J Food Sci Technol (January 2018) 55(1):408–417
https://doi.org/10.1007/s13197-017-2952-6

ORIGINAL ARTICLE

Quality assessment of low-sugar jams enriched with plant raw materials exhibiting health-promoting properties

Anna Banaś[1] · Anna Korus[1] · Małgorzata Tabaszewska[1]

Revised: 28 September 2017 / Accepted: 19 October 2017 / Published online: 30 October 2017

Abstract Low-sugar gooseberry jams enriched by the addition of black chokeberry, elderberry, Japanese quince, flax seeds and wheat germs were examined for the content of total polyphenols, total flavonoids, and total anthocyanins as well as their antioxidant activity (DPPH, ABTS, and FRAP) and individual phenolic compounds. The jams were evaluated immediately after production and after 6 and 12 months of storage. Samples were stored at chilled temperature (10 °C) and room temperature (20 °C). A significant increase in the level of the analyzed components and antioxidant activity were determined in jams with the addition of chokeberry, elderberry and Japanese quince, while in the case of other plant ingredients the differences were not always significant. Immediately after production, the highest levels of total polyphenols (330 mg/100 g), total flavonoids (160 mg/100 g) and total anthocyanins (35 mg/100 g) were recorded in the gooseberry jam with a 15% addition of chokeberry fruit. In the examined jams, *p*-cumaric acid, ferulic acid, caffeic acid, (+)–catechin and rutin were identified and (+)–catechin were determined in the greatest quantities (1.874–5.660 mg/100 g). The storage conditions of jams determined the level of the examined constituents. Storage temperature generally had significant effect on the level of compounds with antioxidant properties, lower in the products which were chill-stored compared to those stored at room temperature. Anthocyanins were found to be the most sensitive components during storage.

✉ Anna Korus
rrkorusa@cyf-kr.edu.pl

[1] Department of Fruit, Vegetable and Mushroom Processing, Faculty of Food Technology, University of Agriculture in Kraków, 122 Balicka Street, 30-149 Krakow, Poland

Keywords Gooseberry · *Ribes uva-crispa* · Jam · Antioxidants · Polyphenol compounds · Storage

Introduction

Fruits are an excellent source of compounds exhibiting health-promoting properties. Numerous studies reveal a strong correlation between a diet rich in fruits and vegetables and health (Folmer et al. 2014; Wang and Stoner 2008). Thus, berries attract special attention. These include: blueberries, raspberries, currants, strawberries and gooseberries (Bordonaba and Terry 2011). They have stronger antioxidant properties, even when compared to citrus fruits, since it is not only vitamin C which has antioxidant properties, as was thought until recently, but also a number of other compounds. These include polyphenols, such as anthocyanins, flavonoids, phenolic acids and tannins, carotenoids, organic acids, and vitamins (B2, B6, E, P, PP) (Coultate 2009; Muraki et al. 2013; Schreiner 2005). Health-promoting components occurring in berries, in particular polyphenols, also show anti-microbial (Määttä-Riihinen et al. 2004), anti-carcinogenic (Takata et al. 2005) and anti-viral effects (Knox et al. 2003).

Gooseberry is one of the forgotten berry species. The explanation for its low commercial utilization is its low yield and susceptibility to diseases, especially powdery mildew. Gooseberry is grown mainly in Europe. The largest producers of this species are: Germany, wherein the harvest in 2014 amounted to 88,000 tonnes; Russia, 55,000 tonnes; and Poland, 12,500 tonnes (FAOSTAT 2014). As gooseberry is available seasonally, there is a trend towards prolonging its availability in the form of processed products. The fruit is most commonly eaten as jelly, in jams and

in juices (Barney and Hummer 2005). Anastasiadi et al. (2016) indicate the wealth of possible applications of gooseberry as a source of bioactive compounds. As Pantelidis et al. (2007) report, the content of polyphenolic compounds in various gooseberry species, calculated as a gallic acid equivalent (GAE), varies between 1257 and 1321 mg/100 dry matter. The main gooseberry phenols are anthocyanins (Määttä-Riihinen et al. 2004; Pantelidis et al. 2007), flavonol, glycosides and proanthocyanins (Chiang et al. 2013).

At present, consumers are looking for natural products with particular nutritive value, which are also sensorially attractive (Wildman 2001). Therefore, traditional products enriched with health-promoting ingredients of natural origin are appreciated in the daily diet and are willingly consumed.

Hence, the present study's objective was to evaluate the effect of adding plant raw materials with health-promoting properties (black chokeberry, elderberry, Japanese quince, flax seeds, and wheat germs) on the content of selected antioxidants in low-sugar gooseberry jams. The level of analyzed parameters was determined in jams immediately after production and after 6- and 12-month storage periods at room temperature (20 °C) and chilled temperature (10 °C).

Materials and methods

Material

The material investigated consisted of low-sugar gooseberry jam prepared from the gooseberry (*Ribes uva-crispa* L.) without plant ingredients, and jams containing enriching additives such as chokeberry (*Aronia melanocarpa*), elderberry (*Sambucus nigra* L.), Japanese quince (*Chaenomeles japonica*), flax seeds (*Linum* L.) and wheat (*Triticum aestivum* L.) germ.

Jams were produced from frozen fruits, which were prepared from fully ripened fresh fruits. These were sorted and washed immediately after harvest, and inedible parts were rejected. Fruits were frozen as a whole, while the fruit of chokeberry, elderberry and Japanese quince was homogenized prior to freezing. After freezing, the raw fruit material was kept in polypropylene bags at − 30 °C until production. Flax was added in the form of ground defatted flaxseeds (Oleofarm, Poland), in which residual fat comprised 10%. Wheat germ obtained from wheat grain was purchased directly from the producer (Sante, Poland). Sucrose, steviol glycoside (Bio Nature24)—as a partial sucrose replacement—citrus-apple pectin (NECJ-A2, Naturex, France), and citric acid (Chem Point, Poland) were also used in the production of jams.

Production of jam

All jams with a final refractometric extract of about 30% were sweetened with sucrose and steviol glycoside, the addition of which allowed for the replacement of part of the sucrose and a reduction in the caloric value of the jams. Steviol glycoside was added in the maximum quantity permitted in the European Union, i.e. 200 mg/1000 g of the product (Commission Regulation (EU) No. 1131/2011). Fruit comprised 50% of the mass of the final product; the total acidity of the jam was set at 1%. Jams were prepared in the following variants:

- G0—strawberry jam without plant ingredients,
- GCh—jam with 15% addition of chokeberry,
- GE—jam with 15% addition of elderberry,
- GJ—jam with 8% addition of Japanese quince,
- GF—jam with 3% addition of flax seeds,
- GWG—jam with 3% addition of wheat germ.

