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INFLUENCE OF PLANT-DERIVED RAW MATERIALS ON THE ANTIOXIDANT PROPERTIES OF LOW-SUGAR CHERRY JAMS

S u m m a r y

Fruits are a good source of bioactive compounds exhibiting pro-health properties. The objective of the study was to evaluate the effect of adding chokeberry, elderberry, Japanese quince, flax seeds and wheat germs on the antioxidant properties of low-sugar cherry jams stored at refrigeration (10 ºC) or room temperature (20 ºC) for 12 months. The highest levels of total polyphenols (3.036 g/kg), total flavonoids (1.372 g/kg) and total anthocyanins (0.902 g/kg) were recorded in the cherry jam with 15 % chokeberry fruit added, immediately after its production. In the cherry jams studied, the following polyphenols were identified: *p*-cumaric acid, ferulic acid, caffeic acid, rutin and (+)- catechin. In the jam without plant ingredients the dominant polyphenols were (+)-catechin (0.023 g/kg) and caffeic acid (0.019 g/kg). The content of vitamin C was the highest (0.085 g/kg) in the jam with Japanese quince added. The level of antioxidant activity ($ABTS^{\cdot+}$, $DPPH^{\cdot}$ and FRAP) was the highest in the cherry jam with 15 % added chokeberry fruit. Both the longer time of storage and higher storage temperature resulted in a decrease in the value of all the parameters analyzed. Enriching cherry jams with pro-health ingredients improved the quality of the final product. These products are a valuable source of antioxidants in daily diet.

Key words: cherry fruit, jam, pro-health additives, antioxidants, polyphenols, storage

Introduction

In recent years, studies were conducted on the health-promoting properties of fruit and their use in the food production. In addition to nutrients, those foods also have compounds showing preventive and therapeutic effects on physical and mental health. In particular, those studies were focused on bioactive compounds that occur naturally in fruit and on the methods used in the production of food, which make it possible to maintain the highest possible level of bioactivity [3].

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The bioactive compounds with antioxidant properties include polyphenols, vitamin A and C, tocopherols, carotenoids, as well as organic acids and minerals [30]. Polyphenols have a beneficial effect on the human immune system and show anti-inflammatory, antimicrobial and anticancer properties. They comprise phenolic acids, and flavonoids including anthocyanins, stilbenes and lignans [21].

Sour cherries (*Prunus cerasus* L.) are increasingly valued not only for their taste and nutritional and mineral compounds contained therein, but also because they contain anthocyanins and other flavonoids exhibiting strong antioxidant and anti-inflammatory properties [32]. Anthocyanins are responsible for the colour of the cherry fruit; their content depends on the variety and the stage of maturity [11]. Over 1.4 million tons of sour cherry are produced annually worldwide. The biggest producers of sour cherry are Russia, Poland and Turkey [9]. The sour cherry fruit is an unstable raw material. Moreover, sour cherries should be quickly processed as their harvest period is limited. They are the raw material for producing concentrated juices, frozen foods, compotes, drinks and jams [1].

Sour cherry jams are willingly added to breakfasts, dinners and desserts, especially the low-sugar ones for the calorie content therein is reduced. They maintain the same excellent quality and sensory features as the fruit they are made from. However, the conditions and the time of storage of jams are important factors that affect their quality, including changes in the level of antioxidant activity [24].

The objective of the research study was to assess the effect of adding plant materials with pro-health properties (black chokeberry, elderberry, Japanese quince, flax seeds and wheat germs) on the level of antioxidants in low-sugar sour cherry jams. The jams for the analysis were stored at refrigeration (10 ºC) and room temperature (20 ºC) for 6 and 12 months.

Materials and methods

Material

The material studied consisted of low-sugar jams prepared from the "Łutówka" sour cherry cv. (*Prunus cerasus* L.) without plant ingredients and of 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 analysed were produced from frozen fruits, which were prepared from the fully ripened fresh fruits. Those fruit were sorted and washed immediately after harvest and inedible parts were discarded. The sour cherries were frozen as a whole, while the fruit of black chokeberry, elderberry and Japanese quince were homogenized prior to freezing. After freezing the raw fruit material was kept in polypropylene bags

at -30 ºC until production. Flax was added in the form of ground defatted flax seeds (Oleofarm, Poland) with residual fat content of 10 %. The wheat germs from wheat grain were purchased directly from the producer (Sante, Poland). Sucrose, steviol glycoside (Bio Nature24) as a partial sucrose replacement, low-esterified 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 the jams with a final refractometric extract of about 30 % were sweetened with sucrose and steviol glycoside. Steviol glycoside was added to replace part of the sucrose and to reduce the caloric value of jams. Steviol glycoside was added in the maximum quantity as permitted in the European Union, i.e. 200 mg/kg of the product [8]. The fruit comprised 50 % of the weight of the final product; the total acidity of the jam was set at 1 %. The following variants of jams were manufactured: SC0 – sour cherry jam without plant ingredients, SCCh – sour cherry jam with 15 % black chokeberry added, SCE – sour cherry jam with 15 % elderberry added, SCJ – sour cherry jam with 8 % Japanese quince added, SCF – sour cherry jam with 3 % flax seeds added, SCWG – sour cherry jam with 3 % wheat germs added.

