POLISH JOURNAL OF NATURAL SCIENCES
Abbrev.: Pol. J. Natur. Sc., Vol 33(3): 385–399, Y. 2018

ANTIOXIDANT PROPERTIES OF LOW-SUGAR STRAWBERRY JAM ENRICHED WITH PLANT RAW MATERIALS*

***Anna Banaś*[1,2], *Anna Korus*[1], *Małgorzata Tabaszewska*[1]**

[1] Department of Fruit, Vegetable and Mushroom Processing
University of Agriculture in Kraków, Kraków, Poland
[2] Fruit and Vegetable Processing Plant "ROMEX" Janina Moryl in Wielopole, Olesno, Poland

Key words: strawberry jam, processing, polyphenols, vitamin C, antioxidants, storage.

Abstract

Low-sugar strawberry jams without enriching ingredients and with the addition of chokeberry, elderberry, Japanese quince, flax seeds and wheat germ were analysed to determine the total level of polyphenols, flavonoids, anthocyanins and the total antioxidant activity and levels of individual phenolic compounds. The jams were both chill-stored and stored at room temperature. As a result of adding plant components to the jams, increases were observed in the levels of the analyzed components and in the total antioxidant activity. The jam with added chokeberry exhibited the highest level of antioxidant properties, showing more than a 3-fold increase in total polyphenols compared with the jamwithout enriching ingredients. However, the jams stored at a cold temperature retained their antioxidant properties better than the products stored at room temperature.

Address: Anna Banaś, University of Agriculture in Kraków, ul. Balicka 122, 30-149 Kraków, Poland, e-mail: amoryl@op.pl
*This research was financed by the Ministry of Science and Higher Education of the Republic of Poland.

WŁAŚCIWOŚCI PRZECIWUTLENIAJĄCE NISKOSŁODZONYCH DŻEMÓW TRUSKAWKOWYCH WZBOGACONYCH W SUROWCE ROŚLINNE

***Anna Banaś*[1,2], *Anna Korus*[1], *Małgorzata Tabaszewska*[1]**

[1] Katedra Technologii Owoców, Warzyw i Grzybów
Uniwersytet Rolniczy w Krakowie, Kraków, Poland
[2] Zakład Przetwórstwa Owocowo-Warzywnego „ROMEX" Janina Moryl w Wielopolu,Olesno, Polska

Słowa kluczowe: dżem truskawkowy, przetwórstwo, polifenole, witamina C, przeciwutleniacze, przechowywanie.

Abstrakt

W niskosłodzonych dżemach truskawkowych bez dodatków wzbogacających oraz z dodatkiem aronii czarnoowocowej, czarnego bzu, pigwowca japońskiego, nasion lnu i zarodków pszennych oznaczono poziom polifenoli ogółem, flawonoidów ogółem, antocyjanów ogółem, ogólną aktywność przeciwutleniającą oraz przeprowadzono identyfikację ilościową polifenoli. Dżemy składowano w temperaturze chłodniczej i pokojowej. W wyniku dodania składników roślinnych do dżemów zaobserwowano wzrosty poziomów analizowanych składników i całkowitej aktywności antyoksydacyjnej. Dodatek do dżemów składników roślinnych wpłynął na wzrost poziomu analizowanych składników i ogólną aktywność przeciwutleniającą. Najwyższymi właściwościami przeciwutleniającymi charakteryzował się dżem z 15% dodatkiem owoców aronii, w którym zawartość polifenoli ogółem wzrosła ponad 3-krotnie w porównaniu z dżemem bez dodatków. Dżemy składowane w temperaturze chłodniczej lepiej zachowały swoje właściwości przeciwutleniające w porównaniu z produktami składowanymi w temperaturze pokojowej.

Introduction

Fresh fruit is an excellent source of antioxidants such as anthocyanins, flavonoids, phenolic acids, tannins, carotenoids and vitamins (DU TOIT et al. 2001). Antioxidants occurring in fruit play an important role in the human organism by quenching free radicals, which contribute to a number of disorders including cardiovascular diseases, cancer, diabetes, neurological diseases, atherosclerosis, accelerated ageing, and other disorders (ZHENG and WANG 2001). This is due to the fact that in an excited state free radicals have a substantial amount of energy and exhibit a high degree of reactivity with other organic compounds, particularly proteins, unsaturated fatty acids, and nucleic acids. Despite the fact that the human body has its own system to protect against free radicals, this system is not

sufficient, particularly in industrialized regions. It is therefore necessary to supply the body with additional external antioxidants, for example, through the increased consumption of fruit and vegetables (LIU and NG 2000, WANG 2006). However, in view of the seasonal availability of fresh fruit, it must be processed in order to be available throughout the year. Fruits are most often processed into frozen foods, juices, jams, marmalades, compotes, dried products, jellies, and candied fruits.

Contemporary consumers expect that food will not only meet basic elementary functions, i.e., the body's energy needs, but will also supply the body with proper quantities of nutrients which have an adequate level of quality, and at the same time they expect food to maintain its sensory attractiveness (WILDMAN 2001). Therefore, more and more frequently traditional fruit products are enriched with pro-health components of natural origin, which enhance immunity, prevent seasonal diseases (such as hay fever and the common cold), prevent cancer and cardiac diseases, but also improve metabolism.