After weighing the components according to the recipe (Table 1), the fruits were boiled together with sweeteners and water in an open pan (for 20 min at 103 °C) until the fruit was saturated with sugar and became an extract of about 35%. Afterwards, a previously prepared 4% solution of gelling agent was added and the whole batch was mixed and cooked again for several minutes. Finally, citric acid was added and mixed. Products were then packaged in glass jars (0.2 L), pasteurized at 82–85 °C for 15 min, and finally cooled to 20 ± 2 °C. Jams were stored at two temperatures: cold (10 °C) and room (20 °C) until evaluation, which was carried out immediately after their production and after 6 and 12 months of storage.

Chemical determination

In order to determine total polyphenols, total flavonoids, and antioxidant activity, sample extracts were prepared using 80% ethanol.

Total polyphenolic content

Polyphenols were determined by the Folin-Ciocalteu method (Singleton et al. 1999), according to which the Folin-Ciocalteu reagent and 25% sodium carbonate were added to the extract, which was previously diluted with deionised water. After 60 min, the absorbance was measured at 765 nm. The content of polyphenols was read from the standard curve prepared for (+)-catechin.

Total flavonoid content

Total flavonoid content was detected by aluminium chloride assay (Zhishen et al. 1999; Ardestani and

Table 1 Recipes of gooseberry jams, g/1 kg

Type of jams[b]	Ingredients[a]										
	G	Ch	E	J	F	WG	Sucrose	Steviol glycoside	Pectin	Citric acid	Water
G0	500						255	0.2	11.2	2.0	231
GCh	350	150					246	0.2	11.2	2.6	240
GE	350		150				250	0.2	11.2	2.6	235
GJ	420			80			255	0.2	11.2	0.0	233
GF	500				30		246	0.2	16.0	2.0	201
GWG	500					30	246	0.2	16.0	2.0	201

[a]*G* gooseberry, *Ch* chokeberry, *E* elderberry, *J* Japanese quince, *F* flax seeds, *WG* wheat germ

[b]Type of jams: G0—gooseberry jam without plant ingredients, GCh—jam with 15% addition of chokeberry, GE—jam with 15% addition of elderberry, GJ—jam with 8% addition of Japanese quince, GF–jam with 3% addition of flax seeds, GWG—jam with 3% addition of wheat germ

Yazdanparast 2007). After appropriate dilution of the extract with deionised water, $NaNO_2$, $AlCl_3$ and NaOH were added; the sample was then thoroughly vortex mixed and placed in darkness for 15 min. Afterwards, the absorbance at 510 nm was measured. The content of flavonoids was read from the standard curve prepared for (+)-catechin.

Identification of polyphenols

Separation and identification of polyphenols was performed by high performance liquid chromatography (HPLC), according to the method described by Klimczak et al. (2007), with our modifications. Jams were ground in a laboratory mill with the addition of distilled water at a ratio of 1:1, then adding NaOH (2 mol/L) in a ratio of 1:1 w/w). Afterwards, samples were mixed using a Labnet vortex mixer (Edison, USA), left in the dark for 4 h (at room temperature) and then neutralized to pH 2.2–2.8 with HCl (2 mol/L) using a Metrohm pH meter (Herisau, Switzerland). The samples were then centrifuged at 4000×*g* for 20 min at 4 °C by means of a MPW - 260R centrifuge (Warsaw, Poland) and transferred quantitatively into a volumetric flask using 1% L-ascorbic acid dissolved in methanol (HPLC grade). Prior to chromatographic analysis, the material examined was again centrifuged (18,000 rpm, 20 min, 4 °C); the samples with wheat germ and those enriched with flax were centrifuged twice. Afterwards, they were filtered through an L-PTFE filter with a pore diameter of 22 µm. Before chromatographic analysis, the samples were stored at 4 °C.

The chromatographic analysis was performed using a Dionex Ultimate 3000 HPLC set equipped with Thermo Scientific DAD detector (Germering, Germany). A column (XBridge™ C18 250 × 4.6 mm; 3.5 µm) with a pre-column (XBridge™ C18, 20 × 4.6 mm; 3.5 µm (Waters,Wexford, Ireland)) was employed for analysis. The mobile phase consisted of two eluents: A—a 2% aqueous solution of acetic acid, and B—100% acetonitrile. The flow rate was 0.8 mL/min. The analysis was carried out for 80 min. using the following gradient: eluent A −15 min, 14%; 20 min, 18%; 30 min, 25%; 55 min, 55%; and 62 min, 100%; until the end of analysis.

Total anthocyanins content and degradation index (DI)

Total anthocyanins and degradation index were determined by means of the spectroscopic method (Giusti and Wrolstad 2001). Samples were prepared for analysis according to the procedure described by Plessi et al. (2007). Anthocyanin content, expressed as cyanidin-3-glucoside equivalent, was calculated from the absorbance measured and the coefficient of sample dilution.

Vitamin C content

Vitamin C content, as the sum of ascorbic and dehydroascorbic acid, was determined using spectrophotometrical method (ISO/6557-2 1984). Oxalic acid solution (2%) was used for extraction of the ascorbic acid. Quantitative reduction of 2,6-dichlorophenolindophenol dyestuff by the ascorbic acid, extraction of the excess dyestuff using xylene, and the excess was measured spectrophotometrically at 500 nm and compared with vitamin C reference standard.

Antioxidant activity measurement

Antioxidant activity was determined by means of three spectrophotometric methods: as scavenging activity against DPPH (1.1-diphenyl-2-picrylhydrazyl) free radical (Pekkarinen et al. 1999); applying ABTS (2,2′-azinobis(3-ethylbenzthiazoline-6-sulfonate) cation radical (Re et al. 1999); and by the ferric reducing antioxidant power (FRAP) method (Benzie and Strain 1996). For the

aforementioned methods, absorbance was measured at 516, 734, and 595 nm respectively.

A Hitachi U-2900 double beam spectrophotometer (Hitachi Europe Ltd) was used to analyse total polyphenols, flavonoids, anthocyanins, vitamin C and antioxidant activity.

Statistical analysis

In order to establish the statistical differences between means the date were treated by one-factor analysis of variance (ANOVA), and the averages were compared with the Snedecor F and Student's t tests at significance level $p < 0.05$. All calculations were performed with statistical software package Statistica 12.0 (StatSoft; Poland).