The fruit were boiled together with the sweeteners and water in an open pan (for 20 min at 103 ºC). Afterwards, a previously prepared 4 % solution of gelling agent was added and the whole batch was mixed and boiled again for several minutes. Finally, citric acid was added and mixed. Then the products were then packaged in glass jars (0.2 l), pasteurized at 82 ÷ 85 ºC for 15 min, and finally cooled to 20 ± 2 ºC.

Storage of jam

The jams produced were stored in dark warehouses at two temperatures: refrigeration temperature (10 ºC) and room temperature (20 ºC) until their assessment carried out immediately after 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. The polyphenols were determined by a Folin-Ciocalteu method [31]. The content of polyphenols was read on the standard curve prepared for (+)-catechin.

The content of total flavonoids was determined using an aluminium chloride assay [35]. The content of flavonoids was read on the standard curve prepared for (+)-catechin.

The polyphenols were separated and identified with the use of high performance liquid chromatography (HPLC) according to the method described by Klimczak *et al.* [15], with the modifications by the authors of the study. The jams studied were ground

in a laboratory mill and distilled water was added at a ratio of 1 : 1, next NaOH (2 mol/l) at a ratio of 1 : 1 w/w was added. Subsequently the samples were mixed using a Labnet vortex mixer (Edison, USA) and left in the dark for 4 h at a temperature of 20 ºC and then neutralized to pH 2.2 - 2.8 with HCl (2 mol/l) using a Metrohm pH meter (Herisau, Switzerland). Next, the samples were centrifuged at 4.000 x *g* for 20 min at 4 ºC in a MPW-260R centrifuge (Warsaw, Poland) and transferred quantitatively into a volumetric flask using a 1 % L-ascorbic acid dissolved in methanol (HPLC grade). Prior to chromatographic analysis, the material examined was centrifuged for the second time (18.000 x *g*, 20 min, 4 ºC); the samples with wheat germs 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 the chromatographic analysis the samples were stored at 4 ºC.

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

The total anthocyanins and the degradation index were determined by means of the spectroscopic method [10]. The content of anthocyanins, expressed as cyanidin-3-glucoside equivalent, was calculated from the absorbance measured and the coefficient of sample dilution. The absorbance of each sample was measured at 510 and 700 nm, against distilled water as a blank. Degradation index (ID) was obtained as the ratio between total anthocyanins and the monomeric anthocyanins:

$$ID = (\text{Total anthocyanins})_{\text{single pH method}} / (\text{Monomeric anthocyanins})_{\text{pH differential method}}$$

The vitamin C content, as a total of ascorbic and dehydroascorbic acid, was determined using spectrophotometrical method [13]. An oxalic acid solution (2 %) was used to extract the ascorbic acid. The following were measured spectrophotometrically at 500 nm and compared with a vitamin C reference standard: the quantitative reduction of 2,6-dichlorophenolindophenol dyestuff by the ascorbic acid, the extraction of the excess dyestuff using xylene and the excess.

The antioxidant activity was determined by means of the three spectrophotometric methods: as the scavenging activity against DPPH· (1,1-diphenyl-2-picrylhydrazyl) free radical [25]; applying $ABTS^{\cdot+}$ (2,2′-azinobis (3-ethylbenzthiazoline-6-sulfonate) cation radical [28] and by the ferric reducing antioxidant power (FRAP) method [4].

For the aforementioned methods the 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 the total polyphenols, flavonoids, anthocyanins, vitamin C and antioxidant activity.

Statistical analysis

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

Results and discussion

Numerous studies indicate that polyphenols are a very important component of the daily diet [2, 6]. Their level in food depends on the type, species and quality of the raw material. The results obtained immediately after the jam production indicate a high content of total polyphenols and total flavonoids in the sour cherry jam without plant ingredients (Tab. 1). However the enriching additives added, such as black chokeberry, elderberry and Japanese quince, caused the content of total polyphenols to significantly increase ($p < 0.05$); the increase ranged from 21 to 173 %. As for the content of total flavonoids, in addition to the aforementioned fruits, wheat germs and flax seeds also contributed to an increase in the level of these compounds. The highest levels of total polyphenols (3036 mg/kg) and total flavonoids (1372 mg/kg) were recorded in the jam with 15 % chokeberry fruit added. This confirms the findings of Wojdyło *et al.* [34], who reported a significant increase in the total polyphenol content in strawberry jam after adding chokeberry.