Strawberries (*Fragaria x ananassa* Duch.) are one of the most popular berry species (AMARO et al. 2012). Strawberries contain a number of bioactive compounds, for example, polyphenols (HANNUM 2004). However, in addition to being seasonally available, strawberries are easily perishable and are particularly sensitive to transportation (PEANO et al. 2014). Therefore, one way to extend their shelf-life is to preserve them in the form of jams – whole or chopped fruits suspended in jelly. Jams are produced by mixing fruit and sugar with a gelling agent and an organic acid. Jams may be classified as single- or multi-fruit, as well as by their sugar content: high- or low-sugar. Such products retain the flavour, fragrance and colour of the fruit from which they were made; therefore, they are willingly purchased by consumers, particularly the low-sugar ones with a lower energy value.

The aim of this research was to evaluate the effect of adding plant materials with pro-health properties (black chokeberry, elderberry, Japanese quince, flax seeds and wheat germ), to low-sugar strawberry jams. The jams were stored at a cold temperature (10°C) and at room temperature (20°C) for 6 and 12 months.

Material and Methods

Material

The material investigated consisted of low-sugar strawberry jam prepared from the Senga Sengana cv. of strawberry (*Fragaria* × *ananassa* Duch.) without enriching ingredients, and jams containing enriching

ingredients such as black chokeberry [*Aronia melanocarpa* (Michx.) Elliott], elderberry (*Sambucus nigra* L.), Japanese quince [*Chaenomeles japonica* (Thunb.) Lindl. ex Spach], flax seeds (*Linum* L.) and wheat (*Triticum aestivum* L.) germ.

The jams were produced from frozen fruits. Flax was added in the form of ground defatted flaxseeds (Oleofarm, Poland), the residual fat comprised only 10% of the original value. Wheat germ was obtained from wheat grain, it 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 strawberry 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 kg^{-1} of the product (EUROPEAN COMMISSION 2011). Fruit comprised 50% of the mass of the final product. Jams were prepared in the following variants: S0 – strawberry jam without enriching ingredients, SCh – strawberry jam with a 15% addition of black chokeberry, SE – strawberry jam with a 15% addition of elderberry, SJ – strawberry jam with an 8% addition of Japanese quince, SF – strawberry jam with a 3% addition of flax seeds, SWG – strawberry jam with a 3% addition of wheat germ.

Table 1

Recipes of strawberry jams [g/1000 g]

Type of jams[b]	Ingredients[a]										
	S	Ch	*E*	*J*	*F*	WG	sucrose	steviol glycoside	pectin	citric acid	water
S0	500	–	–	–	–	–	258	0.2	11.2	5.6	225.0
SCh	350	150	–	–	–	–	258	0.2	11.2	5.4	225.2
SE	350	–	150	–	–	–	260	0.2	11.2	5.0	221.4
SJ	420	–	–	80	–	–	264	0.2	11.2	3.2	221.4
SF	500	–	–	–	30	–	256	0.2	16.0	5.6	192.0
SWG	500	–	–	–	–	30	256	0.2	16.0	5.6	192.0

[a] Ingredients: *S* – strawberry, Ch – black chokeberry, *E* – elderberry, *J* – Japanese quince, *F* – flax seeds, WG – wheat germ

[b] Type of jams: S0 – strawberry jam without enriching ingredients, SCh – strawberry jam with a 15% addition of black chokeberry, SE – strawberry jam with a 15% addition of elderberry, SJ – strawberry jam with an 8% addition of Japanese quince, SF – strawberry jam with a 3% addition of flax seeds, SWG – strawberry jam with a 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 (20 min., 103°C). Afterwards, a previously prepared 4% solution of gelling agent was added and the whole batch was mixed and heated again for several minutes. Finally, citric acid was added and mixed in. The products were then packaged in glass jars (0.2 L), pasteurized at 82–85°C for 15 minutes, and finally cooled to 20 ± 2°C.

Storage of jam and chemical determination

Jams were stored at two temperatures: cold (10°C) and room temperature (20°C) until evaluation, which was carried out immediately after their production and after 6 and 12 months of storage.

In order to determine the total content of polyphenols, flavonoids and antioxidant activity, sample extracts were prepared using 80% ethanol. Polyphenols were determined using the Folin-Ciocalteu method (SINGLETON et al. 1999), according to which, Folin-Ciocalteu reagent and 25% sodium carbonate were added to the extract, which was previously diluted with deionised water. The content of polyphenols was read from the standard curve prepared for (+)-catechin.

Total flavonoid content was detected by aluminium chloride assay (ARDESTANI and 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 minutes. The content of flavonoids was read from the standard curve prepared for (+)-catechin.

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 NaOH was added (2 mol l^{-1} in a ratio of 1:1 w/w). Afterwards, samples were mixed using a Labnet vortex mixer (Edison, USA), and left in the dark for 4 hours (at room temperature) and then neutralized to pH 2.2–2.8 with HCl (2 mol l^{-1}) using a Metrohm pH meter (Herisau, Switzerland). The samples were then centrifuged at 4,000 x *g* for 20 minutes 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 being 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.

