Effect of mixing different kinds of fruit juice with sour cherry puree on nutritional properties

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Abstract The main objective of this study was to investigate the effect of mixing sour cherry puree with apple, pear, quince and flowering quince juices on characteristics of 17 different products (12 smoothies and 5 semi-products). Compounds (phenolic compounds, vitamin C, sugar, pectin), antioxidant activity (ORAC, ABTS, FRAP), and physicochemical parameters (titratable acidity, soluble solids, viscosity, colour) of different products were evaluated. Depending on the type of product, 8 to 20 phenolic compounds, belonging to the anthocyanins, flavan-3-ols, flavonols, hydroxycinnamic acids, and dihydrochalcone, were identified by liquid chromatography/quadrupole time-of-flight mass spectrometry (LC/QTOF-MS). The highest content of polyphenols was observed in the sour cherry–flowering quince smoothie, while the lowest was observed in the sour cherry–pear smoothie. The study showed that the major polyphenols compounds in the smoothies were polymeric procyanidins, which were positively correlated with antioxidant activity. In addition, some kind of synergistic effect was observed between some compounds of sour cherry and flowering quince which could increase the antioxidant activity of the final product. The mixing of various fruit products could be interesting from a nutritional as well as commercial perspective.

Keywords Sour cherry · Smoothies · LC–MS–QTOF; UPLC–PDA–FL · Polyphenols · Antioxidant activity

Introduction

Trends in the pursuit of a healthy lifestyle influence the development of the worldwide food industry, including the fruit and vegetable sector. Consumers are beginning to pay attention to the quality and nutritional value of foods, so they increasingly choose fresh, natural juices and healthy snacks. Therefore, among the most promising sectors are those that deliver convenient, healthy, premium type products, satisfying thirst and hunger—such as a smoothie (Corbo et al. 2014; Sabbe et al. 2009). The accurate knowledge of the chemical composition of plant materials creates the possibility to obtain products of pro-health properties and simultaneously attractive in terms of sensory values. The mixing process of raw materials should be carefully planned and should be carried out in order to supplement the specific components, so as to finally obtain a product with the features of functional foods (Corbo et al. 2014; González-Molina et al. 2012).

Sour cherry (*Prunus cerasus* L.) is a rich source of nutrients and bioactive compounds, including anthocyanins, hydroxycinnamic acids, malic acids, vitamins and minerals, but the tart taste of this fruit is not always accepted by consumers (Damar and Ekşi 2012; Kirakosyan et al. 2009; Wojdyło et al. 2014b). Because of this, there are various sour cherry products including wines, jams, juices or beverages with a high content of sucrose and low levels of the fruit. Hence, new uses for sour cherry fruit should be developed with the aim of minimizing loss of bioactive compounds and simultaneously with a new, more acceptable taste. For this purpose, sour cherry puree could be mixed with other attractive fruits, e.g. pear, apple,

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quince or flowering quince. In this sense, apple, pear and quince have a sweet taste and are a richer source of pectin and other polyphenol compounds, e.g. flavonols and flavan-3-ols, than sour cherry, therefore after mixing these fruits with sour cherry valuable products could be obtained (Kolniak-Ostek and Oszmiański 2015; Wojdyło et al. 2008; Wojdyło et al. 2014c). In turn, flowering quince fruits are very acidic and not suitable for consumption when raw. However, it is an excellent raw material for processing, with high bioactive potential, which could be used as a flavouring additive, enriching the quality of the final products (Nowicka et al. 2015; Tarko et al. 2014).

Therefore, the aim of this study was to investigate the effect of mixing different fruit juices (apple, pear, quince and flowering quince) with sour cherry puree on the content of bioactive compounds (polyphenols, vitamin C, pectins) and physical (viscosity, colour) and chemical (titratable acidity, soluble solids, sugar content) properties.

It was expected that the resulting smoothies would be characterized by a high content of polyphenolic compounds, antioxidant activity and attractive physicochemical properties.

Materials and methods

Chemicals

Trolox (6-hydroxy-2,5,7,8-tetramethylchroman-2-carboxylic acid), 2,2'-azinobis-(3-ethylbenzthiazoline-6-sulfonic acid) (ABTS), 2,2'-azobis (2-amidino-propane) dihydrochloride (AAPH), fluorescein disodium (FL), potassium persulfate, acetic acid, TPTZ (2,4,6-tripyridyl-1,3,5-triazine), FeCl₃, phloroglucinol, arabinose, fructose, sorbitol, glucose, sacharose and methanol were purchased from Sigma-Aldrich (Steinheim, Germany). Quercetin and keampferol-3-*O*-glucoside, cyanidin-3-*O*-rutinoside, -3-*O*-glucoside, -3-*O*-sophoroside, peonidin-3-*O*-rutinoside, pelargonidin-3-*O*-glucoside, *p*-coumaric acid, (+)-catechin, and (–)-epicatechin, procyanidin B2 and C1 were purchased from Extrasynthese (Lyon Nord, France). Chlorogenic, neochlorogenic and cryptochlorogenic acids were supplied by TRANS MIT GmbH (Giessen, Germany). Acetonitrile for ultra—phase liquid chromatography (UPLC, gradient grade) and ascorbic acid were from Merck (Darmstadt, Germany). UPLC grade water, prepared by HPLC SMART 1000 s system (Hydrolab, Gdańsk, Poland), was additionally filtrated through a 0.22 µmol membrane filter immediately before use.