Throughout storage there was a significant decrease ($p < 0.05$) in the total contents of polyphenols and flavonoids in the sour cherry jams. After one year of storage the smallest losses of polyphenols were found in the jams with the Japanese quince added – 28 % at 20 ºC on average, and the highest in those with the elderberry added – 49 % at 20 ºC on average. With regard to the flavonoids, their total losses were higher than the losses of total polyphenols and they ranged from 34 (SCE) to 54 % (SCWG) in the jams stored at room temperature.

Anthocyanins belong to the largest group of plant-derived water-soluble pigments, which are responsible for the characteristic, intense colour. Owing to those properties, anthocyanins are highly valued in the food and pharmaceutical industries [5]. In this study, the cherry jam without plant ingredients and analysed immediately after production contained 363 mg/kg of total anthocyanins (Tab. 1). A similar level

Table 1. Content of total polyphenols, total flavonoids, total anthocyanins and degradation index in sour cherry jams during storage

Tabela 1. Zawartość polifenoli ogółem, flawonoidów ogółem, antocyjanów ogółem oraz indeks degradacji w dżemach wiśniowych podczas składowania

Parameter analysed Badany parametr	Type of jam Rodzaj dżemu	Storage time at 10 ºC and 20 ºC [months] Czas składowania w temp. 10 i 20 ºC [miesiące]					$\bar{x}$
		0	6 temp. 10 ºC	6 temp. 20 ºC	12 temp. 10 ºC	12 temp. 20 ºC	
Total polyphenols [mg/kg f.m.] Polifenole ogółem [mg/kg ś.m.]	SC0	1113 ± 60	997 ± 44	845 ± 45	955 ± 138	761 ± 45	
	SCCh	3036 ± 147	2561 ± 115	2074 ± 88	2159 ± 56	1792 ± 153	2324
	SCE	2061 ± 130	1638 ± 48	1409 ± 65	1221 ± 128	1053 ± 41	1476
	SCJ	1349 ± 88	1301 ± 53	1170 ± 81	1144 ± 58	972 ± 66	1187
	SCF	1222 ± 46	1022 ± 65	891 ± 55	900 ± 48	674 ± 47	942
	SCWG	1197 ± 71	996 ± 91	913 ± 59	876 ± 91	708 ± 62	938
	$\bar{x}$	1663	1419	1217	1209	930	
	LSD $p < 0.05$	I – 52.2, II – 47.7, I × II – 116.8					
Total flavonoids [mg/kg f.m.] Flawonoidy ogółem [mg/kg ś.m.]	SC0	413 ± 18	296 ± 17	245 ± 21	240 ± 43	208 ± 24	280
	SCCh	1372 ± 35	1131 ± 63	921 ± 61	1014 ± 77	843 ± 26	1056
	SCE	895 ± 65	791 ± 55	686 ± 35	671 ± 41	595 ± 79	728
	SCJ	640 ± 39	535 ± 31	455 ± 22	469 ± 29	399 ± 60	499
	SCF	556 ± 50	443 ± 24	312 ± 36	404 ± 52	266 ± 18	396
	SCWG	506 ± 35	422 ± 34	293 ± 40	388 ± 21	233 ± 26	369
	$\bar{x}$	731	603	485	531	424	
	LSD $p < 0.05$	I – 27.0, II – 24.7, I × II – 60.4					
Total anthocyanins [mg/kg f.m.] Antocyjany ogółem [mg/kg ś.m.]	SC0	363 ± 37	345 ± 42	268 ± 26	277 ± 19	196 ± 38	290
	SCCh	902 ± 70	855 ± 25	778 ± 26	706 ± 158	572 ± 53	763
	SCE	668 ± 28	643 ± 30	577 ± 7	543 ± 29	439 ± 70	574
	SCJ	371 ± 55	344 ± 67	290 ± 39	268 ± 42	226 ± 22	300
	SCF	361 ± 47	341 ± 45	288 ± 13	238 ± 67	194 ± 36	284
	SCWG	347 ± 43	320 ± 25	279 ± 45	243 ± 65	177 ± 28	273
	$\bar{x}$	502	475	413	379	301	
	LSD $p < 0.05$	I – 32.0, II – 29.3, I × II – n.s.					
Degradation index Indeks degradacji	SC0	1.25 ± 0.10	1.42 ± 0.09	1.46 ± 0.18	1.80 ± 0.19	1.99 ± 0.17	1.58
	SCCh	1.20 ± 0.03	1.17 ± 0.01	1.26 ± 0.02	1.40 ± 0.06	1.46 ± 0.17	1.30
	SCE	1.17 ± 0.05	1.22 ± 0.04	1.27 ± 0.08	1.37 ± 0.05	1.45 ± 0.12	1.30
	SCJ	1.17 ± 0.06	1.34 ± 0.25	1.43 ± 0.31	1.42 ± 0.36	1.73 ± 0.40	1.42
	SCF	1.27 ± 0.07	1.40 ± 0.15	1.51 ± 0.07	1.60 ± 0.27	1.84 ± 0.10	1.52
	SCWG	1.27 ± 0.09	1.38 ± 0.13	1.46 ± 0.17	1.59 ± 0.31	1.84 ± 0.33	1.51
	$\bar{x}$	1.22	1.32	1.40	1.53	1.72	
	LSD $p < 0.05$	I – 0.115, II – 0.105, I × II – n.s.					

