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ORIGINAL PAPER

The antioxidant properties of exotic fruit juices from acai, maqui berry and noni berries

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Abstract
Various natural sources of antioxidants, which may help defy oxidative stress and thereby reduce the risk of many diseases, are being searched for. Exotic fruits and good quality exotic fruit juices can be an alternative to many berries grown in Europe. This paper presents the antioxidant properties and composition of polyphenols of acai, maqui berry and noni juices. Then they were compared to local juices rich in polyphenols, such as elderberry, raspberry and blueberry juices. The research has shown that the highest antioxidant capacity possessed acai juice among the exotic juices and elderberry juice among the local ones. The same two juices had the highest content of polyphenolic compounds, including flavonoids. Noni and maqui berry juices were inferior to acai and elderberry juices in this respect, and did not surpass considerably the qualities of raspberry and blueberry juices. The highest content of total anthocyanins was detected in elderberry juice. Exotic acai juice contains the highest levels of flavonols (mainly catechins) as well as ferulic and chlorogenic acids. Concluding, juices from exotic acai, noni and maqui berry fruits, because of their antioxidant properties, can be an interesting alternative to local juices. Acai juice seems to be the most valuable, in particular.

Keywords Acai · Maqui berry · Noni · Juices · Antioxidants

Introduction

Polyphenols can play an important role in reducing oxidative stress, which has been implicated as a causal factor of contemporary civilization diseases, such as cardiovascular disorders or neoplasms [1]. The richest sources of polyphenolic compounds in the human diet are fruit and vegetables, fresh or processed [2]. A reliable source of polyphenols, available all year round, is good quality fruit juices, especially ones which have been produced with mild processing technologies. Studies have demonstrated that juices from elderberries, chokeberries [3], raspberries [4, 5] or blueberries [6, 7] possess high levels of polyphenols and high antioxidant capacity. Recently, more exotic sources of antioxidants have been looked for, including tropical fruits originating from South America or islands on the Pacific Ocean, e.g. acai, maqui berry or noni. Acai berries (*Euterpe oleracea* Mart.) are exported from Brazil to Europe and the USA, where they are processed to juices and dietary supplements [8, 9]. Acai juice contains around 90 substances, of which 31% are flavonoids, and other substances present more abundantly include phenolic compounds 23%, lignans 11%, anthocyanins 9% [10]. Fruits of maqui berry (*Aristotelia chilensis*) come from Chile or south-western Argentina, where they grow in large clusters from December to March [11]. There is lack of information regarding the phenolic acids and flavonoids presents in maqui berry fruit [12]. More is known about the composition of anthocyanins such as delphinidin's and cyanidin glycosides [13]. Recent data showed that maqui berry pulp contained much quantities of polyphenols, especially monomeric anthocyanins [14]. The fruit of noni (*Morinda citrifolia* L.) originates from Southeast Asia, where the plant is cultivated in Polynesia and India, but it is also grown in South America and the Caribbean Islands [15]. Traditionally, extraction of juice from noni berries is preceded by fermentation [16]. 45-day old fruits are best for processing

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because they have the highest concentration of flavonoids, tannins, alkaloids, glycosides, sterols and triterpenoids [15]. Various cultivation conditions and processing methods for noni fruit decided about antioxidant activity and the amount of vitamin C and phenolic compounds. The degree of ripeness and post-harvest ageing may reduce bioactive compounds, e.g. scopoletin, rutin, quercetin and iridoids content [17].

Because all above exotic fruits are easily perishable, same as the local berries, they need to be processed, and juices are the most popular products. Hence, the purpose of this research has been to determine the antioxidant properties and the composition of polyphenols in juices from acai, maqui berry and noni berries, and to compare them with selected local sources of antioxidants (elderberry, raspberry and blueberry juices).