Plant material

Fruits of sour cherry (*Prunus cerasus* L.) cv. 'Łutówka', apple (*Malus domestica* Borkh.) cv. 'Champion and pear

fruit (*Pyrus* L.) cv. 'Faworytka' harvested at the Research Station for Cultivar Testing in Zbyszów near Wrocław (Poland). While the quince fruit (*Cydonia oblonga* Mill.) cv. 'Lescovac' and flowering quince (*Chaenomeles japonica* L.) cv. 'Witaminnyj' harvest at the Research Institute of Horticulture in Skierniewice (Poland).

Smoothie production

The production process included 3 main technological stages: (1) juice production; (2) processing of sour cherry fruit into puree; (3) mixing both semi-products in appropriate proportions.

- (1) The apple, pear, quince and flowering quince fruit were ground in a Thermomix appliance (Vorwerk, Wuppertal, Germany), and then the obtained pulps were pressed on a hydraulic press to obtain juices. For pear mash 10% ascorbic acid solution was added in the amount of 10 ml/kg of fruits to prevent enzymatic browning.
- (2) Pitted sour cherries were ground and heated at 80 °C in a Thermomix device (Vorwerk, Wuppertal, Germany) and mashed in a blender (Symbio, Zelmer, Rzeszów, Poland) to obtain puree used to produce smoothies.
- (3) Juice–puree samples were mixed in the proportions 80:20, 50:50 and 20:80, respectively. Then, the products were heated to 100 °C and put into glass jars, pasteurised for 10 min and finally cooled to 20 °C. As a result, seventeen different products were obtained: five semi-products (sour cherry puree (SCP); apple juice (AJ); pear juice (PJ); quince juice (QJ) and flowering quince juice (FQJ)) and twelve smoothies. Each sample was prepared in two replicates. The products were subjected to analyses directly after processing.

Chemical analyses

Titrate acidity (TA) was determined by titration aliquots of homogenate of fresh fruits by 0.1 N NaOH to an end point of pH 8.1 using an automatic pH titration system (pH-metr typ IQ 150; Warsaw, Polska) and expressed as g of malic acid/100 g of products. The soluble solids content (SS) was determined in obtained products with a refractometer (Atago Rx 5000, Atago Co. Ltd., Japan) and expressed as °Brix. Total content of L-ascorbic acid was determined by the PN norm (PN-90/A-75101/11) and expressed as mg/100 g of products. While pectins content was analyzed according to the Moriss method described by Pijanowski et al. (1973) and expressed as g/100 g

products. All determinations were done in triplicate in each replicate.

Determination of sugar content by HPLC coupled to light scattering detector

Obtained products (8–9 g) were mixed with 50 ml of redistilled water, ultrasonicated 15 min, boiled 30 min and after that centrifuged at 20,000g for 10 min. The extracts applied onto the Sep-Pak C-18 (containing 1 g of the carrier, Waters) and eluted by water to give sample solution to estimation of sugar content. A 40 μ L sample was injected by autosampler (L-7200) into a Unison UK-Amino 3 μ L column (3 mm $\times$ 250 mm) (Imtakt, Kyoto, Japan) by liquid chromatograph. Detection was carried out using evaporative light-scattering detector (PL-ELS 1000 Evaporative Light Scattering Detector) with the following input parameters: temperature of the evaporator—80 °C; temperature of the nebulizer—80 °C; nitrogen flow—1.2 SLM. The elution was carried out at 30 °C under a isocratic flow using 85% acetonitrile solution at the flow rate of 0.7 mL/min. Sugar components was identified by comparison with the standards (arabinose, fructose, sorbitol, glucose, sucrose). The calibration curves were prepared by plotting different concentrations ranging from 0.5 to 5 mg/ml ($R^2 \leq 0.9998$) of the standards versus the area measurements in HPLC. All determination were done in triplicate. Results were expressed as grams/100 g product.

Colour measurement

Colour properties (L^* , a^* , b^*) of mixed products were determined using A5 Chroma-Meter (Minolta CR300, Osaka, Japan), referring to colour space CIE $L^*a^*b^*$. The colour coordinates of the samples were determined using Illuminant D65 and 10° observer angle, and the samples were measured against a white ceramic reference plate ($L^* = 93.92$; $a^* = 1.03$; $b^* = 0.52$). The data were mean of three measurements. Total change of colour in analyzed products (ΔE^*) was calculated according to Wojdyło et al. (2014a).

Identification and quantification of polyphenols by LC-PDA-MS method

The solvent for identification (LC/MS QTOF) and quantitative (UPLC-PDA-FL) analysis of polyphenols (anthocyanin, flavan-3-ol, flavonol, phenolic acid and dihydrochalcone) were performed as described previously by Wojdyło et al. (2014b). All measurements were repeated three times. The results were expressed as mg per 100 g of product.

Analysis of polymeric procyanidins by phloroglucinolysis method

An analysis of polymeric procyanidins by phloroglucinol method was performed according to the protocol described previously by Kennedy and Jones (2001). All measurements were repeated three times. The results were expressed as mg per 100 g of product.

Determination of antioxidant activity

A solvent for the analysis of polyphenols was prepared as described previously by Wojdyło et al. (2014b). The ORAC, ABTS and FRAP assays were prepared as previously described by Ou et al. (2002); Re et al. (1999) and Benzie and Strain (1996), respectively. The antioxidant activity was expressed as mmol of Trolox per 100 g dm. ORAC assay was carried out on RF-5301 PC spectrofluorometer (Shimadzu, Kyoto, Japan). Measurements by means of ABTS and FRAP methods involved UV-2401 PC spectrophotometer (Shimadzu, Kyoto, Japan).