Explanatory notes / Objaśnienia:
SC0 – sour cherry jam without plant ingredients / dżem wiśniowy bez dodatków roślinnych, SCCh – sour cherry jam with 15 % black chokeberry added / dżem wiśniowy z 15-procentowym dodatkiem czarnej aronii, SCE – sour cherry jam with 15 % elderberry added / dżem wiśniowy z 15-procentowym dodatkiem czarnego bzu, SCJ – sour cherry jam with 8 % Japanese quince added / dżem wiśniowy z 8-procentowym dodatkiem pigwowca japońskiego, SCF – sour cherry jam with 3 % flax seeds added / dżem wiśniowy z 3-procentowym dodatkiem nasion lnu, SCWG – sour cherry jam with 3 % wheat germs added / dżem wiśniowy z 3-procentowym dodatkiem zarodków pszennych.
Table shows mean values ($\overline{x}$) ± standard deviation / W tabeli przedstawiono wartości średnie ($\overline{x}$) ± odchylenia standardowe; n = 4.
LSD $p < 0.05$ for / LSD $p < 0,05$ dla: type of jams (I) / rodzaj dżemu (I), storage (II) / przechowywanie (II), interaction (I × II) / interakcja (I × II); n.s. – not significant / nieistotne.

(426 mg/kg) thereof in the cherry jam was also reported by Poiana *et al.* [26]. Of the jams studied, the highest anthocyanin content was found in the black chokeberry jam (902 mg/kg) and elderberry jam (668 mg/kg). In the other jams, the anthocyanin content was similar to that of the jam without plant ingredients. As for the jams containing the largest amounts of those pigments and compared to the non-stored jams, the smallest decrease in their content was found during storage, within the range of 19 ÷ 22 %. The reduction in the amount of anthocyanins in the product depends on many factors (pH, content and type of organic acids, sugar content, temperature and time of storage) [23].

The jams stored for 12 months at 10 ºC had 19 ÷ 41 % more anthocyanins than those stored at 20 ºC, depending on the type of jam. This confirms the findings of Koca and Ustun [16], who reported better anthocyanin retention in the cherry jam stored at 4 ºC than at 20 ºC. The highest losses of anthocyanins after one year of storage were found in the jam with flax seeds and wheat germs added, while the smallest were observed in the elderberry jams. Both the longer time of storage and higher storage temperatures have significantly impacted the drop in the content of anthocyanins. This confirms the findings of Hartmann *et al.* [12], who examined strawberry juice and puree throughout the storage. The anthocyanin degradation index (ID) is an indicator of the stability of anthocyanins; the higher the value, the lower the stability of those compounds. In this study, the degradation index ranged from 1.17 to 1.27 depending on the type of jam, but there were no significant differences in ID in all the jams analysed (Tab. 1). However, there was a significant increase in ID during storage, 25 % at 10 ºC and 41 % at 20 ºC on average, as a result of the previously reported losses of anthocyanins in the jams during storage.