Materials and methods

Material

Analyses involved six NFC (not from concentrate) juices ($n = 5$) made from polyphenol-rich fruits. Three juices from exotic fruits of acai (*Euterpe oleracea* Mart. from Brazil), noni (*Morinda citrifolia* L. from French Polynesia) and maqui berry (*A. chilensis* from Chile) were compared with three juices made from Polish fruits: raspberry (*Rubus idaeus* L.), blueberry (*Vaccinium corymbosum* L.) and elderberry (*Sambucus nigra* L.). All juices were cold-pressed from whole fruits and subjected to mild pasteurization at a temperature not exceeding 85 °C. The juices were naturally turbid, without any additives, excluding also water. The juices were produced in August 2016 and stored at a temperature not exceeding 20 °C. The analysis was carried out on freshly opened juices, between September and November 2016.

The pH of the tested samples of juices was measured with a glass electrode at room temperature.

Antioxidant capacity

DPPH assay

The antioxidant capacity of the samples was determined by a modified Yen and Chen method, using 0.1 mmol/L methanol solution of a 1,1-diphenyl-2-picrylhydrazyl (DPPH, Sigma-Aldrich, Steinheim, Germany) [18, 19]. This method is widely used to test the antioxidant capacity of fruits, vegetables and juices. Advantages of the DPPH assay were previously described [20–22]. A 0.1 mL of sample was added to 2.9 mL DPPH solution and mixed. The absorbance was measured on a Hitachi U-1900 spectrophotometer (Hitachi, Tokyo, Japan) at 517 nm after 30 min of incubation in the dark at room temperature. The antioxidant capacity was expressed as milligrams of Trolox (Sigma-Aldrich) per 1 L of sample (mg Tx/L).

ABTS assay

Antioxidant Assay Kit (ELISA–Cayman Chemical Company, Ann Arbor, Michigan, USA) was used to determine the antioxidant capacity of the samples. The assay relies on the ability of antioxidants in a sample to inhibit the oxidation of ABTS (2,2′-azino-di-[3ethylbenzthiazoline sulphonate]) to $ABTS^{+}$ by metmyoglobin. The absorbance was measured on a microplate reader SPEKTROstar Nano (BMG LABTECH, Offenburg, Germany) at 750 nm after incubation in a shaker for 5 min at room temperature. The antioxidant capacity was quantified as millimolar Trolox equivalents (mM Trolox).

Total polyphenol content

Folin–Ciocalteu assay

The total polyphenol content (TP) was determined by the Folin–Ciocalteu assay (Sigma-Aldrich) [23]. First, 0.3 mL of sample was added to a 10-mL capacity tube, next 0.05 mL 2N Folin–Ciocalteu reagent and 0.5 mL 20% sodium carbonate solution were added. The mixture was diluted by addition of 4.15 mL distilled water and mixed. The absorbance was measured on a Hitachi U-1900 spectrophotometer at 765 nm after 30 min incubation in the dark at room temperature. The results were expressed as milligrams of gallic acid equivalents per 1 L of sample (mg GAE/L).

Fast Blue BB assay

Fast Blue BB is a novel method described by Medina [24] to quantify the phenolic compounds through direct interaction of polyphenols with the FBBB reagent (4-benzoylamino-2,5-diethoxybenzenediazonium chloride hemi(zinc chloride) salt; Sigma-Aldrich) in an alkaline medium. This method demonstrates higher values of gallic acid equivalents (GAE) than Folin–Ciocalteu assay does [24]. A 0.2 mL aliquot of 0.1% Fast Blue BB reagent was added to 2 mL of samples, mixed for 1 min and 0.2 mL 5% sodium hydroxide was added. The reaction was allowed to complete at room temperature for 90 min. The absorbance was measured on a Hitachi U-1900 spectrophotometer at 420 nm. The results were expressed as gallic acid equivalents per 1 L of sample (mg GAE/L).

Total flavonoid content

The total flavonoid content was measured using the colorimetric assay developed by Kapci et al. [21]. Briefly, 0.3 mL of 5% sodium nitrite was added to 1 mL of sample at zero time. After 5 min, 0.3 mL of 10% aluminium chloride was added. At the 6th min, 2 mL of 1M sodium hydroxide was added. The mixture was diluted by addition of 2.4 mL distilled water and mixed. The absorbance was measured on a Hitachi U-1900 spectrophotometer at 510 nm. The total flavonoids content was determined by a (+)-catechin (Sigma) standard curve and was expressed as miligrams of catechin equivalents per 1 L of juice (mg CE/L) [21].