Chromatographic analysis was performed using a Dionex Ultimate 3000 HPLC set equipped with a Thermo Scientific DAD detector (Germering, Germany). A column (XBridge^{TM}C18 250 x 4.6 mm; 3.5 μm) with a pre-column (XBridge^{TM} C18, 20 x 4.6 mm; 3.5 μm (Waters, Wexford, Ireland)) was employed for the 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^{-1}. 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 the analysis.

The total anthocyanins and degradation index were determined by means of the spectroscopic method (GIUSTI and WROLSTAD 2001). Anthocyanin content, expressed as cyanidin-3-glucoside equivalent, was calculated from the absorbance measured and the coefficient of sample dilution.

Vitamin C content, as the sum of ascorbic and dehydroascorbic acid, was determined using a spectrophotometrical method (*Fruits, vegetables*… ISO/6557-2, 1984). The quantitative reduction of 2,6 dichlorophenolindophenol dyestuff by the ascorbic acid was flowed by extraction of the excess dyestuff using xylene, and the excess was measured spectrophotometrically at 500 nm and compared with the vitamin C reference standard.

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 nm, 734 nm, 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

All analyses were carried out in four experimental replications.The results were subjected to a two-factor analysis of variance (first factor – type of jam; second factor – storage) on the basis of the Snedecor F and Student's t tests. The least significant difference (LSD) was calculated at the probability level of $P < 0.05$. The Statistica 12.0 (StatSoft; Poland) program was used.

Results and Discussion

Effect of adding enriching ingredients on antioxidant properties

The strawberry jams contained on average of 75.8–239.4 mg total polyphenols per 100 g of fresh matter (Table 2). Among the applied enriching plant ingredients, only black chokeberry, elderberry and Japanese quince had a significant effect ($P < 0.05$) on the total polyphenols in the jams. When compared with the strawberry jam without enriching ingredients, the addition of black chokeberry caused an increase in the level of polyphenols by an average of 213%, elderberry by 75%, and Japanese quince by 40%. In the strawberry jams investigated, total flavonoids accounted for on average 35–55% of total polyphenols (Table 2). The strawberry jam without enriching ingredients was characterized by low average amounts of total flavonoids (27.4 mg/100 g). Similar levels in strawberry jams were also reported by LEVAJ et al. (2012). However, a combination of strawberries and other fruits with significant polyphenol content allowed for products with a high nutritive value to be obtained. Of the examined jams, the jam with black chokeberry had the highest amounts of flavonoids (111.6 mg/100 g), as was the case with total polyphenols. The jams enriched with elderberry and Japanese quince, had an average flavonoid content of 58.1 mg of per 100 g, and may also be regarded as a good source of these nutrients.

Numerous authors, therefore, highlight the beneficial effect of enriching products with plant components with high antioxidant activity. WOJDYŁO et al. (2008) demonstrated a significant increase in polyphenol content after the 10% addition of black chokeberry to strawberry jam, while NAWIRSKA-OLSZAŃSKA et al. (2010) revealed that due to enriching pumpkin jams with Japanese quince, products may be obtained with a high content of polyphenols and strong antioxidant activity. The beneficial effect of adding black chokeberry, strawberry and raspberry to Cornelian cherry puree on the level of polyphenols was also mentioned by KUCHARSKA et al. (2010). On the other hand, KORUS et al. (2015) showed that enriching bilberry jams with the addition of herbs resulted not only in higher polyphenol content in these products, but also in better retention of polyphenols during storage.

Table 2
Total polyphenols, flavonoids, anthocyanins and degradation index in strawberry jams during storage