Statistical analysis

Statistical analysis was conducted using Statistica version 12.0 (StatSoft, Krakow, Poland). Significant differences ($p \leq 0.05$) between means were evaluated by one-way ANOVA and Duncan's multiple range test. All analyses were performed in triplicate. In addition, to better understand the trends and relationships among 17 different products, Principal Components Analysis (PCA) was carried out using the Statistica 12.0.

Identification and quantification of phenolic compounds in the obtained products

Sour cherry puree

Table 1 shows the data of LC/QTOF–MS analysis. The LC/MS analysis of sour cherry puree (SCP) indicated presence of 16 compounds. These can be classified into four groups of phenolic compounds: anthocyanins, hydroxycinnamic acids, flavonols and flavan-3-ols. The total concentration of these compounds was 572.94 mg/100 g puree (presented in Table 2).

Five compounds belonging to anthocyanins were detected in the SCP. These were: cyanidin-3-*O*-sophoroside ($[M + H]^+$ at $m/z = 611$ and MS/MS fragment at $m/z = 287$); cyanidin-3-*O*-glucosyl-rutinoside with $[M + H]^+$ at $m/z = 757$ and MS/MS fragment at $m/z = 287$; cyanidin-3-*O*-glucoside ($[M + H]^+$ at $m/z = 449$ and MS/MS fragment $m/z = 287$); cyanidin-3-*O*-rutinoside

Table 1 Groups of phenolic compounds identified by LC/MS in the analyzed puree, juices and smoothies

Compounds	R_f (min)	λ_{max} (nm)	MS [M-H] [−] (m/z)	MS/MS [M-H] [−] (m/z) ^b	SCP	AJ	SCP [%] ÷ AJ [%]			PJ	SCP [%] ÷ PJ [%]		
							80 ÷ 20	50 ÷ 50	20 ÷ 80		80 ÷ 20	50 ÷ 50	20 ÷ 80
Anthocyanins													
Cyanidin-3- <i>O</i> -sophoroside	3.428	515	611.162 ^{++a}	287.055	x	nd	x	x	x	nd	x	x	x
Cyanidin-3- <i>O</i> -glucosyl- <i>O</i> -rutinoside	3.583	517	757.219 ⁺	611.162/ 287.055	x	nd	x	x	x	nd	x	x	x
Cyanidin-3- <i>O</i> -glucoside	3.774	516	449.109 ⁺	287.055	x	nd	x	x	nd	nd	x	x	nd
Cyanidin-3- <i>O</i> -rutinoside	3.929	517	595.166 ⁺	287.055	x	nd	x	x	x	nd	x	x	x
Peonidin-3- <i>O</i> -rutinoside	4.513	517	609.183 ⁺	463.785/301.884	x	nd	x	x	nd	nd	x	x	nd
Hydroxycinnamic acids													
Neochlorogenic acid	3.081	323	353.094	191.057	x	nd	x	x	x	x	x	x	x
3- <i>p</i> -coumarylquinic acid	3.619	310	337.091	191.057 /183.087	x	x	x	x	x	nd	x	x	x
Chlorogenic acid	4.135	324	353.094	191.057	x	x	x	x	x	x	x	x	x
4- <i>O</i> -caffeoylquinic acid	5.221	320	353.086	191.057	x	x	x	x	x	x	x	x	x
3,5-dicaffeoylquinic acid	7.650	320	515.140	353.069/ 191.055	x	nd	nd	nd	nd	nd	x	x	x
Flavan-3-ols													
(+)-catechin	3.360	278	289.073		x	nd	x	x	x	x	x	x	x
Procyanidin B1	3.670	278	577.133	289.073	nd	nd	nd	nd	nd	x	nd	nd	x
(−)-epicatechin	4.823	278	289.073		nd	x	x	x	x	x	nd	x	x
Procyanidin B2	6.649	278	577.133	289.073	nd	x	nd	nd	x	x	nd	nd	x
Flavonols													
Quercetin-3- <i>O</i> -rutinoside-glucoside	5.530	337	771.196	301.028	x	nd	x	x	x	nd	x	x	x
Quercetin-3- <i>O</i> -rutinoside	6.494	353	609.148	577.241/ 301.029	x	x	x	x	x	x	x	x	x
Quercetin-3- <i>O</i> -galactoside	6.737	350	463.091	301.036	x	nd	x	nd	nd	nd	x	x	x
Kaempferol-3- <i>O</i> -rutinoside	7.017	352	593.151	285.039	x	x	x	x	x	x	x	x	x
Isorhamnetin-3- <i>O</i> -rutinoside	7.148	352	623.156	315.047	x	nd	x	x	x	nd	x	x	x
Isorhamnetin-3-glucoside-7-rhamnoside	7.303	350	623.156	315.047	nd	nd	nd	nd	nd	nd	nd	nd	nd
Dihydrochalcone													
Phloretin-2'-xylo-glucoside	7.701	280	567.169	273.076	nd	x	nd	x	x	nd	nd	nd	nd
Compounds													
	QJ	SCP [%] ÷ QJ [%]			FQJ	SCP [%] ÷ FQJ [%]				SCP [%] ÷ PJ [%]			
		80 ÷ 20	50 ÷ 50	20 ÷ 80		80 ÷ 20	50 ÷ 50	20 ÷ 80					
Anthocyanins													
Cyanidin-3- <i>O</i> -sophoroside	nd		x	x	x		nd				x		x
Cyanidin-3- <i>O</i> -glucosyl- <i>O</i> -rutinoside	nd		x	x	x		nd				x		x
Cyanidin-3- <i>O</i> -glucoside	nd		x	x	x		nd				x		x
Cyanidin-3- <i>O</i> -rutinoside	nd		x	x	x		nd				x		x
Cyanidin-3- <i>O</i> -rutinoside	nd		x	x	x		nd				x		x