The following polyphenols were identified in the sour cherry jams studied: *p*-coumaric acid, ferulic acid, caffeic acid, rutin, and (+)-catechin (Tab. 2); in the jam without plant ingredients (+)-catechin (22.93 mg/kg) and caffeic acid (19.37 mg/kg)

Table 2. Individual phenolic compounds in sour cherry jams during storage [mg/kg]
Tabela 2. Poszczególne związki fenolowe w dżemach wiśniowych podczas składowania [mg/kg]

Component analysed Badany parametr	Type of jam Rodzaj dżemu	Storage time at 10 ºC and 20 ºC [months] Czas składowania w temp. 10 i 20 ºC [miesiące]			$\bar{x}$
		0	12	12	
			temp. 10 ºC	temp. 20 ºC	
p-coumaric acid Kwas *p*-kumarowy	SC0	12.52 ± 0.24	9.07 ± 0.72	5.11 ± 0.10	8.90
	SCCh	24.20 ± 0.14	22.36 ± 0.36	18.19 ± 0.31	21.58
	SCE	19.52 ± 0.20	18.52 ± 0.20	16.72 ± 0.19	18.25
	SCJ	18.71 ± 0.25	16.32 ± 0.05	14.79 ± 0.11	16.61
	SCF	19.24 ± 0.45	17.48 ± 0.05	15.22 ± 0.31	17.31
	SCWG	19.48 ± 0.05	17.23 ± 0.17	15.75 ± 0.05	17.49
	$\bar{x}$	18.94	16.83	14.30	
	LSD p < 0.05	I – 0.264, II – 0.186, I × II – 0.457			
Ferulic acid Kwas felurowy	SC0	3.05 ± 0.01	2.93 ± 0.03	2.52 ± 0.04	2.83
	SCCh	6.69 ± 0.27	5.61 ± 0.24	4.55 ± 0.11	5.62
	SCE	5.21 ± 0.18	4.72 ± 0.05	4.21 ± 0.04	4.71
	SCJ	3.60 ± 0.07	3.43 ± 0.14	3.20 ± 0.07	3.41
	SCF	10.98 ± 0.98	10.08 ± 0.65	7.54 ± 0.32	9.53
	SCWG	9.80 ± 0.43	9.03 ± 0.19	8.56 ± 0.27	9.13
	$\bar{x}$	6.55	5.97	5.10	
	LSD p < 0.05	I – 0.319, II – 0.225, I × II – 0.552			
Caffeic acid Kwas kawowy	SC0	19.37 ± 0.92	15.73 ± 0.13	14.22 ± 0.76	16.44
	SCCh	50.97 ± 0.82	47.57 ± 1.56	42.43 ± 2.43	46.99
	SCE	17.82 ± 0.01	15.37 ± 0.54	14.01 ± 0.90	15.74
	SCJ	21.38 ± 0.94	17.22 ± 0.20	9.86 ± 0.84	16.16
	SCF	24.25 ± 0.22	21.87 ± 0.19	20.92 ± 0.11	22.35
	SCWG	16.18 ± 0.06	14.80 ± 0.12	13.51 ± 0.13	14.83
	$\bar{x}$	25.00	22.09	19.16	
	LSD p < 0.05	I – 0.823, II – 0.582, I × II – 1.425			
Rutin Rutyna	SC0	7.18 ± 0.08	5.18 ± 0.03	3.54 ± 0.16	5.30
	SCCh	15.50 ± 0.02	9.62 ± 0.52	9.43 ± 0.74	11.51
	SCE	17.51 ± 0.14	12.84 ± 0.18	13.90 ± 0.37	14.75
	SCJ	6.53 ± 0.00	5.59 ± 0.08	5.16 ± 0.05	5.76
	SCF	17.93 ± 0.19	13.67 ± 0.22	10.66 ± 0.34	14.09
	SCWG	17.07 ± 0.28	11.82 ± 0.07	10.39 ± 0.14	13.09
	$\bar{x}$	13.62	9.79	8.85	
	LSD p < 0.05	I – 0.262, II – 0.185, I × II – 0.454			
(+)-catechin (+)-katechina	SC0	22.93 ± 0.87	21.08 ± 0.62	19.01 ± 0.29	21.01
	SCCh	23.46 ± 0.90	20.57 ± 0.71	17.41 ± 1.16	20.48
	SCE	36.62 ± 1.67	24.37 ± 0.83	16.89 ± 0.87	25.96

	SCJ	45.56 ± 5.40	22.68 ± 0.79	21.45 ± 0.06	29.90
	SCF	29.10 ± 0.75	25.44 ± 0.65	23.83 ± 0.45	26.12
	SCWG	24.23 ± 0.21	21.92 ± 0.82	17.52 ± 0.46	21.22
	$\overline{x}$	30.32	22.68	19.35	
	LSD $p < 0.05$	I – 1.425, II – 1.008, I × II – 2.468			

Explanatory notes as in Tab. 1. / Objaśnienia jak pod tab. 1.