Analysed parameter[a]	Type of jams[b]	Storage time (months) at 10°C and 20°C					Mean
		0	6 temp. 10°C	6 temp. 20°C	12 temp. 10°C	12 temp. 20°C	
Total polyphenols [mg/100 g]	S0	83.3 ± 5.5	79.2 ± 3.4	75.0 ± 4.0	75.6 ± 6.4	69.1 ± 4.2	76.4
	SCh	288.7± 5.8	241.1 ± 4.7	218.2 ± 6.0	236.4 ± 5.0	212.6 ± 5.2	239.4
	SE	160.1 ± 4.8	137.4 ± 5.0	122.9 ± 4.8	131.0 ± 5.7	118.5 ± 4.8	134.0
	SJ	121.8 ± 5.0	114.4 ± 7.6	98.2 ± 5.7	110.0 ± 4.3	90.7 ± 4.5	107.0
	SF	91.4 ± 4.1	82.7 ± 7.0	78.1 ± 5.9	77.5 ± 5.2	72.8 ± 5.3	80.5
	SWG	88.5 ± 6.3	79.7 ± 5.5	70.3 ± 5.0	74.3 ± 3.4	66.3 ± 3.2	75.8
	mean	139.0	122.4	110.5	117.5	105.0	
	LSD $P < 0.05$[c]			I – 4.82, II – 4.40, I x II – 10.78			
Total flavonoids [mg/100 g]	S0	38.8 ± 1.7	28.3 ± 1.7	23.3 ± 1.9	25.8 ± 2.1	21.0 ± 0.3	27.4
	SCh	162.7 ± 3.3	111.4 ± 3.6	90.2 ± 2.7	106.9 ± 3.2	86.8 ± 2.7	111.6
	SE	95.8 ± 4.6	67.6 ± 2.8	50.3 ± 4.6	48.6 ± 2.6	36.4 ± 1.7	59.8
	SJ	66.6 ± 4.8	51.5 ± 3.0	40.4± 4.3	62.1 ± 3.7	61.6 ± 2.8	56.4
	SF	42.1 ± 2.4	27.3 ± 4.5	23.5 ± 1.6	24.7 ± 0.9	22.2 ± 1.8	28.0
	SWG	39.9 ± 1.9	27.4 ± 2.6	23.2 ± 1.0	25.2 ± 4.0	21.0 ± 2.3	27.3
	mean	74.3	52.3	41.8	48.9	41.5	
	LSD $P < 0.05$			I – 4.04, II – 3.69, I x II – 9.03			
Total anthocyanins [mg/100 g]	S0	19.3 ± 1.3	16.0 ± 2.5	12.7 ± 0.7	9.6 ± 0.4	7.2 ± 1.0	13.0
	SCh	89.1 ± 5.1	75.2 ± 5.3	68.1 ± 5.2	61.4 ± 5.5	46.5 ± 4.3	68.0
	SE	65.7 ± 3.3	58.8 ± 3.0	52.5 ± 2.0	42.8 ± 2.0	34.2 ± 1.4	50.8
	SJ	15.4 ± 0.8	11.3 ± 2.1	10.5 ± 1.4	10.4 ± 0.7	7.0 ± 1.0	10.9
	SF	18.2 ± 1.9	14.4 ± 2.1	13.9 ± 1.5	10.8 ± 0.8	7.4 ± 1.0	12.9
	SWG	18.7 ± 1.5	16.5 ± 1.9	14.1 ± 2.2	11.8 ± 0.8	7.7 ± 0.8	13.8
	mean	37.7	32.0	28.6	24.5	18.3	
	LSD $P < 0.05$			I – 1.88, II – 1.71, I x II – 4.20			
Degradation index	S0	1.40 ± 0.22	1.45 ± 0.13	1.62 ± 0.08	1.61 ± 0.11	1.67 ± 0.10	1.55
	SCh	1.25 ± 0.05	1.35 ± 0.05	1.48 ± 0.06	1.38 ± 0.05	1.57 ± 0.16	1.40
	SE	1.35 ± 0.08	1.36 ± 0.13	1.46 ± 0.20	1.48 ± 0.12	1.56 ± 0.11	1.44
	SJ	1.25 ± 0.09	1.38 ± 0.21	1.54 ± 0.26	1.45 ± 0.10	1.61 ± 0.26	1.45
	SF	1.32 ± 0.14	1.37 ± 0.09	1.48 ± 0.14	1.53 ± 0.23	1.63 ± 0.27	1.47
	SWG	1.31 ± 0.11	1.38 ± 0.09	1.54 ± 0.23	1.54 ± 0.24	1.58 ± 0.03	1.47
	mean	1.31	1.38	1.52	1.50	1.60	
	LSD $P < 0.05$			I – n.s.[d], II – 0.096, I x II – n.s			

[a] Values are presented as mean value ± SD ($n = 4$) and expressed of fresh matter
[b] Type of jams: S0 – strawberry jam without enriching ingredients, SCh – strawberry jam with a 15% addition of black chokeberry, SE – strawberry jam with a 15% addition of elderberry, SJ – strawberry jam with an 8% addition of Japanese quince, SF – strawberry jam with a 3% addition of flax seeds, SWG – strawberry jam with a 3% addition of wheat germ
[c] LSD $P < 0.05$ for: type of jams (I), storage (II), interaction (I x II)
[d] n.s. – not significant

Anthocyanins are the main pigments occurring in strawberries, however, the latter are very sensitive to technological processes and storage. The average anthocyanin content in the jam without enriching ingredients was 13.0 mg/100 g (Table 2) and compared with the level reported by POIANA et al. (2011), but was still lower compared with the findings of KOPJAR et al. (2009). Chokeberry and elderberry as natural plant materials can be valuable additives to enrich food products. These species are one of the richest sources of anthocyanins (WU et al. 2004). In the present work, a statistically significant average increase in anthocyanin content was noted: a 5-fold increase in the strawberry jam with a 15% addition of black chokeberry and a 4-fold increase in the product with elderberry. The remaining plant ingredients which were not abundant in anthocyanins had no effect on an increase in their total contents in the examined products. WOJDYŁO et al. (2008) also recorded an increase of proanthocyanidins in strawberry jams resulting from the addition of black chokeberry. On the other hand, ABDEL-HADY et al. (2014) enriched strawberry jam with a 30% addition of purple carrot that led to a 120% increase of anthocyanins. In the examined jams, the degradation index for anthocyanins increased with increasing degradation of these compounds (Table 2). The plant ingredients used had no effect on it, only the storage conditions.