Results and discussion

Plant-derived polyphenols are a valuable component of a healthy diet, especially a diet which is aimed at cancer prevention (Link et al. 2010). The analyzed gooseberry jams without additives were a good source of total polyphenols (140.6 mg per 100 g final product) (Table 2). This research revealed a significant increase ($p < 0.05$) in the level of total polyphenols in jams enriched with fruit additives. In particular, a 15% addition of chokeberry resulted in a more than two-fold increase in the examined constituent. In turn, total flavonoid content was within the range 25.3–160.2 mg/100 g of jam (Table 2). The gooseberry jam without additives was characterized by a low content of total flavonoids, which was congruent with the vales reported by Levaj et al. (2012) for strawberry jam. The applied additives caused a statistically significant ($p < 0.05$) increase in total flavonoids, from two-fold in the jam containing flax seeds and wheat germs to almost six-fold in the jam with added chokeberry. Many researchers indicate the health benefits of food enrichment with plant components exhibiting strong antioxidant properties. Wojdyło et al. (2008) reported a significant ($p < 0.05$) increase in polyphenols after adding chokeberry to strawberry jams. On the other hand, Nawirska-Olszańska et al. (2010) found that Japanese quince is a good source of polyphenols and when added to pumpkin jam it elevates antioxidant activity. Also, the addition of herbs may improve a jam's quality by increasing polyphenol content and reducing degradation due to storage (Korus et al. 2015).

After 6 months' storage of gooseberry jams a significant ($p < 0.05$) decrease in total polyphenols by 9–18% (10 °C) and by 16–27% (20 °C) was determined (Table 2). A similar correlation was determined in the level of total flavonoids. After a following 6 month period, the losses were higher. The smallest decrease in polyphenols was determined in the gooseberry jam with the addition of Japanese quince stored at 10 °C, which was 23% on average compared to the initial level. In the case of total flavonoids, the smallest losses (26%) were determined in the jam with the addition of elderberry also stored at 10 °C. In general, chill-storage resulted in better retention of both total polyphenols and total flavonoids, on average by 25% compared to room temperature.

In the gooseberry jam without additives, the contents of (+)-catechin (2.442 mg/100 g) and caffeic acid (0.546 mg/100 g) were highest among the identified polyphenols (Table 3). Among the polyphenols, catechins in particular have gained great popularity due to a broad spectrum of antioxidant, anti-mutagenic and anti-carcinogenic properties (Sang et al. 2003). The enrichment of gooseberry jam with plant ingredients resulted in an increase ($p < 0.05$) in the level of identified polyphenols, except for the level of caffeic acid in the jam with wheat germ. Gooseberry jam with a 15% addition of chokeberry had the highest amounts of coffeic acid (4.403 mg/100 g), *p*-cumaric acid (0.638 mg/100 g) and ferulic acid (0.231 mg/100 g) compared to the remaining products, while the highest contents of (+)-catechin were determined in gooseberry jam with black elderberry (5.660 mg/100 g) and Japanese quince (5.469 mg/100 g). In turn, an increase in rutin content was the most significant ($p < 0.05$) in the jam enriched with elderberry, by 395%, as compared to gooseberry jam without additives. The beneficial effects of food enrichment are confirmed by numerous studies. For example, Wojdyło et al. (2008) showed an increase of (+)-catechin after enriching strawberry jam with Japanese quince and increases of *p*-cumaric and coffeic acids after the addition of chokeberry. On the other hand, Ducruet et al. (2017) highlight a significant increase in antioxidant activity and the content of bioactive substances (rutin and 2-O-β-D-glucopyranosyl, L-ascorbic acid) after adding goji berries to beer.

One-year storage of jams significantly reduced ($p < 0.05$) the level of identified polyphenols and significant differences were also determined between storage temperatures. Of the polyphenols identified in the examined jams, ferulic acid was found to be the most unstable; after 12 months of storage its losses were of 18% (10 °C) and 32% (20 °C), compared with the samples taken immediately after production (Table 3). Polyphenol reduction in products depends on various factors and one of them is the storage temperature. According to Wojdyło et al. (2008), losses of ferulic acid (45%) in strawberry jam with added chokeberry were significantly greater after just 6 months of storage at 4 °C, whereas Mäkilä et al. (2017) noted only a 4% drop in this constituent in black currant juice after a 12-month period of storage at 4 °C.

Table 2 Total polyphenols and flavonoids in gooseberry jams during storage, mg/100 g

Analysed component[a]	Type of jams[b]	Storage time/temperature							
		0	6 months		p value[c]	0	12 months		p value
			10 °C	20 °C			10 °C	20 °C	
Total polyphenols	G0	140.6 ± 7.4^{aA}	124.8 ± 8.9^{bA}	118.2 ± 4.9^{bA}	0.005	140.6 ± 7.4^{aA}	88.0 ± 6.0^{bA}	74.5 ± 7.9^{cA}	< 0.001
	GCh	330.0 ± 15.0^{aB}	271.2 ± 10.0^{bB}	239.9 ± 7.0^{cB}	< 0.001	330.0 ± 15.0^{aB}	222.0 ± 5.1^{bB}	181.2 ± 16.6^{cB}	< 0.001
	GE	234.2 ± 16.7^{aC}	191.6 ± 8.1^{bC}	173.0 ± 14.1^{bC}	0.001	234.2 ± 16.7^{aC}	166.0 ± 8.5^{bC}	129.9 ± 10.0^{cC}	< 0.001
	GJ	171.5 ± 15.8^{aD}	156.2 ± 4.8^{aD}	128.9 ± 10.6^{bA}	0.002	171.5 ± 15.8^{aD}	131.3 ± 4.5^{bD}	96.1 ± 12.5^{cD}	< 0.001
	GF	134.0 ± 9.4^{aA}	118.9 ± 6.4^{bA}	108.2 ± 4.4^{bAD}	0.002	134.0 ± 9.4^{aA}	84.4 ± 9.1^{bA}	67.7 ± 8.6^{cA}	< 0.001
	GWG	129.2 ± 9.4^{aA}	115.5 ± 4.1^{bA}	101.6 ± 6.1^{bD}	0.001	129.2 ± 9.4^{aA}	70.1 ± 6.9^{bE}	59.9 ± 4.1^{bA}	< 0.001
p value		< 0.001	< 0.001	< 0.001		< 0.001	< 0.001	< 0.001	
Total flavonoids	G0	25.3 ± 3.1^{aA}	23.4 ± 2.7^{aA}	21.2 ± 3.3^{aA}	0.214	25.3 ± 3.1^{aA}	17.6 ± 1.4^{bA}	13.3 ± 1.8^{cA}	0.001
	GCh	160.2 ± 6.0^{aB}	137.7 ± 5.0^{bB}	113.8 ± 6.6^{cB}	< 0.001	160.2 ± 6.0^{aB}	88.3 ± 12.3^{bB}	70.0 ± 4.0^{cB}	< 0.001
	GE	93.8 ± 6.0^{aC}	83.8 ± 5.2^{bC}	78.2 ± 4.3^{cC}	0.007	93.8 ± 6.0^{aC}	69.0 ± 5.1^{bC}	55.3 ± 6.5^{cC}	< 0.001
	GJ	63.1 ± 9.1^{aD}	53.1 ± 5.1^{bD}	40.2 ± 2.4^{cD}	0.002	63.1 ± 9.1^{aD}	39.6 ± 8.0^{bDE}	27.4 ± 1.7^{cD}	0.002
	GF	46.1 ± 2.7^{aE}	41.6 ± 2.2^{bE}	31.5 ± 2.4^{cE}	< 0.001	46.1 ± 2.7^{aE}	30.3 ± 2.7^{bD}	22.7 ± 2.1^{cD}	< 0.001
	GWG	43.5 ± 1.8^{aE}	38.8 ± 2.9^{bE}	29.8 ± 2.9^{cE}	0.001	43.5 ± 1.8^{aE}	28.9 ± 3.4^{bD}	23.6 ± 2.4^{cD}	< 0.001
p value		< 0.001	< 0.001	< 0.001		< 0.001	< 0.001	< 0.001	