Total anthocyanin content

Total anthocyanin content (TA) was determined by the pH differential method (AOAC Official Method 2005.02). Juices were diluted according to appropriate dilution ratios (1 part sample and 4 parts buffer) by adding both 0.025M potassium chloride (pH 1.0) and 0.4M sodium acetate (pH 4.5) buffer solution. Samples were mixed and left in the dark for 30 min. The absorbance was measured on a Hitachi U-1900 spectrophotometer at 520 and 700 nm, and the results were calculating using the following formula

$$A = \left[\left(A_{520} - A_{700}\right)_{\mathrm{pH}\,1.0} - \left(A_{520} - A_{700}\right)_{\mathrm{pH}\,4.5}\right],$$

where A_{520} is the absorbance measured at 520 nm and A_{700} is the absorbance measured at 700 nm, at pH 1.0 and 4.5, respectively.

Total anthocyanin content was expressed as miligrams of cyanidin-3-glucoside equivalents (molar extinction coefficient = 26,900 L/mol cm and molecular weight = 449.2 g/mol) per L of juice (mg CGE/L) [25].

HPLC analysis of phenolic acids and flavonoids

Phenolic acids and selected flavonoids were determined by HPLC methods described by Krygier et al. [26] and Hertog et al. [27] based on the parameters established in our previous studies [22]. The analyses were performed using a Dionex LC system equipped with a photodiode array detector (PAD, Dionex, Sunnyvale, California, USA) and the absorption spectra were recorded in the range of 200–600 nm. The flow rate was 1 mL/min, the column temperature was 30 °C and the injection volume was 20 µL. Qualitative identification was done by comparing the retention times and spectra with the standards. Simultaneous monitoring was performed at 280 nm for phenolic acids and 360 nm for flavonoids.

Phenolic acids were determined according the method described by Krygier et al. [26]. The separation was performed on a Ascentis C18 (Supelco, Sigma Aldrich) column (250 mm x 4.6 mm; 5 µm). The binary mobile phase consisted of 0.1% (v/v) formic acid in methanol (eluent A) and methanol–acetonitrile (80:20, v/v; eluent B). The gradient program was as follows: 0–5 min (0% B), 7–15 min (10% B), 25 min (25% B), 34 min (65% B), 35–39 min (100% B), and 40–45 min (0% B).

Flavonoids were determined by a modified Hertog et al. method [27], after its acidic hydrolysis. The separation was performed on a Ascentis C18 (Supelco, Sigma-Aldrich) column (250 mm x 4.6 mm; 5 µm). The binary mobile phase consisted of 0.1% (v/v) formic acid in water–methanol (75:25, v/v, pH 2.7; eluent A) and 0.1% (v/v) formic acid in methanol (eluent B). The gradient program was as follows: 0–2 min (0% B), 10–20 min (15% B), 30 min (40% B), 35–44 min (100% B), and 47–51 min (0% B).

Statistical analysis

The results were statistically analysed by calculating the mean and standard deviation. The interpretation of the results was performed with MS Excel 2010 Analysis ToolPak software (Microsoft, Redmond, Washington, USA), with one-way analysis of variance (ANOVA) using the Tukey's as post test: different letters in the same row or column indicate statistical significance (at $p \leq 0.05$).

Results and discussion

pH

All the analysed fruit juices had a relatively low pH, from 3.18 ± 0.01 to 4.41 ± 0.02 (Table 1). Among the exotic juices, noni juice had the lowest pH (pH 3.56 ± 0.01), while acai juice had the highest one (pH 4.41 ± 0.02). The three juices made from local fruits had similar pH, from 3.18 ± 0.01 (blueberry juice) to 4.12 ± 0.02 (elderberry juice).