Table 1 continued

Compounds	QJ	SCP [%] ÷ QJ [%]			FQJ	SCP [%] ÷ FQJ [%]		
		80 ÷ 20	50 ÷ 50	20 ÷ 80		80 ÷ 20	50 ÷ 50	20 ÷ 80
Peonidyno-3- <i>O</i> -rutinoside	nd	x	x	x	nd	x	x	x
Hydroxycinnamic acids								
Neochlorogenic acid	x	x	x	x	nd	x	x	x
3- <i>p</i> -coumarylquinc acid	x	x	x	x	x	x	x	x
Chlorogenic acid	x	x	x	x	x	x	x	x
4- <i>O</i> -caffeoylquinc acid	x	x	x	x	x	x	x	x
3,5-dicaffeoylquinc acid	x	x	x	x	x	x	x	x
Flavan-3-ols								
(+)-catechin	x	x	x	x	x	x	x	x
Procyanidin B1	x	nd	x	x	x	x	x	x
(–)-epicatechin	x	nd	nd	x	x	x	x	x
Procyanidin B2	x	nd	nd	x	x	x	x	x
Flavonols								
Quercetin-3- <i>O</i> -rutinoside-glucoside	nd	x	x	nd	nd	x	x	x
Quercetin-3- <i>O</i> -rutinoside	nd	x	x	x	nd	x	x	x
Quercetin-3- <i>O</i> -galactoside	nd	x	x	x	x	x	x	x
Kaempferol-3- <i>O</i> -rutinoside	nd	x	x	x	x	x	x	x
Isorhamnetin-3- <i>O</i> -rutinoside	nd	x	x	x	x	x	x	x
Isorhamnetin-3-glucoside-7-rhamnoside	nd	nd	nd	nd	x	x	x	x
Dihydrochalcone								
Phloretin-2'-xylo-glucoside	nd	nd	nd	nd	nd	nd	nd	nd

SCP sour cherry puree, AJ apple juice, PJ pear juice, QJ quince juice, FQJ flowering quince juice, [M + H] (*m/z*) for anthocyanins were obtained in the positive ion mode. The *m/z* values of the predominant ions are given in bold type

Table 2 Concentrations of anthocyanins, flavan-3-ols, hydroxycinnamic acids, flavons and dihydrochalcone in mg/100 g of puree, juices and smoothies

Compounds	SCP	AJ	SCP [%]–AJ [%]			PJ	SCP [%]–PJ [%]		
			80 ÷ 20	50 ÷ 50	20 ÷ 80		80 ÷ 20	50 ÷ 50	20 ÷ 80
Anthocyanins									
A1	18.65a	nd	14.77c	8.84g	3.65i	nd	13.04e	7.30h	2.86j
A2	92.86a	nd	72.99d	43.15g	27.48i	nd	67.90e	35.70h	14.47l
A3	0.16	nd	0.13a	0.07a	nd	nd	0.10a	0.07a	nd
A4	39.27a	nd	30.85b	17.92d	7.21f	nd	28.28c	14.71e	5.68g
A5	1.96a	nd	1.46b	0.79de	nd	nd	1.10c	0.63e	nd
Total	152.89a	nd	120.21d	70.77g	38.34i	nd	110.41e	58.41h	23.01l
Flavan-3-ols									
C	19.79d	nd	15.69f	12.05g	8.80i	1.25k	19.17d	11.42h	5.36j
PB ₁	nd	nd	nd	nd	nd	4.91f	nd	nd	3.53g
E	nd	19.42c	2.78i	4.95gh	16.63e	12.42f	nd	11.66f	17.46d
PB ₂	nd	4.08 g	nd	nd	2.31h	9.52d	nd	nd	6.27e
PP	147.28h	117.17j	132.21i	109.26k	106.32l	53.89n	116.92j	83.73m	37.69o
DP	4.46c	1.83j	4.11e	4.25d	3.70f	4.54b	4.20d	4.83a	4.75a
Total	167.07h	140.67j	150.68i	126.26l	136.37k	81.99n	136.09k	106.81m	70.31o
Hydroxycinnamic acid									
NCh	34.75d	nd	27.56e	17.08g	10.94h	85.69a	44.01c	59.91b	84.16a
3pc	7.11a	3.29f	5.61c	3.47ef	4.44d	nd	6.05b	1.72g	1.92 g
Ch	97.91e	113.65c	113.65c	98.72e	106.50d	90.38f	76.50i	70.48j	96.42e
4cq	46.92c	2.81m	32.81g	47.09c	28.11h	17.54k	45.70d	45.14d	39.74f
3,5cq	4.13a	nd	nd	nd	nd	nd	2.62e	2.65e	2.44f
Total	190.83c	119.74 l	179.63e	166.36g	149.99j	193.62b	174.89f	179.89e	224.67a
Flavonols									
QRG	10.16a	nd	8.02c	4.59e	1.96fg	nd	8.57b	5.75d	2.18f
QR	27.14a	1.26i	21.71c	13.52e	5.56g	0.44j	23.02b	14.93d	6.63fg
QG	2.97ab	nd	2.50b	nd	nd	nd	2.26c	1.81d	0.86g
KR	7.42a	1.41hi	5.87c	1.78g	1.14i	nd	6.37b	4.33e	1.78g
IR	14.46a	nd	11.35c	3.00h	2.92hi	1.09l	12.43b	6.07f	3.93g
IRR	nd	nd	nd	nd	nd	nd	nd	nd	nd
Total	62.15a	2.67m	49.45c	22.90g	11.58j	1.53n	52.65b	32.90e	15.37h
Dihydrochalcone									
PXG	nd	2.79a	nd	1.41c	2.53b	nd	nd	nd	nd
Total polyphenols	572.94b	265.87p	499.97f	388.70k	338.81m	277.14o	474.04g	378.01l	333.36n