[a]Values are presented as mean value ± SD (n = 4) and expressed of fresh matter. Different letters (ac) in the same rows or (A–E) in the same columns indicate significant differences ($p < 0.05$)

[b]Type of jams: G0—gooseberry jam without plant ingredients, GCh—jam with 15% addition of chokeberry, GE—jam with 15% addition of elderberry, GJ—jam with 8% addition of Japanese quince, GF—jam with 3% addition of flax seeds, GWG—jam with 3% addition of wheat germ

[c]One-way ANOVA, analysis of variance

Table 3 Identification of polyphenols compounds in gooseberry jams during storage, mg/100 g

Analysed component[a]	Type of jams[b]	Storage time/temperature			
		0	12 months 10 °C	12 months 20 °C	*p* value[c]
p-coumaric acid	G0	0.273 ± 0.004^{aA}	0.208 ± 0.001^{bA}	0.155 ± 0.003^{cA}	< 0.001
	GCh	0.638 ± 0.004^{aB}	0.578 ± 0.002^{bB}	0.530 ± 0.009^{cB}	< 0.001
	GE	0.349 ± 0.005^{aC}	0.264 ± 0.001^{bC}	0.232 ± 0.001^{cC}	< 0.001
	GJ	0.285 ± 0.004^{aD}	0.231 ± 0.001^{bD}	0.171 ± 0.001^{cD}	< 0.001
	GF	0.413 ± 0.003^{aE}	0.338 ± 0.003^{bE}	0.291 ± 0.004^{cE}	< 0.001
	GWG	0.388 ± 0.007^{aF}	0.328 ± 0.002^{bF}	0.282 ± 0.006^{cE}	< 0.001
p value		< 0.001	< 0.001	< 0.001	
Ferulic acid	G0	nd[d]	nd	nd	nd
	GCh	0.231 ± 0.001^{aA}	0.205 ± 0.000^{bA}	0.177 ± 0.006^{cA}	< 0.001
	GE	0.173 ± 0.016^{aB}	0.124 ± 0.003^{bB}	0.099 ± 0.001^{cB}	0.001
	GJ	0.014 ± 0.001^{aC}	0.009 ± 0.001^{bC}	0.007 ± 0.001^{cC}	< 0.001
	GF	0.170 ± 0.005^{aB}	0.148 ± 0.003^{bD}	0.124 ± 0.002^{cD}	< 0.001
	GWG	0.155 ± 0.002^{aD}	0.123 ± 0.001^{bB}	0.099 ± 0.006^{cB}	< 0.001
p value		< 0.001	< 0.001	< 0.001	
Caffeic acid	G0	0.546 ± 0.007^{aA}	0.493 ± 0.005^{bA}	0.330 ± 0.011^{cA}	< 0.001
	GCh	4.403 ± 0.184^{aB}	3.875 ± 0.031^{bB}	3.413 ± 0.036^{cB}	0.001
	GE	0.493 ± 0.004^{aC}	0.464 ± 0.006^{bC}	0.310 ± 0.005^{cA}	< 0.001
	GJ	1.463 ± 0.030^{aD}	1.247 ± 0.007^{bD}	1.029 ± 0.022^{cC}	< 0.001
	GF	0.842 ± 0.036^{aE}	0.734 ± 0.011^{bE}	0.642 ± 0.007^{cD}	0.001
	GWG	0.528 ± 0.003^{aAC}	0.466 ± 0.005^{bC}	0.428 ± 0.003^{bE}	< 0.001
p value		< 0.001	< 0.001	< 0.001	
(+)-catechin	G0	2.442 ± 0.055^{aA}	1.958 ± 0.005^{bA}	1.699 ± 0.086^{cA}	< 0.001
	GCh	1.874 ± 0.048^{aB}	1.610 ± 0.034^{bB}	1.358 ± 0.053^{cB}	< 0.001
	GE	5.660 ± 0.084^{aC}	4.670 ± 0.082^{bC}	4.368 ± 0.000^{cC}	< 0.001
	GJ	5.469 ± 0.135^{aD}	4.592 ± 0.084^{bC}	4.145 ± 0.021^{cD}	< 0.001
	GF	4.277 ± 0.077^{aE}	3.633 ± 0.064^{bD}	2.800 ± 0.059^{cE}	< 0.001
	GWG	3.860 ± 0.053^{aF}	3.258 ± 0.134^{bE}	2.565 ± 0.033^{cF}	< 0.001
p value		< 0.001	< 0.001	< 0.001	
Rutin	G0	0.128 ± 0.004^{aA}	0.102 ± 0.006^{bA}	0.087 ± 0.002^{cA}	0.001
	GCh	0.227 ± 0.006^{aB}	0.213 ± 0.001^{bB}	0.202 ± 0.002^{cB}	0.001
	GE	0.633 ± 0.020^{aC}	0.546 ± 0.003^{bC}	0.513 ± 0.003^{cC}	< 0.001
	GJ	0.097 ± 0.001^{aD}	0.085 ± 0.001^{bD}	0.075 ± 0.004^{cD}	0.001
	GF	0.348 ± 0.006^{aE}	0.327 ± 0.012^{bE}	0.249 ± 0.004^{cE}	< 0.001
	GWG	0.111 ± 0.001^{aD}	0.087 ± 0.004^{bD}	0.054 ± 0.002^{cF}	< 0.001
p value		< 0.001	< 0.001	< 0.001	

[a]Values are presented as mean value ± SD (n = 4) and expressed of fresh matter. Different letters (a–c) in the same rows or (A–F) in the same columns indicate significant differences ($p < 0.05$)

