 samples) and Burgos, Spain (4 samples), and then were stored at 4 °C. For each of the purchased samples, the beetroots came from a single production batch. The experiments were generally performed immediately after procurement. For the juice preparation, random subsamples weighing approximately 1 kg were taken from each combination. The total number of prepared and analysed juices was 14 (7 organic and 7 conventional).

Juice preparation

Three random sub-samples of the beetroots were prepared for juice preparation by the pressing method. The beetroots were washed and divided into 2–4 parts. Juice was made using a quickly rotating juice extractor HR1832/02 Viva (Philips, Amsterdam, The Netherlands). Next, 500 ml of each juice was taken for the analyses. Representative samples of the juice were freeze-dried using Labconco 2.5 (Labconco, Kansas City, Missouri, USA) at a temperature of –40 °C and a pressure of 100 Pa. Then, the samples were ground in a lab grinder Mill A-11 (IKA-Werke, Staufen, Germany), placed in scintillation capillary tubes and held at –80 °C for further analysis.

Chemicals

Acetonitrile, hydrochloric acid (36%), Luff-Schoorl reagent, methyl orange and potassium phosphate were purchased from Chempur (Piekary Śląskie, Poland). Anhydrous sodium carbonate, *n*-hexane and oxalic acid (2%) were purchased from POCH (Gliwice, Poland). Betacyanin standards, namely, betanine-3-O-glucoside and betanidine, 2,6-dichlorophenolindophenol, magnesium carbonate, methanol and organic acid standards, namely, sodium malate, sodium citrate and potassium oxalate, and polyphenol standards, namely, gallic, chlorogenic, caffeic, synaptic, *p*-coumaric, ferulic acids, quercetin-3-O-rutinoside, myricetin, quercetin and kaempferol were purchased from Sigma Aldrich (St. Louis, Missouri, USA). Carrez I (15% potassium ferrocyanide), Carrez II (30% potassium sulfate liquid), citric acid, copper sulfate, ortho-phosphoric acid (85%) and potassium iodide (30%) were purchased from Alchem (Toruń, Poland).

Dry matter determination

Dry matter was determined using a gravimetric method according to the Polish standard [13]. Samples of juice were dried under the following conditions: temperature of 105 °C, constant pressure, time of 24 h, using Dryer KC-65 (Premed, Marki, Poland) with free air circulation. After 24 h, partially dried samples were cooled in a desiccator, weighed and then dried again. This operation was repeated three times to achieve a constant weight. Then, dry matter content was calculated in grams per kilogram of material.

Total and reducing sugars

The total and the reducing sugar concentrations were determined according to the Luff-Schoorl method [14]. A freeze-dried juice sample (100 mg) was placed in a beaker and mixed with 100 ml of distilled water. The beaker content was transferred to a measuring flask along with 5 ml each of Carrez I and Carrez II reagents, and the solution was mixed and diluted with distilled water. The content of the flask was filtered into a conical flask and mixed with 5 ml of concentrated HCl. The next step was acid hydrolysis in a hot water bath (68 °C). 15 ml NaOH (20% water solution) was added to neutralize the sample. The content of the flask was transferred to a measuring flask and diluted with distilled water. The extract was collected from the flask, and 25 ml of Luff solution was added. The sample was heated to reflux in a flask with a reflux condenser. Then, 10 ml of 30% KI, 25 ml of 25% H_2SO_4 and a few drops of starch (5 % water solution) were added to the sample. The sample was titrated with 0.1 $mol{\cdot}l^{-1}$ $Na_2S_2O_3$ until it turned white. A blank test was performed without the addition of the filtrate. The amount of the sodium thiosulfate used to titrate the filtrate was subtracted from the amount used for the blank test, and the sugar concentration was determined from the sugar table that accompanies this methodology.

HPLC analysis of the organic acids

The sample preparation procedure included extraction of the samples (100 mg) with hot deionized water (90 °C) in plastic tubes in an ultrasonic bath (10 min, 80 °C). Next, the samples were centrifuged (10 min, 3 780 ×*g*, 2 °C). Aliquots (1 ml) of the supernatant were transferred into high performance liquid chromatography (HPLC) vials. The HPLC system consisted of two LC-20AD pumps, a CMB-20A system controller, a SIL-20AC autosampler, an ultraviolet–visible SPD-20AV detector, a CTD-20AC oven and a Fusion-RP 80Å column (250 mm × 4.60 mm, particle size 5 μm) were used; all components were from Shimadzu (Kyoto, Japan). Mobile phase A (20 $mol{\cdot}l^{-1}$ potassium phosphate dibasic) and mobile phase B (pure methanol) at a flow rate of 1 $ml{\cdot}min^{-1}$ were used as a gradient solvent system. The wavelength range used for detection was 250–280 nm. External standards of oxalic, citric and malic acids of 95.00–99.99% purity were used. Concentrations of organic acids were calculated based on standard curves and sample dilution coefficients [15].

HPLC analysis of polyphenols

The sample preparation procedure included extraction of the samples (100 mg) with 80% methanol (5 ml) in plastic tubes in an ultrasonic bath (10 min, 30 °C). Then, the samples were centrifuged (12 min, 3 450 ×*g*, 2 °C). Aliquots (1 ml) of the supernatant were transferred into HPLC vials. The same HPLC system was use as for analysis of organic acids. Mixtures of water and acetonitrile (10% in phase A and 55% in phase B) at a flow rate of 1 $ml{\cdot}min^{-1}$ were used as a gradient solvent (1.00–22.99 min phase A 95 %, 23.00–27.99 min phase A 50 %, 28.00–28.99 min phase A 80 %, 29.00–35.99 min phase A 80 %, 36.00–38.00 phase A 95 %). The wavelength range used for detection was 270–360 nm. External standards of the polyphenols of 95.00–99.99% purity were used. The concentrations of polyphenols were calculated based on standard curves and sample dilution coefficients [16].