On our study, the lowest pH among the tested exotic juices was determined in noni juice. The low pH in this juice is attributed to the presence of ascorbic acid (vitamin C), whose content can be as high as over 2000 mg ascorbic acid per kg fresh weight [15, 28]. Approximately same acidity of noni juice was demonstrated in another study, where pH and vitamin C content were 3.4 ± 0.1 and 971 ± 23 mg/kg of juice, respectively [29]. Among the local juices, blueberry juice had the lowest pH (3.18). In another study, the pH determined in blueberry juice was similar, i.e. 3.14 [30] or higher, i.e. 3.70 [31]. Elderberry juice in our research had a higher pH than that determined by Casati et al., i.e. 4.12 ± 0.02 vs. 3.63 ± 0.01 [31].

Table 1 Antioxidant capacity and polyphenols of juices

	Acai	Maqui berry	Noni	Raspberry	Blueberry	Elderberry
pH	4.41 ± 0.02^{a}	3.95 ± 0.02^{b}	3.56 ± 0.01^{c}	3.26 ± 0.02^{c}	3.18 ± 0.01^{c}	4.12 ± 0.02^{b}
DPPH (mg Tx/L)	2004 ± 44^{b}	252 ± 3.0^{e}	905 ± 2.0^{d}	1348 ± 21^{c}	659 ± 8.0^{d}	3475 ± 101^{a}
ABTS (mM Tx)	17.5^{b}	–	8.4^{c}	11.0^{c}	12.2^{c}	21.3^{a}
Total polyphenols (mg GAE/L)	6358 ± 17^{b}	2142 ± 37^{d}	3534 ± 44^{c}	2873 ± 106^{c}	2747 ± 53^{c}	9818 ± 38^{a}
FBBB (mg GAE/L)	$23{,}715 \pm 543^{a}$	4488 ± 80^{c}	4397 ± 275^{c}	5533 ± 91^{c}	3561 ± 72^{d}	$17{,}889 \pm 420^{b}$
Total flavonoids (mg CE/L)	4419 ± 11^{a}	819 ± 8.0^{c}	345 ± 14^{d}	345 ± 5.0^{d}	406 ± 18^{d}	2870 ± 23^{b}
Total anthocyanins (mg CGE/L)	857 ± 31^{b}	111.3 ± 5.0^{c}	557 ± 2.0^{d}	746 ± 39^{b}	67 ± 3.0^{d}	1881 ± 94^{a}

Data are mean ± standard deviation ($n = 5$). Statistical analysis was performed by one-way ANOVA using the Tukey's post hoc test: different letters in the same row indicate statistical significance (at least at $p \leq 0.05$)

DPPH 1,1-diphenyl-2-picrylhydrazyl; *ABTS* 2,2′-azino-di-[3ethylbenzthiazoline sulphonate]; *FBBB* 4-benzoylamino-2,5-diethoxybenzenediazonium chloride hemi(zinc chloride) salt, *Tx* trolox equivalents; *GAE* gallic acid equivalents; *CE* catechin equivalents, *CGE* cyanidin-3-glucoside equivalents

Antioxidant properties

The analysis of antioxidant properties of the exotic juices showed that the highest antioxidant capacity (DPPH assay) was possessed by acai juice 2004 ± 44 mg Tx/L (Table 1). Much lower values were attained by noni and maqui berry juices: 905 ± 2.0 and 252 ± 3.0 mg Tx/L, respectively. The local juices were not inferior to the exotic ones in this regard. Blueberry and raspberry juices had antioxidant capacity equal 659 ± 8.0 and 1348 ± 21 mg Tx/L, respectively. Elderberry juice surpassed all other samples, even acai juice (3475 ± 101 mg Tx/L).

These results were confirmed by the other test method (ABTS assay). Also here, the highest antioxidant capacity was demonstrated by acai and elderberry juices (17.5 and 21.3 mM Tx, respectively). These juices were additionally distinguished by the highest sum of polyphenols: 6358 ± 17 and 9818 ± 38 mg GAE/L, respectively (Table 1). Of the other four juices, high total polyphenols were determined in noni juice 3534 ± 44 mg GAE/L. The lowest TP was noted in maqui berry juice 2142 ± 37 mg GAE/L.