[b]Type of jams: G0—gooseberry jam without plant ingredients, GCh—jam with 15% addition of chokeberry, GE—jam with 15% addition of elderberry, GJ—jam with 8% addition of Japanese quince, GF—jam with 3% addition of flax seeds, GWG—jam with 3% addition of wheat germ

[c]One-way ANOVA, analysis of variance

[d]*Nd* not detected

The visual attractiveness of the final product is a crucial factor in determining consumers' choices of food products. Anthocyanins are the main food colorants responsible for intense colour, which consumers associate with freshness and good quality of the raw material. They belong to the group of polyphenols which have antioxidant properties but are fairly sensitive to technological processes and storage (Kirca et al. 2007). In the gooseberry jam without additives, average anthocyanin content was low and amounted to 1.4 mg/100 g (Table 4). Enriching jams with health-

Table 4 Total anthocyanins and degradation index in gooseberry jams during storage

Analysed component[a]	Type of jams[b]	Storage time/temperature							
		0	6 months		p value[c]	0	12 months		p value
			10 °C	20 °C			10 °C	20 °C	
Total anthocyanins (mg/100 g)	G0	1.4 ± 0.2^{aA}	1.4 ± 0.5^{aA}	1.3 ± 0.3^{aA}	0.842	1.4 ± 0.2^{aA}	1.2 ± 0.6^{aA}	1.0 ± 0.3^{aA}	0.482
	GCh	35.3 ± 2.8^{aB}	26.4 ± 1.5^{bB}	23.4 ± 3.3^{bB}	0.001	35.3 ± 2.8^{aB}	20.0 ± 1.3^{bB}	12.8 ± 1.5^{cB}	< 0.001
	GE	18.6 ± 1.3^{aC}	15.7 ± 2.8^{aC}	11.3 ± 1.5^{bC}	0.002	18.6 ± 1.3^{aC}	12.1 ± 1.2^{bC}	9.5 ± 1.0^{cC}	< 0.001
	GJ	1.1 ± 0.3^{aA}	1.1 ± 0.1^{aA}	0.9 ± 0.3^{aA}	0.295	1.1 ± 0.3^{aA}	0.9 ± 0.1^{abA}	0.7 ± 0.2^{bA}	0.032
	GF	2.5 ± 0.1^{aA}	1.9 ± 0.2^{bA}	1.6 ± 0.4^{bA}	0.002	2.5 ± 0.1^{aA}	1.6 ± 0.2^{bA}	1.1 ± 0.4^{cA}	0.001
	GWG	2.1 ± 0.4^{aA}	1.8 ± 0.2^{aA}	1.6 ± 0.3^{aA}	0.115	2.1 ± 0.4^{aA}	1.5 ± 0.2^{bA}	1.3 ± 0.2^{bA}	0.004
p value		< 0.001	< 0.001	< 0.001		< 0.001	< 0.001	< 0.001	
Degradation index	G0	1.28 ± 0.34^{aA}	1.34 ± 0.30^{aA}	1.42 ± 0.40^{aA}	0.844	1.28 ± 0.34^{aA}	1.63 ± 0.41^{aA}	1.75 ± 0.40^{aA}	0.238
	GCh	1.27 ± 0.04^{aA}	1.30 ± 0.04^{aA}	1.43 ± 0.08^{bA}	0.006	1.27 ± 0.04^{aA}	1.46 ± 0.09^{bA}	1.84 ± 0.42^{cA}	< 0.001
	GE	1.25 ± 0.10^{aA}	1.36 ± 0.06^{aA}	1.47 ± 0.26^{bA}	0.008	1.25 ± 0.10^{aA}	1.56 ± 0.10^{bA}	1.71 ± 0.48^{bA}	0.015
	GJ	1.28 ± 0.36^{aA}	1.27 ± 0.29^{aA}	1.30 ± 0.30^{aA}	0.994	1.28 ± 0.36^{aA}	1.53 ± 0.25^{aA}	1.66 ± 0.45^{aA}	0.358
	GF	1.30 ± 0.06^{aA}	1.36 ± 0.39^{aA}	1.37 ± 0.19^{aA}	0.919	1.30 ± 0.06^{aA}	1.52 ± 0.25^{bA}	1.63 ± 0.54^{bA}	0.013
	GWG	1.26 ± 0.17^{aA}	1.37 ± 0.19^{aA}	1.39 ± 0.13^{aA}	0.512	1.26 ± 0.17^{aA}	1.49 ± 0.13^{bA}	1.56 ± 0.22^{bA}	0.018
p value		0.999	0.974	0.948		0.999	0.919	0.949	

[a]Values are presented as mean value ± SD (n = 4) and expressed of fresh matter. Different letters (a–c) in the same rows or (A–C) in the same columns indicate significant differences ($p < 0.05$)

[b]Type of jams: G0—gooseberry jam without plant ingredients, GCh—jam with 15% addition of chokeberry, GE—jam with 15% addition of elderberry, GJ—jam with 8% addition of Japanese quince, GF—jam with 3% addition of flax seeds, GWG—jam with 3% addition of wheat germ

[c]One-way ANOVA, analysis of variance

promoting components raises the final quality of the end product, which has been confirmed by this study. In gooseberry jams with added chokeberry and elderberry, anthocyanin content was many times higher than in those without additives and was 35.3 and 18.6 mg/100 g, respectively. Wojdyło et al. (2008) also reported an increase in proanthocyanidins after enrichment of strawberry jam with chokeberry. After 6 months' storage, the losses of anthocyanins ($p < 0.05$) were observed only in the jam with chokeberry, elderberry and flax seeds (Table 4). After 12 months' storage, further losses of anthocyanins were noted. The storage temperature did not affect ($p < 0.05$) on the level of anthocyanins in gooseberry jam without plant ingredients, with the addition of Japanese quince and wheat germ. In the other jams a lower degradation was determined in the jams stored at 10 °C, compared to those stored at 20 °C, while the highest decrease in the level of anthocyanins was determined at 20 °C in gooseberry jam with the addition of chokeberry (64%).

In non-stored jams, there were no significant differences ($p < 0.05$) in the degradation index of anthocyanins, which fluctuated between 1.25 and 1.30 (Table 4). The degradation index increased with increasing anthocyanin degradation and after 12 months of storage its average value was higher by 20% (10 °C) and 33% (20 °C) compared to the jams tested immediately after production. Between the jams stored at two different temperatures, both after 6 and after 12 months storage, the differences in the level of DI were not always significant.