were dominant. Adding enriching plant ingredients caused the level of the polyphenols identified to increase ($p < 0.05$). The jam with black chokeberry added had the highest content of *p*-coumaric acid and caffeic acid; whereas, the highest levels of ferulic acid and rutin were recorded in the jams with flax seeds added. With regard to (+)-catechin, its highest content was recorded in the jam with Japanese quince added. This confirms the findings of Wojdyło *et al.* [34] on advantages of jam's enrichment, who observed the highest increase in the content of (+)-catechin in the strawberry jam after adding Japanese quince flowers, while adding black chokeberry fruit resulted in the highest increases in *p*-coumaric acid and caffeic acid. Numerous studies in various food industry branches confirm the beneficial effects of enriching food products. For example, Ducruet *et al.* [7] have shown that adding goji berries to beer led to a significant increase in the antioxidant activity as well as in the level of bioactive substances such as rutin and 2-*o*-β-D-glucopyranosyl-L-ascorbic acid. Sęczyk *et al.* [29] noted an increase in the free-radical scavenging ability on account of a green tea extract added to soy milk, and Kucharska *et al.* [18] showed an increase in the polyphenol content and antioxidant activity when the pumpkin jam was enriched with Japanese quince fruit added.

In the jams analysed, ferulic acid was the most stable polyphenol; its average losses after one year of storage amounted to 9 % (10 ºC) and 22 % (20 ºC). On the other hand, the losses in the rutin content were the highest, 28 % (10 ºC) and 35 % (20 ºC) on average. Wojdyło *et al.* [34] reported substantially higher losses in the level of polyphenols in the strawberry jam after 6 months of storage at 4 ºC. With regard to ferulic acid the losses were 30 % in the jam without additives, 45 % in the jam with black chokeberry added, and 19 % in the jam containing rhubarb. In turn, results reported in this research study are more congruent with the findings of Mäkilä *et al.* [20]. The authors found a 4 % drop in the ferulic acid content in blackcurrant juice after 12 months of storage at 4 ºC.

Sour cherries contain small amounts of vitamin C, about 113 mg/kg fresh weight, which varies depending on the variety [33]. Therefore, enriching sour cherry jams with the ingredients rich in vitamin C allows their pro-health properties to be enhanced, and this in turn makes such products more attractive to consumers. The content of vitamin

Table 3. Content of vitamin C and antioxidant activity (ABTS$^{\cdot+}$, DPPH$^{\cdot}$ and FRAP) in sour cherry jams during storage

Tabela 3. Zawartość witaminy C oraz aktywność przeciwutleniająca (ABTS$^{\cdot+}$, DPPH$^{\cdot}$ i FRAP) w dżemach wiśniowych podczas składowania