Total polyphenols determined by FBBB assay showed that acai juice had the highest sum of polyphenols (23,715 ± 543 mg GAE/L). The other juices had much lower values of TP, except elderberry juice (17,889 ± 420 mg GAE/L). It is worth noticing that the lowest TP determined with this method was detected in blueberry juice (3561 ± 72 mg GAE/L).

Acai juice was also the richest in total flavonoids (4419 ± 11 mg CE/L). This juice was much richer in flavonoids than all other juices, even elderberry juice (2870 ± 23 mg CE/L). The other four juices had much lower levels of total flavonoids (Table 1). Maqui berry juice contained no more than 819.0 ± 8.0 mg CE/L. The lowest values of total flavonoids were determined in noni, raspberry and blueberry juices, which did not differ from one another in a statistically significant manner.

The content of total anthocyanins was considerably the highest in elderberry juice (1881 mg cyd-3-glu/L). It was more than double the content of these compounds in acai and raspberry juices. The other analysed juices were also low in these compounds (Table 1).

Our analysis of the antioxidant properties of juices revealed that the highest antioxidant capacity (DPPH and ABTS assays) as well as the highest total polyphenols (Folin–Ciocalteu assay) were achieved by elderberry juice among the local juices and acai juice among the exotic ones. High antioxidant capacity in acai fruit has been shown by other researchers [32, 33]. Elsewhere, elderberry juice was shown to have a much lower sum of polyphenols (TP), equal 3521 mg GAE/L [34] and 6362 mg GAE/L [35] or slightly higher one, i.e. 10,060 mg/L [31]. Furthermore, acai juice had a threefold higher total phenolic content in our study than reported by Schauss et al. [36]. Twice as much total polyphenols as in our study, i.e. 13,860 ± 1040 mg GAE/kg, was determined by Ferreira et al., but their results pertained to the wet weight of fruits [37]. We determined lower antioxidant capacity in noni, raspberry and blueberry juices. In turn, Seeram et al. showed that blueberry juice had a slightly higher antioxidant capacity than did acai juice [38]. Whereas, Prior et al. noted that acai fruit pulp had about 35% higher antioxidant capacity (total ORAC) than elderberry fruit and over fivefold higher than raspberry [39]. We observed low values of total polyphenolics in blueberry, raspberry and maqui berry juices (below 3000 mg GAE/L). A similar value, i.e. 3210 mg GAE/L, was determined in blueberry juice by Casati et al. [31]. Piljac-Zegarac et al. [30] and Jakobek et al. [35] demonstrated lower sums of polyphenols in blueberry and raspberry juices, i.e. 1795.5 and 1234 mg GAE/L, respectively. Brauch et al. [40] detected thrice as much polyphenols in maqui berry juice (TP 7300 mg GAE/L) as detected in our research. Similar results obtained Casati et al., but in maqui berry pulp [14]. A much higher antioxidant capacity (DPPH assay) in maqui berry juice was reported by Genskowsky et al. [12]. However, our study demonstrated sevenfold higher total phenolic content in noni juice than was reported by Dussossoy et al. [29]. Results approximate to ours were delivered by Yang et al. [28] with respect to the total content of polyphenolics in ripe noni berries. Results of determinations of polyphenols by the Folin–Ciocalteu assay may be not accurate, because fruits, vegetables and juices have such ingredients as glucose, fructose, carotenoids or ascorbic acid that may disturb the measurement of TP [33]. No such interference is observed while applying the Fast Blue BB method, which has been developed relatively recently. The FBBB method was described in detail by Medina [24], while Kang et al. [33] made the first comparison of this method with the popular Folin–Ciocalteu approach in analyses of juice produced from Euterpe fruits. They concluded that the FBBB assay generated approximately 2.9- to 3.4-fold higher sums of polyphenolics than did the F–C assay [33]. In our study, the FBBB tended to yield results which were by 1.2- to twofold higher than the ones obtained with the F–C. Acai juice was an exception as the total polyphenolics determined in this juice with the FBBB method was 3.7-fold higher than determined according to the Folin–Ciocalteu method. Acai juice had the highest total polyphenols determined with the FBBB assay, which was fivefold higher than in maqui berry, noni and raspberry juices. The high content of polyphenols in acai and elderberry juices was a consequence of their high content of flavonoids. We determined that the juice from exotic acai berries contained significantly the highest total flavonoid content, while noni, raspberry and blueberry juices had significantly lower amounts of these compounds. Elderberry juice had the highest total anthocyanin content. The value determined in our study was twice as high as demonstrated by Casati et al. [31]. Acai juice and raspberry juice had the second highest content of anthocyanins. Acai juice in our study was determined to contain approximately twice as much of these compounds as demonstrated by Ferreira et al. [37], while raspberry juice was found to have a total content of anthocyanins over threefold higher than shown by Jakobek et al. [35]. The other juices were low in anthocyanins. In our study, maqui berry juice contained much less of these compounds than reported by Brauch et al. [40], Genskowsky et al. [12] and Casati et al. [14].