Gooseberry jams were characterized by low vitamin C content; they contained an average of 15.2 mg of this vitamin per 100 g of the product immediately after production (Table 5). After enrichment with chokeberry, Japanese quince and elderberry, the level of this constituent increased significantly ($p < 0.05$) by 20, 42 and 52%, respectively. In the remaining cases, the content of vitamin C was comparable to the product without additives.

Throughout the storage period, there was a fall in vitamin C content in all the jams examined (Table 5). After 6 months' storage it was shown that all jams stored at 10 °C had a higher level of vitamin C than jams stored at 20 °C. A similar tendency was observed after the next 6 months. Compared to the jams which were not stored, lower losses were determined in the jams stored at 10 °C (average 24%), while at 20 °C the losses of vitamin C were higher (average 39%). Poiana et al. (2011) also reported losses of vitamin C in the cherry and strawberry jams stored for 3 months at 20 °C, of 22 and 33% respectively, compared to non-stored products.

In this study, the measurement of antioxidant potential, by means of ABTS, DPPH and FRAP assays, was conducted to determine the bioactive properties of jams. In gooseberry jam without additives, antioxidant activity per 1 g at average levels was 67.3 μM Trolox (ABTS), 38.1 μM Trolox (DPPH) and 40.4 μM Trolox (FRAP) (Table 5). Jams' enrichment with fruits rich in bioactive compounds significantly ($p < 0.05$) increased DPPH and ABTS radical scavenging activities and iron ion capture. The best results were recorded in the jams with added chokeberry (56, 52 and 98% respectively) and elderberry (30, 14 and 55% respectively). The Japanese quince fruit can also be a good natural ingredients e.g. in functional foods, while flax seeds and wheat germ did not considerably affect the level of antioxidative activity. The beneficial effects of the jams' enrichment have also been demonstrated by Wojdyło et al. (2008), who found that strawberry jam with added chokeberry puree exhibited the highest antioxidant activity against ABTS cation radical (5.03 μM Trolox/1 g dry matter) and DPPH free radical (40.32 μM Trolox/1 g dry matter).

Numerous authors indicate that such activity in jams decreases during storage. In their opinion, storage conditions are one of the factors affecting the nutritive value, including free radical scavenging ability (Poiana et al. 2011; Rababah et al. 2011). After 6 months' storage, regardless of the temperature, in most jams the level of activity did not change significantly. Significant changes ($p < 0.05$) were observed after 12 months' storage. After this period, in gooseberry jams which were chill-stored, a decrease in the activity of ABTS was determined, on average by 35%, and of DPPH by 18%, which confirms the degradation of antioxidants in the samples. At room temperature, the reduction in radical-scavenging activity was much higher, at 49% (ABTS) and 29% (DPPH), compared to the jams immediately after production. According to Rababah et al. (2011), a decrease in the DPPH level in cherry jam after 5 months of storage at 25 °C was greater (68%) when compared to the non-stored sample. The level of activity measured by the FRAP assay in the examined gooseberry jams stored for 12 months at room temperature decreased from about 22% (jams with added flax seeds and wheat germ) to 44% (jam without ingredients). Poiana et al. (2011) also observed a decrease (11%) in the ferric reducing antioxidant power during a 3-month storage period of cherry jam at 20 °C.

Conclusion

Fruits are a rich source of antioxidants, so jams are a good solution for prolonging their availability for consumption. As shown in the research, gooseberry jams are a good source of polyphenols (140.6 mg/100 g). Enriching products with raw plant such as chokeberry, elderberry and Japanese quince, containing significant amounts of

Table 5 Vitamin C and antioxidant activity (ABTS, DPPH and FRAP) in gooseberry jams during storage