HPLC analysis of betacyanins

The sample preparation procedure included extraction of the samples (100 mg) with 80% methanol (5 ml) in plastic tubes with an ultrasonic bath (10 min, 10 °C). Then the samples were centrifuged (10 min, 3 780 ×*g*, 5 °C). Aliquots (2.5 ml) of supernatants were then transferred to new plastic tubes. HCl (2.5 ml, 10 $mol{\cdot}l^{-1}$) and 5 ml of pure methanol were then added to the tubes. The samples were shaken for 10 min at 5 °C. Aliquots (1 ml) of the centrifuged extract were transferred to HPLC vials. The same HPLC system was use as for analysis of organic acids. A mixture of deionized water (with 5% pure acetic acid), methanol and acetonitrile (70 : 10 : 20 v/v/v) was used as an isocratic solvent. The wavelength range used for detection was 530–570 nm. External standards of betanidine and glucoside-3-O-betanin of 95.00–99.99% purity were used. The concentrations of betacyanins were calculated base on standard curves and sample dilution coefficients [17].

Vitamin C

The vitamin C concentrations were determined according to the Polish standard PN-A-04019:1998 [18] by monitoring the oxidation of L-ascorbic acid to dehydroxyascorbic acid, in an acidic environment, using 2,6-dichlorophenolindophenol. This blue dye is reduced and becomes the same colour as leuco dye and, at pH 4.2, the compound is red, the reaction proceeding quantitatively. The freeze-dried beetroot sample was extracted with 20 ml of oxalic acid solution (2%). The solution was filtered (paper soft filter, type 388, medium-sized pores, Filtrak, Stargard Szczeciński, Poland). The filtrate was collected and excess 0.5 ml 2,6-dichlorophenol-indophenol solution was added. The sample was then extracted with xylene and the colour intensity of the extract was measured using a Unicam Helios spectrophotometer 500 nm (Thermo Scientific, Waltham, Massachusetts, USA). The result was read from a standard curve and the concentration of vitamin C was calculated using the equation:

$$M = V \times n \times 88 \times D \quad (1)$$

where M is the content of vitamin C in milligrams per kilogram of dry weight (DW), n is the equivalent concentration of 2,6-dichlorophenolindophenol solution (0.001555 titre), V is the volume of 2,6-dichlorophenolindophenol solution used in the titration in millilitres, 88 is the chemical equivalent of ascorbic acid and D is dilution factor.

Statistical analysis

Three independent replicates of each prepared beetroot juice were analysed. The results are expressed as mean ± standard deviation. Using Statgraphics 5.1. software (StatPoint Technologies, Warrenton, Virginia, USA), the data were subjected to a one-way analysis of variance (ANOVA), followed by a parametric post-hoc Tukey's test ($p = 0.05$). The p-values are given in the tables.

RESULTS AND DISCUSSION

Dry matter

Slight differences in the contents of dry matter in the juices were observed (Tab. 1). On average, organic and conventional juices were not significantly different in terms of their dry matter contents. However, comparing individual varieties, the highest dry matter content was found in the conventional juice made from Monty, and the lowest were in the organic juices from Belushi and Czerwona Kula varieties as well as in conventional products made from the Czerwona Kula and Okrągły Ciemnoczerwony varieties. Most of the scientific studies had reported the trend of higher contents of dry matter in plants from organic farming, those having been focused on root and leafy vegetables. The phenomenon was explained by differences in the type and doses of fertilizers used in cultivation [19]. An analysis of the literature data conducted by Stefanelli et al. [20] demonstrated that the high-dose mineral fertilization often used in conventional agriculture leads to excessive vegetative growth and reduces the dry matter content in vegetables. However, the results of Bundinienė et al. [21] showed that the differences in nitrogen fertilization did not significantly affect the content of dry matter in carrots. In the case of studies on vegetable juices [22, 23], the authors observed that more dry matter was present in organic beetroot juices and fermented beetroot juices compared to the corresponding conventional ones.

Total and reducing sugars

The present study generally did not show significant ($p \leq 0.05$) differences in the concentrations of total sugars between the juices prepared from different varieties of beetroots or between the juices from organic and conventional cultivation (Tab. 1). Only the juices from the Monty variety contained significantly more total sugars than juices from the Czerwona Kula and Okrągły Ciemnoczerwony varieties. Comparing altogether organic and conventional juices tested, it was found that conventional juices from Monty and Boro varieties were the richest in total sugars compared to the others. In the case of reducing sugars, the differences were slightly larger. Again, among the varieties tested, juices from the Monty variety were the richest in these compounds. These results do not clearly show the impact of organic production methods on the sugar concentration in the raw materials. This is not consistent with numerous studies [9, 24] that found that the juices of organic fruits and vegetables usually had higher concentrations of total sugars than the corresponding conventional ones. However, in other studies of beetroot juice [22, 23], no differences were found between the organic and conventional products. The lack of differences between organic and conventional juices in these instances apparently results from different cultivation conditions and is not directly related to the production system. These conditions can have a significant impact on the nutrient content of agricultural crops [25]. In the case of analyses of products made from marketed beetroots, these factors remain unclear.

Organic acids

No differences were observed either in the concentrations of organic acids among juices from different varieties of beetroots or between organic and conventional juices (Tab. 1). These results are consistent with those of Wruss et al. [26], who studied juices made from seven Austrian varieties of beetroots, and only minor differences were noted.

Tab. 1. Dry matter, sugars and organic acids in experimental organic and conventional beetroot juices.