In the examined strawberry jams, *p*-coumaric acid was dominant (Table 3) among the identified polyphenols, which is consistent with the findings of WOJDYŁO et al. (2008). Due to the enrichment of strawberry jam with black chokeberry, the content of *p*-coumaric acid increased significantly ($P < 0.05$), on average by 72%, while in jams with other plant ingredients it increased by 33-46%. Ferulic acid only occurred in jams with added black chokeberry (0.153 mg/100 g), elderberry (0.190 mg/100 g),

Tablele 3

Individual phenolic compoundsin strawberry jams during storage [mg/100 g]

Analysed component[a]	Type of jams[b]	Storage time (months) at 10°C and 20°C			Mean
		0	12	12	
			temp. 10°C	temp. 20°C	
p-coumaric acid	S0	6.096 ± 0.187	3.429 ± 0.178	3.394 ± 0.118	4.306
	SCh	9.665 ± 0.100	8.446 ± 0.111	4.170 ± 0.182	7.427
	SE	7.893 ± 0.052	5.924 ± 0.181	5.009 ± 0.154	6.275
	SJ	7.271 ± 0.031	6.506 ± 0.030	3.406 ± 0.111	5.728
	SF	7.842 ± 0.043	7.191 ± 0.039	3.641 ± 0.046	6.224
	SWG	7.213 ± 0.167	6.143 ± 0.116	4.087 ± 0.113	5.814
	mean	7.663	6.273	3.951	–
	LSD $P < 0.05$[c]	I – 0.2169, II – 0.1534, I x II – 0.3758			

Ferulic acid	S0	nd[d]	nd	nd	nd
	SCh	0.220 ± 0.007	0.168 ± 0.025	0.071 ± 0.002	0.153
	SE	0.211 ± 0.007	0.204 ± 0.001	0.156 ± 0.013	0.190
	SJ	nd	nd	nd	nd
	SF	0.934 ± 0.042	0.705 ± 0.030	0.541 ± 0.020	0.727
	SWG	0.853 ± 0.004	0.544 ± 0.021	0.338 ± 0.008	0.579
	mean	0.370	0.270	0.184	
		LSD $P < 0.05$	I – 0.0238, II – 0.0168, I x II – 0.0412		
Ellagic acid	S0	1.222 ± 0.051	1.112 ± 0.029	0.841 ± 0.198	1.058
	SCh	0.853 ± 0.040	0.764 ± 0.044	0.555 ± 0.026	0.724
	SE	1.312 ± 0.021	1.244 ± 0.054	1.022 ± 0.027	1.193
	SJ	1.157 ± 0.028	1.073 ± 0.025	0.813 ± 0.011	1.014
	SF	1.104 ± 0.039	0.884 ± 0.050	0.597 ± 0.090	0.861
	SWG	1.226 ± 0.027	1.080 ± 0.014	0.880 ± 0.004	1.062
	mean	1.146	1.026	0.785	
		LSD $P < 0.05$	I – 0.0669, II – 0.0473, I x II – n.s.[e]		
Quercetin	S0	0.021 ± 0.001	0.011 ± 0.002	0.008 ± 0.002	0.014
	SCh	0.038 ± 0.003	0.028 ± 0.002	0.014 ± 0.002	0.027
	SE	0.034 ± 0.002	0.021 ± 0.001	0.017 ± 0.002	0.024
	SJ	0.028 ± 0.001	0.018 ± 0.001	0.010 ± 0.001	0.019
	SF	nd	nd	nd	nd
	SWG	nd	nd	nd	nd
	mean	0.020	0.013	0.008	
		LSD $P < 0.05$	I – 0.0007, II – 0.0005, I x II – 0.0013		
(+)-catechin	S0	1.267 ± 0.012	0.883 ± 0.038	0.463 ± 0.084	0.871
	SCh	1.044 ± 0.016	0.818 ± 0.016	0.650 ± 0.010	0.837
	SE	4.756 ± 0.042	1.705 ± 0.092	0.941 ± 0.045	2.467
	SJ	2.904 ± 0.055	2.354 ± 0.023	1.763 ± 0.022	2.341
	SF	2.809 ± 0.056	1.615 ± 0.033	0.981 ± 0.035	1.802
	SWG	2.146 ± 0.003	1.822 ± 0.042	0.932 ± 0.019	1.633
	mean	2.488	1.533	0.955	
		LSD $P < 0.05$	I – 0.0779, II – 0.0551, I x II – 0.1350		

[a] Values are presented as mean value ± SD ($n = 4$) and expressed of fresh matter
[b] Type of jams: S0 – strawberry jam without enriching ingredients, SCh – strawberry jam with a 15% addition of black chokeberry, SE – strawberry jam with a 15% addition of elderberry, SJ – strawberry jam with an 8% addition of Japanese quince, SF – strawberry jam with a 3% addition of flax seeds, SWG – strawberry jam with a 3% addition of wheat germ
[c] LSD $P < 0.05$ for: type of jams (I), storage (II), interaction (I x II)
[d]nd– not detected, [e]n.s. – not significant

wheat germ (0.727 mg/100 g), and flax (0.579 mg/100 g). In turn, ellagic acid predominated significantly ($P < 0.05$) in the jams enriched with elderberry and Japanese quince, whereas (+)-catechin was present in the jams with flax seeds and wheat germ.