Table 2 continued

Compounds	QJ	SCP [%]–QJ [%]			FQJ	SCP [%]–FQJ [%]			
		80 ÷ 20	50 ÷ 50	20 ÷ 80		80 ÷ 20	50 ÷ 50	20 ÷ 80	
Anthocyanins									
A1	nd	15.58b	9.25f	3.56i	nd	14.50d	3.60i	0.93 k	
A2	nd	75.54b	45.27f	18.64j	nd	73.95c	15.95 k	5.50 m	
A3	nd	0.13a	0.08a	0.02a	nd	0.12a	0.03a	0.01a	
A4	nd	31.12b	18.32d	7.19f	nd	30.92b	6.42f	2.11 h	
A5	nd	1.50b	0.88d	0.33f	nd	1.44b	0.32f	0.10 g	
Total	nd	123.88b	73.80f	29.75j	nd	120.94c	26.31 k	8.64 m	
Flavan-3-ols									
C	26.29b	20.77c	22.38c	30.96a	19.33d	11.00h	14.18f	17.02e	
PB ₁	10.33c	nd	3.71g	7.61e	14.75b	8.25d	8.67d	16.68a	
E	6.22g	nd	nd	4.68h	40.39a	5.46g	17.01d	30.41b	
PB ₂	14.02c	nd	nd	2.27h	38.93a	5.48f	6.40e	17.55b	
PP	232.32d	132.34i	193.40f	201.51e	563.89a	155.28g	253.34c	354.73b	
DP	3.30g	4.68ab	4.32d	4.25d	1.95j	3.41g	2.77 h	2.27i	
Total	289.18d	153.11i	197.11f	247.03e	677.29a	185.47g	299.60c	436.39b	
Hydroxycinnamic acid									
NCh	0.39l	29.16e	19.12f	8.13i	nd	28.32e	7.08j	3.56k	
3pc	1.06h	5.62c	3.72e	3.27f	0.58i	6.22b	1.86 g	1.63g	
Ch	139.81a	82.47g	94.30ef	129.18b	37.64i	79.22 h	30.15j	38.53i	
4cq	2.84m	65.69a	52.85b	21.07i	4.36 l	41.85e	19.18j	4.62l	
3.5cq	1.83h	3.42b	2.82d	1.10i	2.07 g	3.00c	3.07c	0.82j	
Total	145.93k	186.36d	172.82f	162.55 h	44.64o	158.60i	61.34m	49.16n	
Flavonols									
QRG	nd	7.62c	4.72e	2.15f	nd	8.65b	1.91g	0.52h	
QR	nd	20.24c	13.21e	7.32f	nd	23.09b	5.79g	3.30h	
QG	nd	1.99cd	1.43e	0.97f	0.45h	3.10a	0.82g	0.77g	
KR	nd	5.44d	3.52f	1.80g	0.43k	6.10bc	1.62h	0.92j	
IR	nd	10.44d	6.40e	2.88i	2.93i	11.79bc	2.77j	1.27k	
IRR	nd	nd	nd	nd	2.93a	0.76c	1.57b	2.65a	
Total	nd	45.73d	29.28f	12.97i	6.74l	52.74b	14.47h	8.91k	
Dihydrochalcone									
PXG	nd	nd	nd	nd	nd	nd	nd	nd	

Table 2 continued

Compounds	QJ	SCP [%]–QJ [%]	FQJ	SCP [%]–FQJ [%]	
		80 ÷ 20	20 ÷ 80	50 ÷ 50	20 ÷ 80
Total polyphenols	435.11i	509.08e	473.01g	454.65h	728.67a

SCP sour cherry puree, AJ apple juice, PJ pear juice, FQJ quince juice, A1 cyanidin-3-O-sophoroside, A2 cyanidin-3-O-glucosyl-rutinoside, A3 cyanidin-3-O-glucoside, A4 cyanidin-3-O-rutinoside, A5 peonidin-3-O-rutinoside, C (+)-catechin, PB₁ procyanidin B₁, E (–)-epicatechin, PB₂ procyanidin B₂, PP polymeric procyanidins, DP degree of polymerization, NCh neochlorogenic acid, 3pc 3-p-coumaroylquinic acid, Ch chlorogenic acid, 4cq 4-O-caffeoylquinic acid, 3,5cq 3,5-dicaffeoylquinic acid, QRG quercetin-3-O-rutinoside-glucose, QR quercetin-3-O-rutinoside, KR kaempferol-3-O-rutinoside, IRR isorhamnetin-3-O-rutinoside, IRR isorhamnetin-3-O-rutinoside, PXR phloretin-2'-xylo-glucoside