Juices prepared from varieties	Dry matter [g·kg⁻¹]	Sugars [g·l⁻¹]		Organic acids [g·l⁻¹]		
		Total	Reducing	Citric	Malic	Oxalic
Organic juices						
Belushi	79.5 ± 3.20 a	74.5 ± 4.6 a	67.9 ± 0.8 a	221.5 ± 4.7 a	8.4 ± 0.1 a	3.84 ± 0.45 a
Monty	114.8 ± 3.4 b	108.5 ± 1.0 ab	102.4 ± 3.5 b	261.5 ± 17.0 a	10.1 ± 0.1 a	4.49 ± 0.68 a
Boro	101.7 ± 13.7 ab	89.1 ± 17.0 a	75.1 ± 21.0 ab	224.8 ± 22.9 a	8.5 ± 0.7 a	4.00 ± 0.31 a
Czerwona Kula	97.2 ± 11.8 a	79.0 ± 9.3 a	71.7 ± 8.3 ab	211.7 ± 40.0 a	8.0 ± 1.3 a	3.59 ± 0.59 a
Okrągły Ciemnoczerwony	107.8 ± 20.4 ab	84.7 ± 12.2 a	63.5 ± 8.7 a	208.1 ± 29.4 a	7.7 ± 1.1 a	3.51 ± 0.47 a
Opolski	103.5 ± 18.0 ab	89.1 ± 16.0 a	67.6 ± 7.0 a	221.1 ± 13.7 a	8.1 ± 0.6 a	3.51 ± 0.36 a
Rywal	104.7 ± 22.3 ab	90.1 ± 21.4 a	64.3 ± 14.3 a	217.1 ± 29.0 a	8.1 ± 1.1 a	3.51 ± 0.77 a
Conventional juices						
Belushi	115.2 ± 1.5 b	105.4 ± 12.0 ab	91.4 ± 0.5 b	234.0 ± 13 a	8.6 ± 0.1 a	4.51 ± 0.36 a
Monty	138.0 ± 3.3 c	127.7 ± 19.0 b	103.0 ± 5.4 c	275.3 ± 5.8 a	10.7 ± 0.2 a	5.34 ± 0.14 a
Boro	129.8 ± 0.3 bc	122.7 ± 6.9 b	105.6 ± 13.3 c	317.8 ± 7.6 a	11.1 ± 0.4 a	5.03 ± 0.38 a
Czerwona Kula	97.6 ± 1.0 a	79.9 ± 3.5 a	67.5 ± 9.9 a	223.0 ± 4.9 a	7.8 ± 0.3 a	3.12 ± 0.22 a
Okrągły Ciemnoczerwony	79.1 ± 4.2 a	69.8 ± 2.7 a	62.8 ± 11.0 a	230.9 ± 5.8 a	8.0 ± 0.2 a	3.46 ± 0.19 a
Opolski	127.7 ± 0.7 bc	116.3 ± 5.2 ab	73.8 ± 12.0 ab	235.9 ± 8.3 a	8.8 ± 0.3 a	3.91 ± 0.32 a
Rywal	125.2 ± 4.9 bc	108.0 ± 2.1 ab	77.2 ± 7.1 ab	244.4 ± 7.6 a	9.2 ± 0.2 a	4.24 ± 0.10 a
Average for juices from different production systems						
Organic juices	102.4 ± 19.4 A	90.1 ± 19.3 A	70.7 ± 17.5 A	224.7 ± 35.4 A	8.4 ± 1.4 A	3.68 ± 0.77 A
Conventional juices	114.6 ± 19.0 A	100.5 ± 22.4 A	84.6 ± 19.5 A	252.0 ± 31.3 B	9.2 ± 1.2 B	4.71 ± 0.78 A
Average for juices prepared from different varieties						
Belushi	97.3 ± 18.0 ab	90.0 ± 15.8 ab	79.6 ± 11.8 ab	227.7 ± 7.1 ab	8.5 ± 0.1 a	4.18 ± 0.33 a
Monty	126.4 ± 12.1 b	118.1 ± 9.7 b	105.3 ± 5.4 b	268.4 ± 8.1 b	10.4 ± 0.3 a	4.92 ± 0.43 a
Boro	108.8 ± 17.0 ab	97.5 ± 21.0 ab	82.7 ± 23.4 ab	248.0 ± 45.1 a	9.1 ± 1.3 a	4.26 ± 0.55 a
Czerwona Kula	97.3 ± 17.4 a	79.2 ± 20.2 a	70.7 ± 20.1 a	214.6 ± 5.4 a	8.0 ± 2.0 a	3.48 ± 0.12 a
Okrągły Ciemnoczerwony	100.6 ± 21.7 a	80.9 ± 12.5 a	63.3 ± 7.6 a	213.8 ± 27.5 a	7.8 ± 0.9 a	3.50 ± 0.42 a
Opolski	101.9 ± 15.8 ab	84.4 ± 10.0 ab	66.7 ± 6.3 a	226.8 ± 16.0 a	8.2 ± 0.6 a	3.70 ± 0.48 a
Rywal	105.6 ± 19.5 ab	92.2 ± 18.9 ab	67.0 ± 13.7 ab	226.5 ± 30.8 a	8.3 ± 1.0 a	3.81 ± 0.85 a
***p*-value**						
Production system	ns	ns	ns	0.034	0.008	ns
Variety	0.0103	0.0038	0.0002	< 0.0001	ns	ns
Interaction	0.0020	ns	0.012	ns	ns	ns

Data represent mean ± standard deviation with ANOVA *p*-value. Means in the same column followed by the same letter are not significantly different ($p < 0.05$). ns – not significant.

Our study showed that conventional juices, on average, did not differ from organic juices in terms of the concentration of oxalic acid, but they contained more citric and malic acids than juices from organic beetroots. These results do not confirm other results of Rudrappa et al. [27], which had shown increased synthesis of malic acid in organic crops due to the presence of beneficial bacteria *Rhizobacterium* in soil. No effect of the production system on the concentrations of organic acids in juices was shown in the juice studies [22, 23]. Organic acids promote resistance to many leaf diseases by activating the defence system of the plant. Badri and Vivanco [28] claim that the general increase in the synthesis of organic acids by plant roots can also be the result of a shortage of phosphorus in the organic soil system. In our study, the variety of beetroot showed no effect on the concentrations of organic acids in the juices. On the other hand, in a study of Wruss et al. on seven beetroot varieties [26], impact of variety on the concentrations of oxalic acid in the juice was observed.