Analysed parameter[a]	Type of jams[b]	Storage time/temperature							
		0	6 months		p value[c]	0	12 months		p value
			10 °C	20 °C			10 °C	20 °C	
Vitamin C (mg/100 g)	G0	12.8 ± 0.6^{aA}	11.4 ± 0.7^{aA}	9.7 ± 1.4^{bA}	0.005	12.8 ± 0.6^{aA}	9.8 ± 1.5^{bA}	7.2 ± 1.1^{cA}	0.001
	GCh	15.3 ± 0.6^{aB}	13.8 ± 0.6^{bB}	12.4 ± 0.5^{cB}	0.001	15.3 ± 0.6^{aB}	10.8 ± 1.7^{bA}	9.1 ± 1.3^{bB}	0.001
	GE	18.2 ± 0.9^{aC}	17.2 ± 0.7^{aC}	15.0 ± 0.9^{bC}	0.001	18.2 ± 0.9^{aC}	13.8 ± 1.1^{bC}	11.8 ± 0.8^{cD}	< 0.001
	GJ	19.4 ± 0.9^{aC}	18.0 ± 0.3^{bC}	15.8 ± 0.6^{cC}	0.001	19.4 ± 0.9^{aC}	15.8 ± 1.6^{bD}	12.0 ± 1.1^{cD}	0.001
	GF	12.5 ± 0.9^{aA}	11.9 ± 0.6^{aA}	10.1 ± 1.0^{bA}	0.009	12.5 ± 0.9^{aA}	9.2 ± 1.5^{bA}	7.0 ± 0.7^{cA}	0.001
	GWG	12.9 ± 1.1^{aA}	11.9 ± 0.5^{aA}	10.2 ± 1.1^{bA}	0.007	12.9 ± 1.1^{aA}	9.9 ± 1.2^{bA}	8.0 ± 1.1^{cA}	0.001
p value		< 0.001	< 0.001	< 0.001		< 0.001	< 0.001	< 0.001	
ABTS (μM Tx/1 g)	G0	67.3 ± 7.9^{aA}	65.7 ± 2.4^{aA}	63.9 ± 4.2^{aA}	0.684	67.3 ± 7.9^{aA}	37.3 ± 3.4^{bA}	27.9 ± 3.6^{cA}	< 0.001
	GCh	105.1 ± 8.5^{aB}	101.1 ± 3.4^{aB}	94.4 ± 4.3^{aB}	0.080	105.1 ± 8.5^{aB}	79.4 ± 0.8^{bB}	69.7 ± 2.5^{cB}	< 0.001
	GE	87.2 ± 8.1^{aC}	85.5 ± 6.0^{aC}	83.4 ± 3.9^{aC}	0.709	87.2 ± 8.1^{aC}	60.3 ± 1.7^{bB}	39.5 ± 1.8^{cC}	< 0.001
	GJ	76.4 ± 8.7^{aA}	74.7 ± 2.5^{aD}	74.0 ± 4.3^{aD}	0.844	76.4 ± 8.7^{aA}	50.8 ± 2.5^{bC}	42.1 ± 2.4^{cC}	< 0.001
	GF	71.2 ± 5.8^{aA}	69.2 ± 2.6^{aA}	66.2 ± 6.7^{aA}	0.435	71.2 ± 5.8^{aA}	41.6 ± 3.5^{bA}	33.8 ± 2.7^{cD}	< 0.001
	GWG	68.9 ± 5.2^{aA}	67.3 ± 3.7^{aA}	65.9 ± 2.7^{aA}	0.591	68.9 ± 5.2^{aA}	40.7 ± 2.4^{bA}	31.7 ± 4.0^{cD}	< 0.001
p value		< 0.001	< 0.001	< 0.001		< 0.001	< 0.001	< 0.001	
DPPH (μM Tx/1 g)	G0	38.1 ± 4.0^{aA}	37.0 ± 1.3^{aA}	36.2 ± 1.1^{aA}	0.565	38.1 ± 4.0^{aA}	33.7 ± 1.5^{bA}	26.8 ± 1.4^{cA}	0.001
	GCh	58.0 ± 6.2^{aB}	52.6 ± 1.5^{aB}	48.5 ± 2.0^{bB}	0.020	58.0 ± 6.2^{aB}	44.3 ± 1.4^{bB}	39.7 ± 2.6^{bB}	0.001
	GE	43.6 ± 2.5^{aC}	42.4 ± 1.5^{aC}	37.8 ± 2.0^{bA}	0.007	43.6 ± 2.5^{aC}	35.9 ± 5.3^{bA}	30.2 ± 3.4^{bA}	0.003
	GJ	41.9 ± 3.2^{aC}	40.1 ± 1.8^{aC}	37.4 ± 1.7^{aA}	0.068	41.9 ± 3.2^{aC}	34.9 ± 1.2^{bA}	29.9 ± 3.4^{cA}	0.001
	GF	38.7 ± 5.7^{aA}	37.0 ± 1.1^{aA}	34.6 ± 1.2^{aA}	0.273	38.7 ± 5.7^{aA}	31.5 ± 1.7^{aA}	28.3 ± 1.2^{aB}	0.006
	GWG	38.9 ± 1.5^{aA}	37.5 ± 1.8^{aA}	35.8 ± 0.6^{bA}	0.042	38.9 ± 1.5^{aA}	32.0 ± 2.3^{bA}	29.7 ± 4.0^{bA}	0.003
p value		< 0.001	< 0.001	< 0.001		< 0.001	< 0.001	< 0.001	
FRAP (μM Fe^{2+}/1 g)	G0	40.4 ± 1.7^{aA}	37.9 ± 4.0^{aA}	31.7 ± 2.7^{bA}	0.007	40.4 ± 1.7^{aA}	27.8 ± 2.3^{bA}	22.7 ± 1.7^{cA}	< 0.001
	GCh	80.0 ± 4.5^{aB}	78.8 ± 6.8^{aB}	74.2 ± 7.6^{aB}	0.440	80.0 ± 4.5^{aB}	66.8 ± 4.3^{bB}	59.7 ± 1.8^{cB}	0.001
	GE	62.8 ± 1.9^{aC}	61.2 ± 2.9^{aC}	59.8 ± 2.8^{aC}	0.289	62.8 ± 1.9^{aC}	54.5 ± 1.2^{bC}	44.6 ± 2.4^{cC}	< 0.001
	GJ	53.0 ± 2.8^{aD}	52.2 ± 3.4^{aD}	48.8 ± 0.9^{aD}	0.111	53.0 ± 2.8^{aD}	43.2 ± 0.8^{bD}	39.1 ± 1.3^{aD}	< 0.001
	GF	47.7 ± 2.5^{aE}	46.9 ± 1.9^{aD}	44.9 ± 2.6^{aD}	0.274	47.7 ± 2.5^{aE}	40.3 ± 1.9^{bDE}	37.5 ± 0.6^{cD}	0.001
	GWG	44.1 ± 3.0^{aA}	43.6 ± 0.9^{aE}	41.7 ± 1.9^{aD}	0.288	44.1 ± 3.0^{aA}	38.1 ± 1.3^{bE}	34.6 ± 3.2^{cD}	0.002
p value		< 0.001	< 0.001	< 0.001		< 0.001	< 0.001	< 0.001	

[a]Values are presented as mean value ± SD (n = 4) and expressed of fresh matter. Different letters (a–c) in the same rows or (A–E) in the same columns indicate significant differences ($p < 0.05$)

[b]Type of jams: G0—gooseberry jam without plant ingredients, GCh—jam with 15% addition of chokeberry, GE—jam with 15% addition of elderberry, GJ—jam with 8% addition of Japanese quince, GF—jam with 3% addition of flax seeds, GWG—jam with 3% addition of wheat germ

[c]One-way ANOVA, analysis of variance

antioxidants, improves the nutritive value of final products. The addition of all plant ingredients to gooseberry jams resulted in a significant increase in the majority of identified polyphenols. The highest content was determined in the level of (+)-catechin in gooseberry jam with the addition of elderberry (5.660 mg/100 g) and caffeic acid (4.403 mg/100 g) in jam with chokeberry. Addition of chokeberry fruit increased the level of total polyphenols by 135%, total flavonoids by 533% and total anthocyanins by 2421%, compared to the gooseberry jam without plant ingredients. Elderberry and Japanese quince increased the level of vitamin C by 42% and by 50% respectively, whereas fax seeds and wheat germ, had a significant effect only on the level of total flavonoids and the content of identified polyphenols. However, a decline in the antioxidant properties of jams was observed during storage, depending on the plant ingredients used. In the jams stored at room temperature, degradation of the analyzed components, which increased with storage time, was much faster when compared to those chill-stored. Therefore, in order to maintain a high level of antioxidant capacity in gooseberry jam, the products should be stored at reduced temperature.

Acknowledgements This research was financed by the Ministry of Science and Higher Education of the Republic of Poland.