Furthermore, we determined the correlation of analytical methods. The correlation coefficients (R^2) ranged from 0.578 to 0.988 (Table 2). Obtained results confirmed a high linear correlation between antioxidant capacity (DPPH and ABTS assay) and total polyphenols content (0.969 and 0.924, respectively). Moreover, a high correlation coefficient between TP and TA (0.931) showed that anthocyanins strongly decided about antioxidant properties of analysed juices. It should be stated that novel FBBB method demonstrated lower correlation with antioxidant capacity (DPPH and ABTS assay) than standard Folin–Ciocalteu method (TP). However, a high correlation was found between FBBB and TF.

Phenolic compounds

Next, the tested exotic juices were analysed with respect to the composition of polyphenols, and compared with antioxidant-rich local juices made from elderberry, raspberry and blueberry. The results of HPLC led to the identification of phenolic acids, particularly chlorogenic and ferulic acids (12.6 ± 0.5 and 16.3 ± 0.5 mg/kg) in acai juice (Table 3). This juice also contained the highest level of flavonols, especially catechin (4.2 ± 0.1 mg/kg). The other two exotic juices contained much less of polyphenols. Maqui berry and noni juices contained small quantities of phenolic acids. For comparisons, among the local juices analysed, elderberry juice was the richest in polyphenolic compounds. This juice had the highest amount of flavonols, especially quercetin (133.2 ± 7.4 mg/kg), out of all the juices tested. Moreover, it contained large quantities of phenolic acids, especially chlorogenic acid and caffeic acid (100.9 ± 0.1 and 138.2 ± 14.6 mg/kg, respectively). Elderberry juice was also found to contain relatively large amount of flavones, especially apigenin (19.5 ± 0.5 mg/kg). Raspberry and blueberry juices were determined to contain less of polyphenolic compounds. Raspberry juice contained mainly gallic and ferulic acids, while blueberry juice had mostly luteolin, which belongs to flavones. In addition, these juices had the highest quantities of resveratrol: 9.6 ± 0.2 and 13.1 ± 0.5 mg/kg, respectively.

Our analysis of the composition of polyphenols (HPLC) showed that the exotic acai juice was a rich source of

Table 2 The correlation coefficients (R^2)

	DPPH	ABTS	TP	FBBB	TF	TA
DPPH		0.909	0.969	0.771	0.683	0.976
ABTS	0.909		0.924	0.841	0.817	0.786
TP	0.969	0.924		0.815	0.756	0.931
FBBB	0.771	0.841	0.815		0.988	0.678
TF	0.683	0.817	0.756	0.988		0.578
TA	0.976	0.786	0.931	0.678	0.578	

Table 3 HPLC analysis of selected phenolic compounds of juices (mg/kg)