Polyphenolic compounds

Beetroots contain significant amounts of polyphenolic compounds, especially betalain pigments and phenolic acids, and smaller amounts of flavonoids [29]. The production of polyphenols by plants largely depends on the amount of easily available soil mineral nitrogen [20]. Recent review papers [9, 24] concluded that organic plant products contained more phenolic compounds than are found in the corresponding conventional products, growing with high availability of nitrogen. Our study results, however, do not correspond with these findings, as concentrations of total phenolic acids (Tab. 2) and total flavonoids (Tab. 3) were similar in the juices from organic and conventional beetroots. Similar lack of clear differences between the organic and conventional juices was also stated in previous comparative studies of beetroot juices [22, 23]. This may indicate the importance of other factors not related to the production system, such as genetic, climate, soil conditions and the level of fertilization, in the synthesis of these components [30]. Our results show quite big differences between the juices produced from different varieties (Tab. 2). The juice from the organically produced Okrągły Ciemnoczerwony variety contained the highest concentration of total polyphenols and total phenolic acids. The juice from this variety contained significantly more gallic acid, the most widely represented polyphenol in the test juices,

Tab. 2. Total polyphenols, total phenolic acids and individual phenolic compounds in experimental organic and conventional beetroot juices.

Juices prepared from varieties	Total polyphenols [mg·l^{-1}]	Phenolic acids [mg·l^{-1}]				
		Total	Gallic	Chlorogenic	Caffeic	*p*-Coumaric
Organic juices						
Belushi	250.6 ± 51.8^{ab}	248.1 ± 51.9^{ab}	217.0 ± 52.9^{a}	17.6 ± 0.9^{a}	21.0 ± 0.0^{a}	11.4 ± 0.5^{ab}
Monty	278.8 ± 14.8^{ab}	276.4 ± 14.8^{ab}	205.1 ± 11.1^{a}	12.6 ± 1.0^{a}	45.7 ± 5.0^{d}	13.0 ± 1.8^{b}
Boro	340.9 ± 66.7^{ab}	336.4 ± 66.9^{ab}	279.9 ± 65.1^{ab}	25.6 ± 11.9^{a}	18.4 ± 1.0^{bc}	12.6 ± 9.1^{b}
Czerwona Kula	457.6 ± 85.3^{b}	453.9 ± 84.5^{b}	335.1 ± 126.3^{b}	16.8 ± 11.7^{a}	10.3 ± 8.2^{b}	91.7 ± 29.3^{d}
Okrągły Ciemnoczerwony	646.4 ± 206.7^{c}	641.2 ± 207.9^{c}	596.8 ± 205.8^{c}	24.4 ± 5.7^{a}	11.1 ± 6.6^{b}	8.9 ± 6.2^{a}
Opolski	357.8 ± 58.4^{ab}	353.8 ± 58.3^{ab}	301.9 ± 66.8^{ab}	20.0 ± 9.9^{a}	7.7 ± 6.0^{ab}	24.2 ± 10.4^{c}
Rywal	465.6 ± 180.8^{bc}	461.3 ± 179.2^{bc}	426.0 ± 170.5^{bc}	21.0 ± 11.5^{a}	7.8 ± 5.9^{ab}	6.5 ± 4.0^{a}
Conventional juices						
Belushi	217.2 ± 18.0^{a}	213.7 ± 16.7^{a}	155.0 ± 16.5^{a}	32.9 ± 0.4^{a}	15.3 ± 0.1^{b}	10.6 ± 06^{a}
Monty	298.0 ± 82.7^{ab}	293.0 ± 82.6^{ab}	249.8 ± 80.4^{ab}	16.7 ± 1.0^{a}	20.6 ± 0.7^{c}	5.8 ± 11^{a}
Boro	397.1 ± 7.7^{b}	394.0 ± 7.5^{b}	346.0 ± 5.3^{b}	34.9 ± 2.3^{a}	5.9 ± 0.1^{ab}	7.2 ± 0.0^{a}
Czerwona Kula	339.9 ± 14.2^{ab}	336.9 ± 14.2^{ab}	155.7 ± 1.7^{a}	33.5 ± 2.4^{a}	20.8 ± 5.0^{c}	126.9 ± 16.0^{e}
Okrągły Ciemnoczerwony	496.2 ± 16.4^{bc}	493.6 ± 16.3^{bc}	465.2 ± 15.1^{bc}	11.9 ± 0.8^{a}	4.1 ± 0.2^{a}	12.4 ± 1.0^{b}
Opolski	416.4 ± 34.1^{b}	411.8 ± 34.1^{b}	345.0 ± 34.8^{b}	22.6 ± 0.4^{a}	16.0 ± 0.7^{b}	28.2 ± 5.0^{c}
Rywal	644.9 ± 34.5^{c}	638.5 ± 34.3^{c}	591.2 ± 32.7^{c}	32.6 ± 10.0^{a}	4.4 ± 0.3^{a}	10.4 ± 4.0^{a}
Average for juices from different production systems						
Organic juices	375.0 ± 172.6^{a}	371.2 ± 172.2^{a}	325.7 ± 176.5^{a}	19.2 ± 10.1^{a}	11.8 ± 11.6^{a}	14.6 ± 3.3^{a}
Conventional juices	294.3 ± 118.6^{a}	290.8 ± 118.8^{a}	248.6 ± 133.1^{a}	22.8 ± 8.7^{b}	12.8 ± 6.9^{a}	6.6 ± 4.2^{a}
Average for juices prepared from different varieties						
Belushi	233.9 ± 42.0^{a}	230.9 ± 42.2^{a}	186.0 ± 49.9^{a}	25.2 ± 7.7^{a}	8.7 ± 6.6^{a}	11.0 ± 0.7^{a}
Monty	288.4 ± 60.2^{a}	284.7 ± 59.9^{a}	227.4 ± 61.6^{a}	14.7 ± 2.3^{a}	33.2 ± 13.1^{c}	9.4 ± 3.9^{a}
Boro	354.9 ± 62.8^{b}	350.8 ± 63.2^{b}	296.4 ± 63.3^{ab}	27.9 ± 11.1^{a}	15.3 ± 10.9^{b}	11.2 ± 8.2^{a}
Czerwona Kula	428.2 ± 76.4^{bc}	424.6 ± 75.7^{bc}	290.2 ± 116.3^{ab}	21.0 ± 11.2^{a}	12.9 ± 7.4^{ab}	100.5 ± 3.1^{c}
Okrągły Ciemnoczerwony	608.9 ± 190.7^{c}	604.3 ± 191.3^{c}	563.9 ± 187.2^{c}	21.3 ± 7.4^{a}	9.3 ± 6.0^{a}	9.8 ± 56^{a}
Opolski	314.0 ± 92.8^{b}	310.4 ± 92.2^{b}	263.3 ± 90.2^{ab}	19.6 ± 8.6^{a}	8.2 ± 5.3^{a}	19.3 ± 1.4^{b}
Rywal	469.0 ± 157.6^{bc}	465.1 ± 156.3^{bc}	430.1 ± 148.7^{b}	21.5 ± 10.0^{a}	7.2 ± 5.2^{a}	6.2 ± 2.5^{a}
***p*-value**						
Production system	ns	ns	ns	0.0054	ns	ns
Variety	< 0.0001	< 0.0001	< 0.0001	ns	< 0.0001	< 0.0001
Interaction	ns	ns	ns	ns	< 0.0001	0.0080