Values are means of two repetitions. Mean values of $n = 2$ followed by different letters are statistically different at $p < 0.05$. nd not detected

with $[M + H]^+$ at $m/z = 595$ and also MS/MS fragment $m/z = 287$; and peonidin-3-O-rutinoside ($[M + H]^+$ at $m/z = 609$). The concentration of anthocyanins was 152.89 mg/100 g SCP. The quantitatively the largest contributions of these compounds were: cyanidin-3-O-glucosyl-rutinoside (61% of total content anthocyanins in SCP) and cyanidin-3-O-rutinoside (26%). Presence of the same compounds in sour cherry products was confirmed by Kirakosyan et al. (2009) and in dried sour cherry by Zorić et al. (2014). Only four anthocyanin compounds were reported in the study by Repajić et al. (2015), but they also reported that the dominant compounds in sour cherry juice are cyanidin-3-O-glucosyl-rutinoside and cyanidin-3-O-rutinoside.

Hydroxycinnamic acids were the next major group of polyphenols identified in SCP—190.83 mg/100 g fresh product (Tables 1 and 2). The LC/MS analysis identified five compounds belonging to this group of polyphenols. The dominant hydroxycinnamic acids of the SCP were three derivatives of caffeoylquinic acid: neochlorogenic acid ($R_t = 3.08$ min, $[M-H]^-$ at $m/z = 353$), chlorogenic acid ($R_t = 4.14$ min, $[M-H]^-$ at $m/z = 353$) and 4-O-caffeoylquinic acid ($R_t = 5.22$ min, $[M-H]^-$ at $m/z = 353$). The concentration of the three main hydroxycinnamic acids in SCP were 97.91 mg (chlorogenic acid), 46.92 mg (4-O-caffeoylquinic acid) and 34.75 mg (neochlorogenic acid) in 100 g of SCP. The same configuration of these compounds was described in different cultivars of sour cherries by Wojdyło et al. (2014b) and in dried sour cherry by Nowicka et al. (2015).

Also three types of flavonol derivatives with a fragment at m/z 301, 285 and 315, characteristic for quercetin, kaempferol and rhamnetin derivatives, respectively, were found in SCP (Table 1). The main flavonols identified in SCP were quercetin-3-O-rutinoside with $[M-H]^-$ at $m/z = 609$ and MS/MS fragment at $m/z = 301$; isorhamnetin-3-O-rutinoside ($[M-H]^-$ at $m/z = 625$ and MS/MS fragment at $m/z = 315$) and quercetin-3-O-rutinoside-glucose with $[M-H]^-$ at $m/z = 771$ and MS/MS fragment at $m/z = 301$. In addition, quercetin-3-O-galactoside and kaempferol-3-O-rutinoside were detected in the SCP. The total content of these compounds was 62.15 mg/100 g product, including almost 50% quercetin-3-O-rutinoside (Table 2). These results were confirmed by Kirakosyan et al. (2009), who determined the presence of kaempferol, quercetin and isorhamnetin in tart cherry products. Also Nowicka and Wojdyło (2015), analysing stability of phenolic compounds in sour cherry puree during storage, identified the same flavonols.

The (+)-catechin, at a concentration of 19.79 mg/100 g of SCP, was identified. In addition polymeric procyanidins were detected in the analysed product. The content of polymeric procyanidins, determined by the phloroglucinol

method, was 147.28 mg/100 g fresh puree. Kołodziejczyk et al. (2013), in their study on sour cherry pomace extract, also suggested that polymeric flavan-3-ols are present in higher concentrations than their monomers.

Table 2 presents the degree of polymerization (DP; number of flavan-3-ol units), which modulates the physicochemical properties of polymeric procyanidins. The DP of the SCP polymeric fraction was 4.5. In different cultivars of sour cherries DP ranged from 2.6 to 6.6 (Wojdyło et al. 2014b), while DP in sour cherry puree analysed by Nowicka and Wojdyło (2015) was 3.4.

Sour cherry–apple smoothies

In apple juice (AJ), which was the base for a mixture of SCP–AJ smoothies, were identified only 8 polyphenol compounds belonging to the hydroxycinnamic acid (3), flavonol (2), flavan-3-ol (2) and dihydrochalcone (1) groups (Table 1). Total content of polyphenols in AJ was 265.87 mg/100 ml juice (Table 2). The study showed that the two main compounds (chlorogenic acid and polymeric procyanidins) determine to the greatest extent the final concentration of polyphenol content in this product. The concentration of chlorogenic acid and polymeric flavan-3-ols was 113.65 mg and 117.17 mg/100 g of juice, which was 43 and 44% of the total content of polyphenols, respectively. Also Francini and Sebastiani (2013) and Wojdyło et al. (2008) showed that the dominant compounds in different cultivars of apple were polymeric procyanidins and chlorogenic acid.

The LC/MS analysis helped identify in AJ one compound belonging to the dihydrochalcone group. It was phloretin-2'-xylo-glucoside ($R_f = 7.701$; $\lambda_{\max} = 280$) with $[M-H]^-$ at $m/z = 567$ and MS/MS fragment at $m/z = 273$. Cuthbertson et al. (2012), Vrhovsek et al. (2004) and Wojdyło et al. (2008) confirmed the presence of phloretin-2'-xylo-glucoside in apple fruit and its products.