Table 4

Vitamin C and antioxidant activity (ABTS, DPPH and FRAP) in strawberry jams during storage

Analysed parameter[a]	Type of jams[b]	Storage time (months) at 10°C and 20°C					Mean
		0	6 temp. 10°C	6 temp. 20°C	12 temp. 10°C	12 temp. 20°C	
Vitamin C [mg/100 g]	S0	13.4 ± 0.9	11.5 ± 0.5	10.8 ± 0.6	9.9 ± 1.1	8.5 ± 0.8	10.9
	SCh	13.3 ± 0.7	12.2 ± 0.6	11.9 ± 0.4	10.8 ± 0.7	9.4 ± 1.2	11.5
	SE	15.4 ± 1.0	13.6 ± 0.4	13.3 ± 0.6	12.2 ± 0.6	11.7 ± 0.5	13.3
	SJ	14.3 ± 0.7	12.8 ± 0.2	12.1 ± 0.4	11.5 ± 0.8	10.3 ± 0.6	12.2
	SF	12.4 ± 0.7	11.3 ± 0.7	10.4 ± 0.8	9.9 ± 0.9	8.3 ± 0.9	10.5
	SWG	12.2 ± 0.6	11.2 ± 0.7	10.3 ± 0.7	9.2 ± 0.8	8.5 ± 0.9	10.3
	mean	13.5	12.1	11.5	10.6	9.5	–
	LSD $P < 0.05$[c]			I – 0.46, II – 0.42, I x II – n.s[d]			
ABTS [μM Tx/1 g]	S0	38.9 ± 1.5	34.7 ± 2.0	30.8 ± 1.9	31.2 ± 2.2	27.6 ± 1.9	32.6
	SCh	127.1 ± 2.0	115.6 ± 1.9	102.7 ± 1.5	111.0 ± 1.4	95.8 ± 1.6	110.5
	SE	106.6 ± 1.4	98.1 ± 2.1	89.3 ± 2.9	92.5 ± 2.2	83.3 ± 2.7	94.0
	SJ	84.2 ± 1.2	76.1 ± 1.2	72.8 ± 1.8	71.6 ± 1.4	68.1 ± 1.9	74.5
	SF	45.0 ± 1.0	39.8 ± 1.6	35.3 ± 2.1	36.1 ± 1.7	31.3 ± 1.7	37.5
	SWG	42.1 ± 2.2	37.6 ± 1.3	33.1 ± 1.5	35.2 ± 1.1	30.0 ± 1.7	35.6
	mean	74.0	67.0	60.7	62.9	56.0	–
	LSD $P < 0.05$			I – 3.94, II – 3.60, I x II – n.s.			
DPPH [μM Tx/1 g]	S0	37.7 ± 1.2	34.8 ± 1.9	31.4 ± 1.9	30.6 ± 1.3	25.0 ± 1.4	31.9
	SCh	53.8 ± 1.9	48.3 ± 3.0	43.9 ± 1.0	43.6 ± 1.4	38.8 ± 0.8	45.7
	SE	46.3 ± 1.3	41.5 ± 1.3	35.9 ± 2.1	37.9 ± 1.2	30.2 ± 0.7	38.3
	SJ	43.3 ± 1.5	41.0 ± 1.7	37.5 ± 1.6	39.0 ± 1.1	32.8 ± 1.0	38.7
	SF	41.7 ± 1.6	38.8 ± 1.3	35.9 ± 1.6	33.5 ± 1.4	30.2 ± 1.6	36.0
	SWG	39.0 ± 1.5	35.1 ± 1.8	33.5 ± 1.9	32.8 ± 1.6	29.5 ± 1.4	34.0
	mean	43.6	39.9	36.3	36.2	31.1	–
	LSD $P < 0.05$			I – 2.33, II – 2.13, I x II – n.s.			
FRAP [μM Fe^{2+}/1 g]	S0	35.3 ± 1.3	34.6 ± 1.9	30.4 ± 2.2	31.1 ± 1.0	29.3 ± 0.6	32.1
	SCh	73.1 ± 1.6	67.2 ± 1.4	57.1 ± 1.3	61.6 ± 1.1	51.8 ± 1.1	62.2
	SE	55.0 ± 1.9	51.6 ± 1.4	47.3 ± 1.3	47.6 ± 1.5	42.2 ± 1.9	48.8
	SJ	44.6 ± 1.3	41.9 ± 1.9	36.7 ± 1.9	37.4 ± 1.9	33.1 ± 1.5	38.7
	SF	40.9 ± 1.9	36.4 ± 1.8	33.2 ± 1.1	33.8 ± 1.0	30.5 ± 0.7	35.0
	SWG	38.3 ± 1.9	34.6 ± 1.6	31.0 ± 3.3	30.8 ± 1.3	29.0 ± 0.7	32.7
	mean	47.9	44.4	39.3	40.4	36.0	–
	LSD $P < 0.05$			I – 2.06, II – 1.88, I x II – n.s.			

[a] Values are presented as mean value ± SD ($n = 4$) and expressed of fresh matter

[b] Type of jams: S0 – strawberry jam without enriching ingredients, SCh – strawberry jam with a 15% addition of black chokeberry, SE – strawberry jam with a 15% addition of elderberry, SJ – strawberry jam with an 8% addition of Japanese quince, SF – strawberry jam with a 3% addition of flax seeds, SWG – strawberry jam with a 3% addition of wheat germ

[c] LSD $P < 0.05$ for: type ofjams (I), storage (II), interaction (I x II)

As PINELLI et al. (2015) reported, the content of *p*-coumaric acid and quercentin in strawberry jams corresponded to the results obtained in this work; however, the levels of ferulic acid (0.370 mg/100 g), ellagic acid (2.751 mg/100 g), and (+)-catechin (0.472 mg/100 g) were different.