Parameter analysed Badany parametr	Type of jam Rodzaj dżemu	Storage time at 10 ºC and 20 ºC [months] Czas składowania w temp. 10 i 20 ºC [miesiące]					$\bar{x}$
		0	6 temp. 10 ºC	6 temp. 20 ºC	12 temp. 10 ºC	12 temp. 20 ºC	
Vitamin C Witamina C [mg/kg]	SC0	52.9 ± 11.0	46.7 ± 10.0	41.3 ± 9.7	40.6 ± 4.8	32.3 ± 5.9	
	SCCh	73.2 ± 5.4	70.0 ± 7.2	67.3 ± 5.3	62.4 ± 6.7	53.0 ± 7.9	65.2
	SCE	77.9 ± 6.0	73.2 ± 3.2	69.7 ± 7.7	65.4 ± 7.7	50.1 ± 8.6	67.3
	SCJ	84.9 ± 7.1	80.5 ± 4.3	77.2 ± 4.3	74.4 ± 3.0	64.1 ± 6.5	76.2
	SCF	51.6 ± 5.7	45.9 ± 8.8	40.3 ± 2.5	37.2 ± 6.7	30.7 ± 8.7	41.1
	SCWG	51.1 ± 4.2	43.8 ± 5.1	40.7 ± 3.0	38.8 ± 7.3	31.6 ± 7.7	41.2
	$\bar{x}$	65.3	60.0	56.1	53.1	43.6	
	LSD $p < 0.05$	I – 4.25, II – 3.88, I × II – n.s.*					
ABTS$^{\cdot+}$ [µmol Tx/g]	SC0	117.5 ± 7.8	105.7 ± 10.7	73.7 ± 10.1	90.1 ± 7.9	62.6 ± 13.0	89.9
	SCCh	171.0 ± 18.3	165.3 ± 15.7	145.5 ± 13.7	150.2 ± 4.2	124.9 ± 5.5	151.4
	SCE	148.4 ± 24.9	138.7 ± 21.9	108.1 ± 5.2	101.5 ± 0.9	84.9 ± 2.4	116.3
	SCJ	131.5 ± 22.2	120.0 ± 11.6	103.5 ± 5.9	101.5 ± 1.4	81.0 ± 9.4	107.5
	SCF	125.4 ± 10.4	113.5 ± 7.5	91.2 ± 14.5	84.1 ± 14.5	61.8 ± 7.2	95.2
	SCWG	120.8 ± 15.4	115.2 ± 6.9	87.7 ± 2.7	86.8 ± 2.1	63.6 ± 3.3	94.8
	$\bar{x}$	135.8	126.4	101.6	102.4	79.8	
	LSD $p < 0.05$	I – 7.22, II – 6.59, I × II – n.s.					
DPPH$^{\cdot}$ [µmol Tx/g]	SC0	32.0 ± 1.1	30.1 ± 0.9	25.5 ± 1.8	26.8 ± 0.9	22.5 ± 0.9	27.4
	SCCh	50.0 ± 1.8	44.6 ± 1.7	40.8 ± 2.7	40.6 ± 3.4	35.9 ± 1.5	42.4
	SCE	42.0 ± 2.5	38.0 ± 1.3	33.6 ± 1.1	34.8 ± 3.8	29.5 ± 1.7	35.6
	SCJ	39.5 ± 1.0	36.6 ± 1.6	29.9 ± 1.5	32.3 ± 4.8	26.9 ± 2.4	33.0
	SCF	37.4 ± 2.1	35.1 ± 2.7	26.0 ± 1.8	32.5 ± 1.6	23.1 ± 1.4	30.8
	SCWG	35.7 ± 0.9	32.2 ± 1.0	26.8 ± 1.2	27.1 ± 4.5	24.3 ± 1.5	29.2
	$\bar{x}$	39.4	36.1	30.4	32.3	27.0	
	LSD $p < 0.05$	I – 1.37, II – 1.25, I × II – 3.06					
FRAP [µmol Fe^{2+}/g]	SC0	47.5 ± 0.6	45.0 ± 2.3	38.8 ± 1.3	41.4 ± 0.8	33.6 ± 2.4	41.3
	SCCh	85.8 ± 0.7	82.2 ± 7.5	74.3 ± 6.6	78.7 ± 5.2	63.2 ± 4.6	76.8
	SCE	63.1 ± 6.6	60.6 ± 3.4	58.5 ± 5.3	55.0 ± 3.4	50.6 ± 3.0	57.6
	SCJ	57.6 ± 1.8	53.5 ± 1.0	48.9 ± 1.1	50.9 ± 3.8	44.5 ± 2.4	51.1
	SCF	53.2 ± 1.6	50.6 ± 1.5	46.8 ± 1.6	46.7 ± 5.7	39.3 ± 1.0	47.3
	SCWG	49.6 ± 0.6	47.3 ± 0.9	44.3 ± 1.4	42.1 ± 1.2	39.6 ± 1.8	44.6
	$\bar{x}$	59.5	56.5	51.9	52.5	45.1	
	LSD $p < 0.05$	I – 2.12, II – 1.93, I × II – n.s.					

Explanatory notes as in Tab. 1. / Objaśnienia jak pod tab. 1.

C in the non-stored sour cherry jams fluctuated between 51.1 mg/kg and 84.9 mg/kg (Tab. 3). The highest level of vitamin C (84.9 mg/kg), 60 % higher compared to the jam without plant ingredients, was found in the jam with Japanese quince fruit added. In this case, vitamin C was the most stable during storage. In turn, the jams with black chokeberry and elderberry added had, respectively, a 38 % and 47 % higher content of vitamin C compared to the jam without additives. In the jams enriched with flax seeds and wheat germs the level of vitamin C was comparable to the cherry jam without plant ingredients.

During storage, the degradation of vitamin C was reported in all samples; however, after 12 months of storage the losses thereof were significantly lower at 10 ºC and averaged 18 % compared to the non-stored jams. Then again the losses were higher ($p < 0.05$) at higher temperatures and they were 32 %, on average. This confirms the findings of Poiana *et al.* [26], who found 22 % losses of vitamin C in cherry jams stored at 20 ºC for 3 months.

In the jams analysed, the level of antioxidant activity was determined using three methods: $ABTS^{\cdot+}$, $DPPH^{\cdot}$ and FRAP assay. In non-stored jams the level of activity varied from 117.5 µmol Trolox eq./g to 171.0 µmol Trolox eq./g ($ABTS^{\cdot+}$) and from 32.0 µmol Trolox eq./g to 50.0 µmol Trolox eq./g ($DPPH^{\cdot}$) – Tab. 3. The highest antioxidant activity was found in the black chokeberry jam, while the lowest was in the sour cherry jam without plant ingredients. This confirms the findings of Wojdyło *et al.* [34]. According to the authors of this paper the strawberry jam enriched with chokeberry puree had the highest antioxidant activity measured against $ABTS^{\cdot+}$ (5.03 µmol Trolox eq./g dry matter) and against $DPPH^{\cdot}$ (40.32 µmol Trolox eq./g dry matter). Chokeberry fruit are deemed to be valuable additives to enrich various fruit products [22], owing to their content of numerous phenolic acids, high antioxidant potential [14] and the presence of many bioactive compounds [17] as well as their health-promoting properties [19].