Data represent mean ± standard deviation with ANOVA *p*-value. Means in the same column followed by the same letter are not significantly different ($p < 0.05$). ns – not significant.

Tab. 3. Total flavonoids and individual phenolic compounds in experimental organic and conventional beetroot juices.

Juices prepared from varieties	Total flavonoids	Quercetin-3-O-rutinoside	Kaempferol-3-O-glucoside	Luteolin
	[mg·l⁻¹]			
Organic juices				
Belushi	2.5 ± 0.1 a	0.7 ± 0.0 a	0.9 ± 0.0 a	1.0 ± 0.0 a
Monty	2.4 ± 0.2 a	1.0 ± 0.2 ab	0.5 ± 0.1 a	0.9 ± 0.0 a
Boro	4.5 ± 1.1 c	1.0 ± 0.6 ab	2.5 ± 1.1 a	1.0 ± 0.2 a
Czerwona Kula	3.7 ± 0.9 b	1.0 ± 0.4 ab	1.6 ± 1.3 a	1.1 ± 0.1 a
Okrągły Ciemnoczerwony	5.2 ± 1.5 d	1.0 ± 0.3 ab	3.1 ± 1.8 a	1.1 ± 0.3 a
Opolski	4.0 ± 0.7 bc	1.1 ± 0.7 ab	1.7 ± 0.6 a	1.2 ± 0.1 a
Rywal	4.3 ± 1.6 c	0.8 ± 0.2 a	2.6 ± 1.2 a	1.0 ± 0.3 a
Conventional juices				
Belushi	3.5 ± 0.1 b	0.9 ± 0.0 a	1.0 ± 0.1 a	1.6 ± 0.1 c
Monty	5.0 ± 0.2 d	2.5 ± 0.01 c	1.2 ± 0.0 a	1.3 ± 0.0 b
Boro	3.1 ± 0.3 ab	0.9 ± 0.0 a	0.6 ± 0.2 a	1.6 ± 0.1 c
Czerwona Kula	3.0 ± 0.1 ab	1.7 ± 0.0 b	0.4 ± 0.0 a	1.0 ± 0.0 a
Okrągły Ciemnoczerwony	2.5 ± 0.1 a	0.7 ± 0.0 a	1.0 ± 0.0 a	0.8 ± 0.0 a
Opolski	4.6 ± 0.0 c	2.0 ± 0.0 c	1.4 ± 0.0 a	1.2 ± 0.0 ab
Rywal	6.4 ± 0.1 e	1.0 ± 0.0 ab	4.2 ± 0.0 a	1.2 ± 0.1 ab
Average for juices from different production systems				
Organic juices	3.7 ± 1.4 A	0.9 ± 0.4 A	1.8 ± 0.1 B	1.0 ± 0.3 A
Conventional juices	3.5 ± 0.8 A	1.2 ± 0.7 B	1.0 ± 0.1 A	1.3 ± 0.3 B
Average for juices prepared from different varieties				
Belushi	3.0 ± 0.5 a	0.8 ± 0.1 a	0.9 ± 0.1 a	1.3 ± 0.3 a
Monty	3.7 ± 1.3 a	1.8 ± 0.8 c	0.8 ± 0.3 a	1.1 ± 0.2 a
Boro	4.2 ± 1.1 a	1.0 ± 0.5 a	2.0 ± 1.2 a	1.1 ± 0.3 a
Czerwona Kula	3.5 ± 0.8 a	1.2 ± 0.4 b	1.3 ± 1.2 a	1.1 ± 0.3 a
Okrągły Ciemnoczerwony	4.5 ± 1.8 a	0.9 ± 0.3 a	2.6 ± 1.8 a	1.1 ± 0.3 a
Opolski	3.6 ± 0.9 a	1.0 ± 0.6 a	1.5 ± 0.6 a	1.1 ± 0.1 a
Rywal	4.0 ± 1.5 a	0.8 ± 0.2 a	2.1 ± 1.3 a	1.1 ± 0.3 a
***p*-value**				
Production system	ns	0.0012	0.0039	0.0089
Variety	ns	< 0.0001	ns	ns
Interaction	0.0008	< 0.0001	ns	0.0001

Data represent mean ± standard deviation with ANOVA *p*-value. Means in the same column followed by the same letter are not significantly different ($p < 0.05$). ns – not significant.

compared to the rest of the juices. Similar to juice from Okrągły Ciemnoczerwony, concentrations of total phenolic acids and gallic acid were found in the juice made from Rywal coming from conventional production (Tab. 2). In the case of flavonoids, significant differences were noted only between some of the juices within the production systems. However, there were no significant differences between the total flavonoid concentrations in juices from different cultivars regardless of the production system (Tab. 3). Studies comparing juices produced from different varieties of organic and conventional beetroots are virtually absent from the scientific literature. Only Wruss et al. [26] compared juices in terms of total phenolics and showed some differences among varieties, but these were not statistically significant.