Strawberry jams contained small amounts of vitamin C – on average, 10.9 mg/100 g (Table 4). However, the addition of black chokeberry, Japanese quince, and elderberry significantly influenced ($P < 0.05$) its level: by 6%, 12% and 22% respectively. The vitamin C content in the jams with flax seeds and wheat germ was comparable with that determined in the strawberry jam without enriching ingredients.

In view of the results above, the combination of strawberries with other plant compounds rich in bioactive constituents seems to be justified. When compared with the jam without enriching ingredients, the remaining ones showed higher antioxidant activity, on average by 9–239% (ABTS), 7–43% (DPPH), and 2–94% (FRAP) – Table 4. The additive which elevated the total antioxidant activity to the greatest extent was black chokeberry, while wheat germ elevated it to the least extent.

Influence of storage conditions on antioxidant properties

The storage conditions of the jam had a significant effect ($P < 0.05$) on all the analyzed constituents and total antioxidant activity. The average content of total polyphenols in the examined products after 6 and 12 months of storage decreased by 16% and 20% respectively, while losses in flavonoids were higher and were 37% and 39% (Table 2). However, it has been found that storing jams at lower temperatures results in better retention of the constituents examined ($P < 0.05$). After a year of storage, significant losses ($P < 0.05$) were noted in the content of the identified polyphenols (Table 3). The average losses of these compounds in the jams stored at 10°C ranged from 10% (ellagic acid) to 38% ((+)-catechin). In contrast, the average losses observed at 20 °C were significantly higher and amounted to 48% (*p*-cumaric acid) and 62% ((+)-catechin). Similar or greater reductions in the level of polyphenols in strawberry jams were reported by WOJDYŁO et al. (2008). The authors highlight that (+)-catechin content may either increase or decrease during storage due to the fact that this compound is released from complex compounds during the first storage period, so that its content increases and then decreases during prolonged storage.

The average losses in total anthocyanin content in chill-stored jams after 6 and 12 months were 15% and 35% respectively. In turn, for jams stored at 20°C, losses after 6- and 12-months of storage were 24% and 51% respectively (Table 2). POIANA et al. (2011) also observed losses in antho-

cyanins during storage of strawberry jam. In addition, WICKLUND et al. (2005) and PATRAS et al. (2011) found that the retention of anthocyanins in the jams stored at 4°C was better, which is consistent with the results of KOPJAR et al. (2009) who noted a smaller decrease in anthocyanins in strawberry jams stored at 4°C for six weeks (21%), compared with those kept at room temperature (51%).

What should be emphasized here is the fact that the jams with added fruit and those enriched with wheat germ and flax seeds retained their total content of anthocyanins better than the jam without added plant ingredients. This agrees with the findings of ABDEL-HADY et al. (2014), who observed better retention of total anthocyanins in the strawberry jams enriched with puree of purple carrot compared with those without added plant ingredients.

Average losses of vitamin C in strawberry jams after 6 and 12 months of storage were respectively 10% and 21% in the jam kept at 10°C, and 15% and 30% for those kept at 20°C (Table 4). The studies of POIANA et al. (2011) proved that losses of vitamin C in the strawberry jam were much more higher (33%) after only 3 months of storage at room temperature. The lower storage temperature had a significant effect ($P < 0.05$) on the better retention of vitamin C in the products investigated.

According to numerous authors, storage conditions of jams are one of the factors that affect their nutritive value, including radical scavenging activity (PATRAS et al. 2011). In the jams examined, the level of antioxidant activity decreased compared with the non-stored products, on average by 14% (ABTS), 13% (DPPH) and 13% (FRAP) after 6-months of storage and by 20%, 23% and 20% respectively after 12 months of storage (Table 4). Many authors also noted a reduction in the level of activity in the stored jams (POIANA et al. 2011, PATRAS et al. 2011). Moreover, jams stored at 10°C always had higher levels ($P < 0.05$) of antioxidant activity compared with those stored at 20°C. In turn, the biggest declines in activity were recorded in the jams without added plant ingredients, which were stored at both temperatures, this relates well to the results obtained by WOJDYŁO et al. (2008).

Conclusions

At present, consumers pay much more attention to the composition of food products. They particularly expect a natural product with low caloric value to have beneficial effects on human health. Enrichment of the daily diet with pro-health components of natural origin can contribute to

the improvement of quality of life. Such components as black chokeberry, elderberry, Japanese quince, flax seeds and wheat germ can be valuable additives, increasing the nutritive value of products, as shown by the results reported in this paper. The addition of these components with health-promoting properties to jams had a significant effect on the total antioxidant activity when compared with jam without these ingredients. Such products may therefore be a good source of antioxidants in the diet. In addition, enrichment with these products generally led to better retention of antioxidants during storage. With regard to such jams, however, we would recommend chill-storage. This is due to the lower losses of bioactive components compared with storage at room temperature, which was confirmed by our findings.