Compounds	Acai	Maqui berry	Noni	Raspberry	Blueberry	Elderberry
Phenolic acids						
Free phenolic acids						
Gallic acid	Tr[d]	0.8 ± 0.1[c]	Nd[d]	2.4 ± 0.1[a]	1.6 ± 0.2[b]	1.8 ± 0.1[b]
Chlorogenic acid	12.6 ± 0.5[b]	1.2 ± 0.1[c]	Nd[d]	Tr[d]	2.0 ± 0.1[c]	100.9 ± 0.1[a]
Caffeic acid	0.7 ± 0.1[c]	Nd[d]	0.9 ± 0.1[c]	1.6 ± 0.1[b]	0.5 ± 0.1[c]	8.6 ± 0.1[a]
Coumaric acid	0.5 ± 0.1[c]	1.8 ± 0.1[b]	Tr[d]	1.2 ± 0.1[b]	Tr[d]	2.9 ± 0.1[a]
Ferulic acid	3.9 ± 1.2[a]	0.3 ± 0.1[c]	Nd[d]	1.8 ± 0.1[b]	0.9 ± 0.1[c]	0.3 ± 0.1[c]
Bound phenolic acids						
Caffeic acid	3.9 ± 0.1[c]	6.1 ± 0.1[b]	0.7 ± 0.1[d]	3.7 ± 0.1[c]	4.4 ± 0.1[c]	138.2 ± 14.6[a]
Coumaric acid	5.0 ± 0.3[b]	1.9 ± 0.1[c]	0.2 ± 0.1[d]	5.7 ± 0.1[b]	1.2 ± 0.1[c]	65.2 ± 5.8[a]
Ferulic acid	16.3 ± 0.5[a]	2.3 ± 0.1[b]	1.1 ± 0.1[c]	13.4 ± 0.1[a]	2.8 ± 0.1[b]	14.5 ± 0.1[a]
Galic acid	Nd[c]	0.5 ± 0.1[b]	Nd[c]	16.2 ± 0.1[a]	1.4 ± 0.1[b]	0.4 ± 0.1[b]
Flavonoids						
Flavanols						
Catechin	4.2 ± 0.1[a]	Nd[b]	Nd[b]	Nd[b]	Nd[b]	Nd[b]
Epicatechin	1.9 ± 0.3[a]	Nd[b]	Nd[b]	Tr[b]	Nd[b]	2.4 ± 0.1[a]
Flavonols						
Quercetin	4.0 ± 0.1[b]	1.9 ± 0.4[b]	Nd[c]	5.5 ± 0.1[b]	Nd[c]	133.2 ± 7.4[a]
Kaempferol	0.6 ± 0.1[c]	Tr[d]	1.3 ± 0.3[b]	1.2 ± 0.1[b]	1.7 ± 0.1[b]	2.5 ± 0.1[a]
Myricetin	1.8 ± 0.1[b]	Nd[c]	Nd[c]	1.1 ± 0.1[b]	6.7 ± 0.2[a]	1.5 ± 0.2[b]
Flavones						
Apigenin	Nd[c]	0.9 ± 0.1[b]	Nd[c]	1.3 ± 0.2[b]	Nd[c]	19.5 ± 0.5[a]
Luteolin	0.9 ± 0.1[c]	Nd[d]	0.5 ± 0.1[c]	Nd[d]	14.3 ± 0.2[a]	2.2 ± 0.1[b]
Stilbenes						
Resveratrol	1.8 ± 0.2[c]	Nd[d]	7.6 ± 0.5[b]	9.6 ± 0.2[b]	13.1 ± 0.5[a]	8.2 ± 0.4[b]

Data are mean ± standard deviation ($n = 3$). Statistical analysis was performed by one-way ANOVA using Tukey's as post test: different letters in the same row indicate statistical significance (at least $p \leq 0.05$)