The occurrence of betalain in individual varieties of this vegetable are very rarely investigated [31]. In or study, the concentration of betanin-3-O-glucoside was several-fold higher than the betanidine concentrations in the juices (Tab. 4). Significant differences among the juices from different varieties and different production systems of beetroots were observed in terms of their average concentrations. As shown in Tab. 4, organic juices contained significantly more betanin-3-O-glucoside and betanidine than the conventional ones. KAZIMIERCZAK et al. [23] obtained similar results, with higher concentrations of betanin-3-O-glucoside being found in organic versus conventional beetroots, but the same trend was not true for fermented beetroot juices. However, another study on beetroot juices [22] showed opposite trends. The results showing a higher concentration of betanin in the organic juices are consistent with the hypothesis presented by MORENO et al. [32] regarding the increase in the synthesis of betalain when smaller doses of nitrogen are applied at the time of beetroot cultivation. The betalain concentration in the juice from the Monty variety was substantially different from the rest of the juices in terms of betalain concentration (Tab. 4). This was confirmed by the results obtained by others [26, 33], who found that the content of these pigments in products is dependent on the variety of beetroot.

Vitamin C

Beetroots and beetroot juices are known to have low vitamin C concentrations but, due to the interaction of vitamin C with flavonoids, the con-

Tab. 4. Vitamin C and betacyanins in experimental organic and conventional beetroot juices.

Juices prepared from varieties	Vitamin C [mg·l^{-1}]	Betanine-3-O-glucoside [g·l^{-1}]	Betanidine [mg·l^{-1}]
Organic juices			
Belushi	23.6 ± 3.2^{ab}	5.25 ± 0.17^{a}	80.8 ± 7.5^{c}
Monty	25.3 ± 0.5^{ab}	9.45 ± 0.91^{d}	164.3 ± 4.4^{e}
Boro	25.4 ± 2.3^{ab}	7.72 ± 1.28^{b}	84.4 ± 13.7^{c}
Czerwona Kula	21.9 ± 7.7^{ab}	7.74 ± 0.43^{b}	82.1 ± 21.0^{c}
Okrągły Ciemnoczerwony	20.6 ± 8.9^{ab}	8.13 ± 1.40^{bc}	82.4 ± 19.9^{c}
Opolski	17.1 ± 8.8^{ab}	7.93 ± 0.82^{bc}	80.8 ± 16.0^{c}
Rywal	30.9 ± 2.4^{b}	7.83 ± 1.33^{b}	89.7 ± 22.0^{c}
Conventional juices			
Belushi	33.0 ± 7.4^{b}	4.52 ± 0.70^{a}	62.2 ± 1.8^{b}
Monty	32.0 ± 2.6^{b}	10.90 ± 2.50^{e}	198.3 ± 4.3^{f}
Boro	8.9 ± 1.7^{a}	8.48 ± 0.80^{c}	70.7 ± 0.8^{b}
Czerwona Kula	4.6 ± 2.0^{a}	6.09 ± 0.60^{ab}	35.6 ± 0.5^{a}
Okrągły Ciemnoczerwony	9.7 ± 2.2^{a}	6.12 ± 2.60^{ab}	37.8 ± 1.8^{a}
Opolski	27.4 ± 1.3^{ab}	9.02 ± 1.00^{d}	51.1 ± 2.2^{d}
Rywal	63.7 ± 0.5^{c}	8.67 ± 3.80^{c}	68.0 ± 4.3^{d}
Average for juices from different production systems			
Organic juices	24.1 ± 12.3^{A}	7.75 ± 1.37^{B}	94.9 ± 25.5^{B}
Conventional juices	26.1 ± 12.1^{A}	6.41 ± 2.13^{A}	74.9 ± 52.1^{A}
Average for juices prepared from different varieties			
Belushi	28.3 ± 7.4^{b}	4.89 ± 3.90^{a}	71.5 ± 10.8^{a}
Monty	28.6 ± 3.8^{b}	10.18 ± 0.77^{c}	181.3 ± 17.6^{c}
Boro	21.3 ± 7.5^{ab}	7.91 ± 1.16^{b}	80.9 ± 13.2^{b}
Czerwona Kula	17.6 ± 8.8^{a}	7.33 ± 1.24^{b}	70.5 ± 24.3^{a}
Okrągły Ciemnoczerwony	179.0 ± 9.1^{a}	7.63 ± 1.50^{b}	71.2 ± 25.9^{a}
Opolski	153.0 ± 8.3^{a}	7.15 ± 1.52^{b}	73.4 ± 18.9^{a}
Rywal	30.6 ± 20.3^{b}	7.22 ± 1.57^{b}	84.3 ± 21.3^{b}
***p*-value**			
Production system	ns	< 0.0001	< 0.0001
Variety	0.0014	< 0.0001	< 0.0001
Interaction	ns	0.0058	0.0003

Data represent mean ± standard deviation with ANOVA *p*-value. Means in the same column followed by the same letter are not significantly different ($p < 0.05$). ns – not significant.

centration of vitamin C is very important even if it is low. Interactions between flavonoids and ascorbic acid promote increased absorption of vitamin C from the gastrointestinal tract [34]. Analysis of variance confirmed that, on average, no differences in the content of vitamin C were observed between the conventional and the organic juices in our investigation (Tab. 4). The trend indicating a higher level of vitamin C in organic products was described by Kazimierczak et al. [22, 23]. Juices of the Rywal, Belushi and Monty varieties contained, on average, significantly more vitamin C than juices from the other varieties of beetroots. The differences between conventional and organic juices in terms of vitamin C were not consistent with the results of the most recent meta-analysis [9], which reported a higher concentration of vitamin C in organic products compared to their conventional counterparts. However, according to the literature, the vitamin C concentration in the tissues of the plants depends, to a large extent, on the climatic and other environmental factors and the type of fertilizers applied [20].

CONCLUSIONS

All the juices from the seven beetroot varieties are good sources of bioactive compounds, especially betalain, phenolic acids and flavonoids. Most of the data obtained on chemical composition of juices did not confirm the assumption of the theory of increased synthesis of polyphenolic compounds when using organic production practices. Only betanin behaved in line with this theory. In addition, some significant differences in the concentrations of certain ingredients, such as sugars, citric acid, total phenolic acids and total polyphenols as well as betalain pigments, were observed among the juices made from different varieties of beetroots. Thus, the use of the varieties richest in beneficial compounds in terms of their health-promoting properties can be fundamentally important for the development of the production of juices or dietary supplements from beetroots. The Monty and Okrągły Ciemnoczerwony varieties described in our study can be great raw materials for products of optimal quality.