Translated by Bożena Firek (UR Kraków), native speaker (Skrivanek – Office Translation)
Accepted for print 6.07.2018

References

Abdel-Hady M.M., Mamila M.A., Afaf M.A. 2014. *Color stability of strawberry jam fortified by purple carrot puree.* Egypt. J. Agric. Res., 92(1): 323–336.

Amaro L.F., Soares M.T., Pinho C., Almeida I.F., Ferreira V.O., Pinho O. 2012. *Influence of Cultivar and storage conditions in anthocyanin content and radical-scavenging activity of strawberry jams.* Int. J. Biol. Food. Vet. Agric. Eng., 6(9): 656–660.

Ardestani A., Yazdanparast R. 2007. *Antioxidant and free radical scavenging potential of Achilleasantolina extracts.* Food Chem., 104: 21–29.

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

European Commission 2011. *Commission Regulation (EU) No 1131/2011 of 11 November 2011 amending Annex II to Regulation (EC) No 1333/2008 of the European Parliament and of the Council with regard to steviol glycosides*. Official Journal of the European Union L 295., 54: 205–2016.

Du Toit R., Volsteedt Y., Apostolides Z. 2001. *Comparison of the antioxidant content of fruits, vegetables and teas measured as vitamin C equivalents*. Toxicology, 166: 63–69.

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

Giusti M.M., Wrolstad R.E. 2001. *Characterization and measurement of anthocyanins by UV-visible spectroscopy*. Curr. Protoc. Food Anal. Chem., F1.2.1–F1.2.13.

Hannum S.M. 2004. *Potential impact of strawberries on human health: a review of the science.* Crit. Rev. Food Sci., 44: 1–17.

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.

Kopjar M., Piližota V., Nedićtiban N., Šubarić D., Babić J., Ačkar Đ., Sajdl M. 2009. *Strawberry jams: Influence of different pectins on colour and textural properties.* Czech J. Food Sci., 27: 20–28.

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.

KUCHARSKA A.Z., KOWALCZYK K., NAWIRSKA-OLSZAŃSKA A., SOKÓŁ-ŁĘTOWSKA A. 2010. *Effect of chokeberry, strawberry, and raspberry added to cornelian cherry purée on its physical and chemical composition.* ZNTJ, 4: 95–106.

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.

LIU F., NG T.B. 2000. *Antioxidative and free radical scavenging activities of selected medicinal herbs.* Life Sci., 66: 725–735.

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.

PATRAS A., BRUNTON N.P., TIWARI B.K., BUTLER F. 2011. *Stability and degradation kinetics of bioactive compounds and colour in strawberry jam during storage.* Food Bioprocess. Tech., 4: 1245–1252.

PEANO C., GIUGGIOLI N.R., GIRGENTI V. 2014. *Effect of different packaging materials on postharvest quality of Cv. Envie2 strawberry*. Int. Food Res. J., 21: 1165–1170.

PEKKARINEN S.S., HEINONEN I.M., HOPIA A.I. 1999. *Flavonoids quercetin, myricetin, kaemferol and (+) catechin and antioxidants in methyl linoleate*. J. Sci. Food Agric., 79: 499–506.

PINELLI L.D.O., MORETTI C.L., CHIARELLO M., MELO L. 2015. *Influence of strawberry jam color and phenolic compounds on acceptance during storage.* Rev. Ceres., 62(3): 233–240.

POIANA M.A., MOIGRADEAN D., DOGARU D., MATEESCU C., RABA D., IOSIFGERGEN I. 2011. *Processing and storage impact on the antioxidant properties and color quality of some low sugar fruit jams.* Rom. Biotech. Lett., 16(5): 6504–6512.

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 Radical.* Bio. Med., 26: 1231–1237.

SINGLETON V.L., ORTHOFER R., LAMUELA-RAVENTÓS RM. 1999. *Analysis of total phenols and other oxidation substrates and antioxidants by means of Folin-Ciocalteu reagent*. Methods in Enzymol., 299: 152–178.

WANG S.Y. 2006. *Effect of pre-harvest conditions on antioxidant capacity in fruits.* Acta Hortic., 712: 299–305.

WICKLUND T., ROSENFELD H.J., MARTINSEN B.K., SUNDFØR M.W., LEA P., BRUUN T., BLOMHOFF R., HAFFNER K. 2005. *Antioxidant capacity and colour of strawberry jam as influenced by cultivar and storage conditions.* LWT – Food Sci. Technol., 38: 387–391.

WILDMAN R.E.C. 2001. *Handbook of nutraceuticals and functional foods. Nutraceuticals: a brief review of historical and teleological aspects.* Boca Raton, Florida, USA, CRC Press Taylor & Francis Group.

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.

WU X.L., GU L.W., PRIORI R.L., MCKAY S. 2004. *Characterization of anthocyanins and proanthocyanidins in some cultivars of Ribes, Aronia and Sambucus and their antioxidant capacity.* J. Agric. Food Chem., 52: 7846–7856.

ZHENG W., WANG S.Y. 2001. *Antioxidant activity and phenolic compounds in selected herbs.* J. Agric. Food Chem., 49: 5165–5170.