References

Anastasiadi M, Mwangi PM, Ordaz-Ortiz JJ, Redfern SP, BerryM Simmonds MS, Terry LA (2016) Tissue biochemical diversity of 20 gooseberry cultivars and the effect of ethylene supplementation on postharvest life. Postharvest Biol Technol 117:141–151

Ardestani A, Yazdanparast R (2007) Antioxidant and free radical scavenging potential of Achillea santolina extracts. Food Chem 104:21–29

Barney DL, Hummer KE (2005) Currants, gooseberries, and jostaberries: a guide for growers, marketers, and researchers in North America. CRC Press, Hawthorn

Benzie IF, Strain JJ (1996) The ferric reducing ability of plasma (FRAP) as a measure of "antioxidant power": the FRAP assay. Anal Biochem 239:70–76

Bordonaba JG, Terry LA (2011) Health-promoting properties of fruits and vegetables. In: Terry LA (ed) Ribes and Rubus [Blackberry, Currants and Raspberry, etc.], CABI, Wallingford, pp 261–290

Chiang CJ, Kadouh H, Zhou K (2013) Phenolic compounds and antioxidant properties of gooseberry as affected by in vitro digestion. LWT Food Sci Technol 51(2):417–422

Coultate T (2009) Food: the chemistry of its components. RSC Publishing, Royal Society of Chemistry, Cambridge

Ducruet J, Rébénaque P, Diserens S, Kosińska-Cagnazzo A, Héritier I, Andlauer W (2017) Amber ale beer enriched with goji berries—the effect on bioactive compound content and sensorial properties. Food Chem 226:109–118

FAOSTAT (2014). Food and Agriculture Organization of the United Nations. Accessed 24 April 2017. http://www.fao.org/faostat/en/#data/QC

Folmer F, Basavaraju U, Jaspars M, Hold G, El-Omar E, Dicato M, Diederich M (2014) Anticancer effects of bioactive berry compounds. Phytochem Rev 13(1):295–322

Giusti MM, Wrolstad RE (2001) Characterization and measurement of anthocyanins by UV-visible spectroscopy. Current Protocols in Food Anal Chem F1.2.1–F1.2.13

ISO/6557-2 (1984) Fruits, vegetables and derived products—determination of ascorbic acid content. Part 2. Routine methods. Geneve 20, Switzerland: International Organization for Standardization

Kirca A, Özcan M, Cemeroğlu B (2007) Storage stabillity of strawberry of jam color enhanced with black carrot juice concentrate. J Food Process Preserv 31:531–545

Klimczak I, Małecka M, Szlachta M, Gliszczyńska-Świgło A (2007) Effect of storage on the content of polyphenols, vitamin C and the antioxidant activity of orange juices. J Food Comp Anal 20:313–322

Knox YM, Suzutani T, Yosida I, Azuma M (2003) Anti influenza virus activity of crude extract of Ribes nigrum L. Phytother Res 17(2):120–122

Korus A, Jaworska G, Bernaś E, Juszczak L (2015) Characteristics of physico-chemical properties of bilberry (*Vaccinium myrtillus* L.) jams with added herbs. J Food Sci Technol 52(5):2815–2823

Levaj B, Bursać Kovačević D, Bituh M, Dragović-Uzelac V (2012) Influence of jam processing upon the contents of phenolics and antioxidant capacity in strawberry fruit (Fragaria ananassa × -Duch.). Croat J Food Technol Biotechnol Nutr 7:18–22

Link A, Balaguer F, Goel A (2010) Cancer chemoprevention by dietary polyphenols: promising role for epigenetics. Biochem Pharmacol 80:1771–1792

Määttä-Riihinen KR, Kamal-Eldin A, Mattila PH, González-Paramás AM, Törrönen AR (2004) Distribution and contents of phenolic compounds in eighteen Scandinavian berry species. J Agric Food Chem 52(14):4477–4486

Mäkilä L, Laaksonen O, Kallio H, Yang B (2017) Effect of processing technologies and storage conditions on stability of black currant juices with special focus on phenolic compounds and sensory properties. Food Chem 221:422–430

Muraki I, Imamura F, Manson JE, Hu FB, Willett WC, Van Dam RM, Sun Q (2013) Fruit consumption and risk of type 2 diabetes: results from three prospective longitudinal cohort studies. Br Med J 347:f5001

Nawirska-Olszańska A, Kucharska AZ, Sokół-Łętowska A, Biesiada A (2010) Quality assessment of pumpkin jams enriched with japanese quince, cornelian cherry and strawberries. ZNTJ 1:40–48

Pantelidis GE, Vasilakakis M, Manganaris GA, Diamantidis GR (2007) Antioxidant capacity, phenol, anthocyanin and ascorbic acid contents in raspberries, blackberries, red currants, gooseberries and Cornelian cherries. Food Chem 102:777–783

Pekkarinen SS, Heinonen IM, Hopia AI (1999) Flavonoids quercetin, myricetin, kaemferol and (+) catechin and antioxidants in methyl linoleate. J Sci Food Agric 79:499–506

Plessi M, Bertelli D, Albasini A (2007) Distribution of metals and phenolic compounds as a criterion to evaluate variety of berries and related jams. Food Chem 100:419–427

Poiana MA, Moigradean D, Dogaru D, Mateescu C, Raba D, Gergen I (2011) Processing and storage impact on the antioxidant properties and color quality of some low sugar fruit jams. Rom Biotechnol Lett 16(5):6504–6512

Rababah TM, Al-Mahasneh MA, Kilani I, Yang W, Alhamad MN, Ereifej K, Al-U'datt M (2011) Effect of jam processing and storage on total phenolics, antioxidant activity, and anthocyanins of different fruits. J Sci Food Agric 91:1096–1102

Re R, Pellegrini N, Proteggente A, Pannala A, Yang M, Rice-Evans C (1999) Antioxidant activity applying an improved ABTS radical cation decolorization assay. Free Radic Biol Med 26:1231–1237

Sang S, Tian S, Wang H, Stark RE, Rosen RT, Yang CS, Ho CT (2003) Chemical studies of the antioxidant mechanism of tea catechins: radical reaction products of epicatechin with peroxyl radicals. Bioorg Med Chem 11(16):3371–3378

Schreiner M (2005) Vegetable crop management strategies to increase the quantity of phytochemicals. Eur J Clin Nutr 44:85–94

Singleton VL, Orthofer R, Lamuela-Raventós RM (1999) Analysis of total phenols and other oxidation substrates and antioxidants by means of Folin-Ciocalteu reagent. Method Enzymol 299:152–178

Takata R, Yamamoto R, Yanai T, Konno T, Okubo T (2005) Immunostimulatory effects of a polysaccharide-rich substance with antitumor activity isolated from black currant (Ribes nigrum L.). Biosci Biotechnol Biochem 69(11):2042–2050

Wang LS, Stoner GD (2008) Anthocyanins and their role in cancer prevention. Cancer Lett 269:281–290

Wildman REC (2001) Nutraceuticals: a brief review of historical and teleological aspects. Handbook of Nutraceuticals and Functional Foods, Boca Raton, Florida

Wojdyło A, Oszmiański J, Bober I (2008) The effect of addition of chokeberry, flowering quince fruits and rhubarb juice to strawberry jams on their polyphenol content, antioxidant activity and colour. Eur Food Res Technol 227:1043–1051

Zhishen J, Mengcheng T, Jianming W (1999) The determination of flavonoid contents in mulberry and their scavenging effects on superoxide radicals. Food Chem 64:555–559