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REFERENCES

1. Wootton-Beard, P. C. – Moran, A. – Ryan, L.: Stability of the antioxidant capacity and total polyphenol content of 23 commercially available vegetable juices before and after *in vitro* digestion as measured by FRAP, DPPH, ABTS and Folin Ciocalteu methods. Food Research International, *44*, 2011, pp. 217–224. DOI: 10.1016/j.foodres.2010.10.033.
2. Bavec, M. – Turinek, M. – Grobelnik-Mlakar, S. – Slatnar, A. – Bavec, F.: Influence of industrial and alternative forming systems on contents of sugars, organic acids, total phenolic content, and antioxidant activity of red beet (*Beta vulgaris* L. *ssp. vulgaris* Rote Kugel). Journal of Agricultural and Food Chemistry, *58*, 2010, pp. 11825–11831. DOI: 10.1021/jf103085p.
3. Singh, B. – Singh-Hathan, B.: Chemical composition, functional properties and processing of beetroot – a review. International Journal of Scientific and Engineering Research, *5*, 2014, pp. 679–684. ISSN: 2229-5518. <https://www.ijser.org/researchpaper/Chemical-composition-functional-properties-and-processing-of-Beetroot.pdf>.
4. Pitalua, E. – Jimenez, M. – Vernon-Carter, E. J. – Beristain, C. I.: Antioxidative activity of microcapsules with beetroot juice using gum Arabic as wall material. Food and Bioproducts Processing, *88*, 2010, pp. 253–258. DOI: 10.1016/j.fbp.2010.01.002.
5. Žitňanová, I. – Ranostajová, S. – Sobotová, H. – Demelová, D. – Pecháň, I. – Ďuračková, Z.: Antioxidative activity of selected fruits and vegetables. Biologia, *61*, 2006, pp. 279–284. DOI: 10.2478/s11756-006-0051-7.
6. Delgado-Vargas, F. – Jiménez, A. R. – Paredes-López, O.: Natural pigments: Carotenoids, anthocyanins, and betalains – characteristics, biosynthesis, processing, and stability. Critical Reviews in Food Science and Nutrition, *40*, 2000, pp. 173–289. DOI: 10.1080/10408690091189257.
7. Han, X. H. – Gao, Z. J. – Xiao, X. G.: Enzymes and genes involved in the betalain biosynthesis in higher plants. African Journal of Biotechnology, *8*, 2009, pp. 6735–6744. ISSN: 1684-5315. <https://www.ajol.info/index.php/ajb/article/download/68660/56739>
8. Shashi, K. – Kottala, S. Y. – Singh, R.: A review of sustainability, deterrents, personal values, attitudes and purchase intentions in the organic food supply chain. Pacific Science Review B: Humanities and Social Sciences, *1*, 2015, pp. 114–123. DOI: 10.1016/j.psrb.2016.09.003.
9. Barański, M. – Średnicka-Tober, D. – Volakakis, N. – Seal, C. – Sanderson, R. – Stewart, G. B. – Benbrook, C. – Biavati, B. – Markellou, E. – Giotis, C. – Gromadzka-Ostrowska, J. – Rembiałkowska, E. – Skwarło-Sońta, K. – Tahvonen, R. – Janovská, D. – Niggli, U. – Nicot, F. – Leifert, C.: Higher antioxidant and lower cadmium concentrations and lower incidence of pesticide residues in organically grown crops: a systematic literature review and meta-analyses. British Journal of Nutrition, *112*, 2014, pp. 794–811. DOI: 10.1017/S0007114514001366.
10. Bickel, R. – Rossier, R.: Sustainability and quality of

organic food. Frick : Research Institute of Organic Agriculture, 2015. ISBN: 978-3-03736-282-2. <https://shop.fibl.org/CHde/mwdownloads/download/link/id/335/?ref=1>