Supplementation of AJ by SCP resulted in a change of the polyphenol profile and also an increase of polyphenol content in the tested smoothies. The LC/MS analysis of SCP–AJ smoothies allowed for characterization of anthocyanins in each of them. In the products with 80 and 50% addition of SCP were identified all 5 anthocyanins previously determined in 100% SCP, while in the product with 20% sour cherry were only detected cyanidin-3-*O*-sophoroside, -3-*O*-glucosyl-rutinoside and -3-*O*-rutinoside. The content of these compounds was positively correlated with the concentrations of SCP in tested samples and was 120.21 mg (80% SCP:20% AJ) > 70.77 mg (50% SCP:50% AJ) > 38.34 mg (20% SCP:80% AJ) in 100 g of smoothies. A similar trend was observed in the case of the hydroxycinnamic acids. In the analysed smoothies were determined 4 compounds of this group, previously determined

in SCP: neochlorogenic acid, chlorogenic acid, 3-*p*-coumaroylquinic acid and 4-*O*-caffeoylquinic acid. Depending on the type of smoothie, total hydroxycinnamic acids contents were 179.63 > 166.36 > 149.99 mg in 100 g of smoothie with 80% > 50% > 20% SCP, respectively.

In the obtained smoothies were also identified flavonols, but depending on the contribution of puree both their quantity and quality changed. The smoothie with the smallest content of AJ (20%) was characterized by all five flavonols previously determined in the SCP, while in the other mixed products quercetin-3-*O*-galactoside was not identified.

In apple–sour cherry smoothie were also detected compounds belonging to the flavan-3-ols. (+)-Catechin from SCP and (–)-epicatechin from AJ were detected in all discussed mixed products. Moreover, in the smoothie with 80% AJ, procyanidin B2 was identified. Total content of flavan-3-ols (monomer, dimers and polymeric procyanidins) ranged from 126.68 mg (50% SCP:50% AJ) to 150.68 mg (80% SCP:20% AJ) in 100 g of product.

Generally, all mixed smoothies produced from AJ with SCP were characterized by a higher content of phenolic compounds compared with AJ. It was observed that a larger addition of SCP was connected with a higher concentration of the bioactive compounds: 499.97 mg (80% SCP:20% AJ); 388.70 mg (50% SCP:50% AJ) and 338.81 mg (20% SCP:80% AJ) in 100 g of smoothies. As a consequence, apple–sour cherry smoothies contain from 27 to 88% more polyphenols than AJ. The observed trend is extremely important for determining pro-health properties.

Sour cherry–pear smoothies

The next group of smoothies was based on pear juice (PJ) and SCP mixed in three different proportions (80:20; 50:50 and 20:80). The LC/MS analysis of PJ revealed characterization of 9 compounds. These can be classified into three groups of phenolic compounds—hydroxycinnamic acids (3), flavonols (2) and flavan-3-ols (4)—and their total concentration was 277.14 mg/100 ml juice.

Hydroxycinnamic acids were the dominant group of polyphenols in PJ. In PJ three derivatives of caffeoylquinic acid were identified: neochlorogenic acid, chlorogenic acid and 4-*O*-caffeoylquinic acid. The summary content of these compounds was 193.62 mg/100 ml PJ, which accounted for around 70% of the total content of polyphenols. In addition in the PJ flavan-3-ols were identified: two monomers, two dimers, and polymeric procyanidins. The most abundant flavan-3-ols in 100 ml of PJ were polymeric procyanidins (53.89 mg) > (–)-epicatechin (12.42 mg) > procyanidin B2 (9.52 mg) > procyanidin B1 (4.91 mg) and least (+)-catechin (1.25 mg). In PJ were also identified

flavonols, but their total content was low—1.53 mg/100 ml fresh juice. Also Kolniak-Ostek and Oszmiański (2015) reported the presence of these compounds in different anatomical pear parts.

As in the case of apple smoothies, SCP–PJ smoothies were detected to have anthocyanins, previously identified in SCP. All of these were determined in smoothies with 80 and 50% addition of puree, but 20% SCP:80% PJ smoothie contained three major anthocyanins: cyanidin-3-*O*-sophoroside; -3-*O*-glucosyl-rutinoside and -3-*O*-rutinoside. The highest content of anthocyanins was detected in 80% SCP:20% PJ smoothie (110.41 mg/100 g product > 58.41 mg/100 g 50% SCP:50% PJ), while the lowest was detected in 20% SCP:80% PJ smoothie (23.01 mg/100 g product). The addition of SCP also enriched mixed products with all hydroxycinnamic acids and flavonols previously identified in sour cherry. Their content in analysed smoothies ranged from 174.89 mg/100 g (80% SCP:20% PJ) to 224.67 mg/100 g (20% SCP:80% PJ) in the case of hydroxycinnamic acid. The content of flavonols was from 3.93 mg/100 g smoothie in 80% PJ to 12.43 mg/100 g smoothie in 20% PJ; in comparison with PJ it was from 10 to 80 times more. In turn, the addition of PJ enriched smoothies with flavan-3-ols, especially (-)-epicatechin, but also dimeric procyanidins in the case of 20% SCP:80% PJ smoothie. The total polyphenol content in PJ–SCP smoothies was 474.4 mg/100 g smoothie with 80% SCP > 378.01 mg/100 g smoothie with 50% SCP > 333.36 mg/100 g smoothie with 20% SCP, which was 71, 36 and 20% more compared with PJ.