After one year of storing the jams at 10 ºC, a reduction was shown in the radical scavenging activity, 25 % ($ABTS^{\cdot+}$) and 18 % ($DPPH^{\cdot}$) on average. The reduction could be attributed to the degradation of individual components with antioxidant properties. After 12 months storage at 10 ºC the level of activity increased 17 % ($ABTS^{\cdot+}$) and 13 % ($DPPH^{\cdot}$) compared to that at 20 ºC. This confirms the findings of Rababah *et al.* [27], who reported a 68 % drop in the $DPPH^{\cdot}$ level in the cherry jam after 5 month storage at 25 ºC.

As for $ABTS^{\cdot+}$ and $DPPH^{\cdot}$ the highest FRAP was determined in the jam with black chokeberry added, where the power was on average 81 % higher ($p < 0.05$) compared to the jam without plant ingredients. Also the level of the ferric ions captured in the enriched sour cherry jams increased significantly ($p < 0.05$): 33 % (elderberry), 21 % (Japanese quince) and 12 % (flax seeds). After 12 months of storage at the room

temperature the level of activity decreased from 20 % (jams with elderberry and wheat germs) to 29 % (jam without plant ingredients). Poiana *et al.* [26] showed an 11 % decrease in FRAP in the cherry jam after 3 months of storage at 20 ºC.

Conclusions

1. The enrichment of sour cherry jam with black chokeberry, elderberry, Japanese quince as well as flax seeds or wheat germs led to an increase in total polyphenols, total flavonoids and the antioxidant activity.
2. In the majority of the jams containing plant ingredients, there was also an increase in the number of polyphenols identified, such as p-coumaric acid, ferulic acid, caffeic acid, rutin and (+)-catechin, compared to the jam without plant ingredients.
3. The adding of chokeberry and elderberry caused the content of total anthocyanins in the jams to increase 2.5 and 1.8 times, respectively, and the fruit of Japanese quince added have enriched the sour cherry jams with vitamin C.
4. In order to minimize losses in the antioxidant properties the storage temperature of jams should be decreased and the time of storage of those products should be maximally reduced.

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WPŁYW SUROWCÓW ROŚLINNYCH NA WŁAŚCIWOŚCI PRZECIWUTLENIAJĄCE NISKOSŁODZONYCH DŻEMÓW WIŚNIOWYCH

S t r e s z c z e n i e

Owoce są bardzo dobrym źródłem związków bioaktywnych o właściwościach prozdrowotnych. Celem pracy była ocena wpływu dodatku owoców aronii, bzu czarnego, pigwowca japońskiego, nasion lnu i zarodków pszennych na właściwości przeciwutleniające niskosłodzonych dżemów wiśniowych przechowywanych przez 12 miesięcy w temperaturze chłodniczej (10 ºC) i pokojowej (20 ºC). Najwyższe poziomy polifenoli ogółem (3,036 g/kg), flawonoidów ogółem (1,372 g/kg) i antocyjanów ogółem (0,902 g/kg) bezpośrednio po produkcji stwierdzono w dżemie wiśniowym z 15-procentowym dodatkiem owoców aronii. W badanych dżemach wiśniowych zidentyfikowano następujące polifenole: kwas *p*-kumarowy, kwas felurowy, kwas kawowy, rutynę, (+)-katechinę. W dżemie bez dodatków dominującymi polifenolami były (+)-katechina (0,023 g/kg) i kwas kawowy (0,019 g/kg). Zawartość witaminy C (0,085 g/kg) była największa w dżemie z dodatkiem owoców pigwowca japońskiego. Poziom aktywności przeciwutleniającej ($ABTS^{\cdot+}$, $DPPH^{\cdot}$ i FRAP) był najwyższy w dżemie wiśniowym z 15-procentowym dodatkiem owoców aronii. Zarówno dłuższy czas, jak i wyższa temperatura przechowywania wpłynęły na zmniejszenie wartości wszystkich badanych parametrów. Wzbogacenie dżemów wiśniowych dodatkami o właściwościach prozdrowotnych wpłynęło na poprawę jakości wyrobu gotowego. Produkty te mogą być cennym źródłem przeciwutleniaczy w codziennej diecie.

Słowa kluczowe: owoce wiśni, dżem, dodatki prozdrowotne, przeciwutleniacze, polifenole, przechowywanie