Nd non detected (detection limit 0.1 mg/kg); *Tr* trace amount

phenolic acids (mainly chlorogenic and ferulic acids) and catechin as well as quercetin. Other researchers also identified ferulic acid and chlorogenic acid in acai juice, alongside the compounds such as p-hydroxybenzoic, gallic, protocatechuic, ellagic, vanillic, benzoic, syringic, *p*-coumaric acids, and ellagic acid glycoside [10, 41, 42]. The quoted researchers have also detected the presence of resveratrol in acai, a compound which was identified in acai juice tested in our study as well. Small levels of phenolic acids and quercetin were detected in exotic maqui berry juice we tested. Genskowsky et al. [12] detected the presence of myricetin and ellagic acids (undetected in our study) as well as quercetin, coumaric, chlorogenic and gallic acid. Exotic noni juice contained phenolic acids, kaempferol, luteolin and resveratrol. Dussossoy et al. [29] detected such phenolic compounds in noni juice as rutin, quercetin, quercetin derivatives and kaempferol derivatives. Thus far, over 100 different compounds classified as flavonoids, lignans, iridoids, coumarins, have been identified in noni juices [28, 43, 44]. Among the local juices tested, elderberry juice contained most polyphenolic compounds. This juice had the highest content of flavonols (especially quercetin) and phenolic acids. As demonstrated in our previous research, elderberry juice has a dominant share of chlorogenic and coumaric acids, while quercetin is the prevalent flavonol [3]. Other researchers have identified substantial amounts of anthocyanins, mostly cyanidin-3-glucoside and cyanidin-3-sambubioside in elderberry juice [45]. Aside the composition of anthocyanins, Bermudez-Soto and Tomas-Barberan [1] demonstrated the presence of quercetin and quercetin derivatives as well as chlorogenic and neochlorogenic acids in elderberry juice. Raspberry juice we analysed was shown to contain phenolic acids (particularly gallic and ferulic acids), quercetin and resveratrol. Jakobek et al. [35] showed that raspberry juice was characterized by higher concentrations of phenolic acids. However, in contrast to our results, they suggested that ellagic acid was dominant, while caffeic, ferulic, *p*-coumaric and *p*-hydroxybenzoic acids were found in much smaller concentrations [35]. We were able to determine 5.5 mg quercetin in a litre of raspberry juice, whereas Hakkinen et al. [46] reported the concentration of this compound at 4 mg/kg. They also detected small quantities of myricetin and kaempferol, which we did not observe. However, the composition of polyphenols determined in blueberry juice was dominated by luteolin and resveratrol, while myricetin and phenolic acids (mostly caffeic acid) appeared in smaller amounts. Large concentrations of chlorogenic acid but small quantities of resveratrol (three- to fivefold less than in our tests) were reported in raspberry fruits by Wang et al. [47]. Differences in levels of compounds have arisen from different cultivation methods (conventional/organic).

The high content of polyphenolic compounds in the analysed exotic fruit juices (especially acai), apart from local berry fruits (especially elderberry) could be useful in reducing oxidative stress and improve human health. A similar conclusion was stated by Prior et al., who indicated that consumption of berries individually and/or in combination provide a balance in protection from oxidative stress [39]. Furthermore, it should be taken into account that the efficacy of antioxidants depends on the nature of oxidants, and that various antioxidants acts selectivity. Therefore, Morita et al. recommended consumption of antioxidants with foods rather than supplements or single compounds [7]. The literature data showed that natural antioxidants present in fruits, vegetables, spices and supplements have shown promise, both in in vitro and in animal models [48]. Intake of natural antioxidants plays a crucial role in the prevention of civilization diseases, such as cardiovascular, cancer, and other degenerative pathologies. Particularly valuable are bioactive compounds of berry fruits [49, 50].

Conclusions

The study reported in this paper showed that juices from exotic acai, noni and maqui berry fruits, because of their antioxidant properties, can be an interesting alternative to local juices. Acai and elderberry juices were characterized by the highest antioxidant capacity (DPPH, ABTS) and the highest total polyphenols content (TP and FBBB assays), including the highest content of flavonoids and anthocyanins (TF and TA). Noni and maqui berry juices had a lower antioxidant properties, but still comparable to that of raspberry and blueberry juices. A high correlation coefficients between DPPH/ABTS and TP as well as TP and TA showed that polyphenols, especially anthocyanins strongly decided about antioxidant properties of analysed juices. Our analysis of the composition of polyphenols compounds proved that exotic acai juice contained the highest level of flavanols (mainly catechin). Maqui berry juice was not confirmed to have such high antioxidant properties as indicated in references, despite the presence of some compounds that belong to flavonoids and anthocyanins. Among all analysed exotic juices acai juice seems to be the most valuable source of antioxidants.

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Compliance with ethical standards

Conflict of interest The authors declare that there are no conflicts of interest.

Compliance with ethics requirements This article does not contain any studies with human or animal subjects.

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