11. Mie, A. – Wivstad, M.: Organic food – food quality and potential health effects. A review of current knowledge, and a discussion of uncertainties. Uppsala : EPOK – Centre for Organic Food and Farming, 2015. ISBN: 978-91-576-9274-0. <http://orgprints.org/29439/1/Organic_food_quality_and_health_webb.pdf>
12. Napolitano, A. – Cascone, A. – Grazziani, G. – Ferracane, R. – Scalfi, L. – Di Vaio, C. – Ritieni, A. – Fogliano, V.: Influence of variety and storage on the polyphenol composition of apple flesh. Journal of Agricultural and Food Chemistry, *52*, 2004, pp. 6526–6531. DOI: 10.1021/jf049822w.
13. PN-EN 12145:2001. Soki owocowe i warzywne - Oznaczanie całkowitej suchej substancji - Metoda grawimetryczna. (Fruit and vegetable juices - Determination of dry matter - Gravimetric method.) Warsaw: The Polish Committee for Standardization, 2001. In Polish.
14. Fortuna, T. – Juszczak, L. – Sobolewska-Zielińska, J.: Podstawy analizy żywności. (The basics of the food analysis.) Kraków : Wydawnictwo AR, 2003. ISBN: 8386524790. In Polish.
15. Zheng, H. – Zhang, Q. – Quan, J. – Zheng, O. – Xi, W.: Determination of sugars, organic acids, aroma components, and carotenoids in grapefruit pulps. Food Chemistry, *205*, 2016, pp. 112–121. DOI: 10.1016/j.foodchem.2016.03.007.
16. Hallmann, E. – Kazimierczak, R. – Marszałek, K. – Drela, N. – Kiernozek, E. – Toomik, P. – Matt, D. – Luik, A. – Rembiałkowska, E.: The nutritive value of organic and conventional white cabbage (*Brassica oleracea* L. var. *capitata*) and anti-apoptotic activity in gastric adenocarcinoma cells of sauerkraut juice produced therof. Journal of Agricultural and Food Chemistry, *65*, 2017, pp. 8171–8183. DOI: 10.1021/acs.jafc.7b01078.
17. Shepherd, A. I. – Gilchrist, M. – Winyard, P. G. – Jones, A. M. – Hallmann, E. – Kazimierczak, R. – Rembialkowska, E. – Benjamin, N. – Shore, A. C. – Wilkerson, D. P.: Effects of dietary nitrate supplementation on the oxygen cost of exercise and walking performance in individuals with type 2 diabetes: a randomised, double blind, placebo-controlled cross-over trial. Free Radical Biology and Medicine, *86*, 2015, pp. 200–208. DOI: 10.1016/j.freeradbiomed.2015.05.014.
18. PN-A-04019:1998. Produkty spożywcze - Oznaczanie zawartości witaminy C. (Food products - Determination of vitamin C.) Warsaw: The Polish Committee for Standardization, 1998. In Polish.
19. Lairon, D.: Nutritional quality and safety of organic food - a review. Agronomy for Sustainable Development, *30*, 2010, pp. 33–41. DOI: 10.1051/agro/2009019.
20. Stefanelli, D. – Goodwin, I. – Jones, R.: Minimal nitrogen and water use in horticulture: Effects on quality and content of selected nutrients. Food Research International, *43*, 2010, pp. 1833–1843. DOI: 10.1016/j.foodres.2010.04.022.
21. Bundinienė, O. – Kavaliauskaitė, D. – Starkutė, R. – Jankauskienė, J. – Zalatorius, V. – Bobinas, Č.: Influence of fertilizers with prolongation effect on productivity of root-crop vegetables and biochemical composition before and after storage. In: Maldonado, A. I. L. (Ed.): Horticulture. Rijeka : InTech, 2012, pp. 19–40. ISBN: 978-953-51-0252-6. <https://www.intechopen.com/books/horticulture/influence-of-fertilizers-with-prolongation-effect>
22. Kazimierczak, R. – Siłakiewicz, A. – Hallmann, E. – Średnicka-Tober, D. – Rembiałkowska, E.: Chemical composition of selected beetroot juices in relation to beetroot production system and processing technology. Notulae Botanicae Horti Agrobotanici Cluj-Napoca, *44*, 2016, pp. 491–498. DOI: 10.15835/nbha44210372.
23. Kazimierczak, R. – Hallmann, E. – Lipowski, J. – Drela, N. – Kowalik, A. – Püssa, T. – Matt, D. – Luik, A. M. – Gozdowski, D. – Rembiałkowska, E.: Beetroot (*Beta vulgaris* L.) and naturally fermented beetroot juices from organic and conventional production: metabolomics, antioxidant levels and anticancer activity. Journal of the Science of Food and Agriculture, *94*, 2014, pp. 2618–29. DOI: 10.1002/jsfa.6722.
24. Matt, D. – Rembiałkowska, E. – Luik, A. – Peetsmann, E. – Pehme, S.: Quality of organic vs. conventional food and effects on health. Tartu : Estonian University of Life Sciences, 2011. ISBN: 978-9949-484-06-5. <http://orgprints.org/19504/1/Report_2011_%281%29.pdf>
25. Köpke, U.: Influence of organic and conventional farming systems on nutritional quality of food. In: Impacts of agriculture on human health and nutrition, Vol. II. In: UNESCO - Encyclopedia of Life Support Systems (EOLSS) [online]. Paris : EOLSS Publishers, 2001 [cit. 24 September 2018]. <http://www.eolss.net/sample-chapters/c10/e5-21-05-01.pdf>
26. Wruss, J. – Waldenberger, G. – Huemer, S. – Uygun, P. – Lanzerstorfer, P. – Müller, U. – Höglinger, O. – Weghuber, J.: Compositional characteristics of commercial beetroot products and beetroot juice prepared from seven beetroot varieties grown in Upper Austria. Journal of Food Composition and Analysis, *42*, 2015, pp. 46–55. DOI: 10.1016/j.jfca.2015.03.005.
27. Rudrappa, T. – Czymmek, K. J. – Paré, P. W. – Bais, H. P.: Root secreted malic acid recruits beneficial soil bacteria. Plant Physiology, *148*, 2008, pp. 1547–1556. DOI: 10.1104/pp.108.127613.
28. Badri, D. V. – Vivanco, J. M.: Regulation and function of root exudates. Plant, Cell and Environment, *32*, 2009, pp. 666–681. DOI: 10.1111/j.1365-3040.2009.01926.x.
29. Wootton-Beard, P. C. – Ryan, L.: A beetroot juice shot is a significant and convenient source of bioaccessible antioxidants. Journal of Functional Foods, *3*, 2011, pp. 329–334. DOI: 10.1016/j.jff.2011.05.007.
30. Jeffery, E. H. – Brown, A. F. – Kurilich, A. C. – Keek, A. S. – Matusheski, N. – Klein, B. P.: Variation

in content of bioactive components in broccoli. Journal of Food Composition and Analysis, *16*, 2003, pp. 323–330. DOI: 10.1016/S0889-1575(03)00045-0.
31. Gliszczyńska-Świgło, A. – Szymusiak, H. – Malinowska, P.: Betanin, the main pigment of red beet: molecular origin of its exceptionally high free radical-scavenging activity. Food Additives and Contaminants, *23*, 2006, pp. 1079–1087. DOI: 10.1080/02652030600986032.
32. Moreno, D. A. – García-Viguera, C. – Gil, I. J.: Betalains in the era of global agri-food science, technology and nutritional health. Phytochemistry Reviews, *7*, 2008, pp. 261–280. DOI: 10.1007/s11101-007-9084-y.
33. Lee, E. J. – An, D. – Nguyen, C. T. – Patil, B. S. – Kim, J. – Yoo, K. S.: Betalain and betaine composition of greenhouse- or field-produced beetroot (*Beta vulgaris* L.) and inhibition of HepG2 cell proliferation. Journal of Agricultural and Food Chemistry, *62*, 2014, pp. 1324–1331. DOI: 10.1021/jf404648u.
34. Majewska-Wierzbicka, M. – Czeczot, H.: Przeciwnowotworowe działanie flawonoidów. (Anticancer activity of flavonoids.) Polski Merkuriusz Lekarski, *33*, 2012, pp. 364–369. ISSN: 1426-9686. In Polish.

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