Sour cherry–quince smoothies

In quince juice (QJ), which was the base for SCP–QJ smoothies, were detected two groups of polyphenols: hydroxycinnamic acids and flavan-3-ols. Among the hydroxycinnamic acids were identified five compounds: neochlorogenic acid ($R_t = 3.08$ min, $[M-H]^-$ at $m/z = 353$), chlorogenic acid ($R_t = 4.14$ min, $[M-H]^-$ at $m/z = 353$), 4-*O*-caffeoylquinic acid ($R_t = 5.22$ min, $[M-H]^-$ at $m/z = 353$), 3-*p*-coumaroylquinic acid ($R_t = 3.62$ min, $[M-H]^-$ at $m/z = 337$), and 2,3-dicaffeoylquinic acid ($R_t = 7.65$ min, $[M-H]^-$ at $m/z = 515$), wherein in the highest concentration was chlorogenic acid (96% total content of hydroxycinnamic acid). Wojdyło et al. (2014c) in their study also detected these compounds in quince juice, but they found neochlorogenic acid to be the dominant component in all quince juices. In addition, in the QJ were determined four flavan-3-ols, the same as in the pear juice, the contents of which were confirmed by Wojdyło et al. (2014c). The total content of flavan-3-ols (monomer, dimers and polymeric procyanidins) in QJ was 289.18 mg/100 ml of juice.

All SCP–QJ smoothies contained anthocyanins, but the composition varied. The highest content of anthocyanins was observed for products with 80% SCP (122.88 mg/100 g smoothie), then with 50% of SCP (73.80 mg/100 g smoothie), and the lowest was observed in 20% SCP:80% QJ mix (29.75 mg/100 g final products). With the increase of the addition of SCP in smoothie, the content of hydroxycinnamic acids and flavonols also increased: from 161.65 mg to 186.36 mg and from 12.97 mg to 45.73 mg/100 g of smoothies, respectively. Another trend was observed with flavan-3-ols content. It was found that the increase of QJ content in the smoothies resulted in a higher concentration of flavan-3-ols, especially polymeric procyanidins. In the product with 80% QJ there was 247.03 mg > 197.11 mg (50% SCP:50% QJ) > 153.11 mg (20% SCP:80% QJ) flavan-3-ols in 100 g of analysed smoothies. Generally the smoothies based on SCP and QJ were characterized by 4% to 17% higher content of polyphenols than QJ. In addition, in the SCP–QJ smoothies there were higher contents of bioactive compounds than in the SCP–AJ and SCP–PJ smoothies.

Sour cherry–flowering quince smoothies

Based on the LC/MS technique, 12 compounds belonging to polyphenols were detected and identified in the flowering quince juice (FQJ). These can be classified into three groups of phenolic compounds – hydroxycinnamic acids (4), flavonols (4) and flavan-3-ols (4) – which accounted for, respectively, 6, 1 and 93% of total content of polyphenols. Teleszko and Wojdyło (2015), studying phenolic compounds and antioxidant potential in selected edible fruit, also found that in flowering quince flavan-3-ols are dominant groups of polyphenols. Among the tested products, the FQJ was characterized by the highest concentrations of phenolic compounds – 728.67 mg/100 g of juice. It was nearly three times more than in AJ and PJ and two times more compared with QJ. Therefore, the smoothies with SCP and FQJ were characterized by a very interesting polyphenol profile, both qualitatively and quantitatively. Tarko et al. (2014) confirmed that the flowering quince is an excellent raw material for processing, with high bioactive potential, which could be used as a flavouring additive, enriching the quality of the final products. In all SCP–FQJ smoothies 20 polyphenol compounds were detected and identified. These can be classified into four groups: anthocyanins (5), hydroxycinnamic acids (5), flavan-3-ols (4) and flavonols (6). Among the flavonols, one more compound was identified, compared with earlier analysed samples. It was isorhamnetin-3-glucoside-7-rhamnoside with $[M-H]^-$ at $m/z = 623$ and MS/MS fragment at $m/z = 315$. The conducted analysis showed that all the SCP–FQJ smoothies contained this

compound. As in the previously analysed smoothies, quantitative concentration of polyphenols was dependent on the proportion of the individual components used during production of the final product. Therefore, the smoothie with the highest content of SCP was characterized by higher content of hydroxycinnamic acids (155.60 mg/100 g smoothie), flavonols (52.74 mg/100 g smoothie) and anthocyanins (120.94 mg/100 g smoothie). In turn, higher content of FQJ resulted in a higher concentration of flavan-3-ols: 436.39 mg (20% SCP:80% FQJ) > > 299.60 mg (50% SCP:50% FQJ) > > 185.47 mg (80% SCP:20% FQJ). Finally, the total content of polyphenols in SCP–FQJ smoothies ranged from 531.00 mg in 20% SCP:80% FQJ to 401.72 mg in 50% SCP:50% FQJ/100 g final product.

The main advantage of mixing different species of fruit is the high final quality of the obtained product. Mixing fruit with different polyphenolic profiles contributes to diversity of the chemical composition, improving the nutritional value and healthy properties of the final products. This was confirmed by Balaswamy et al. (2013), who studied smoothies containing purees and juices of pineapple, banana, grapes, pomegranate, and mango.

Antioxidant activity in obtained smoothies

Antioxidant activity of analysed smoothies was evaluated based on three different methods—the ABTS method, ferric reducing/antioxidant power (FRAP), and oxygen

radical absorbance capacity (ORAC)—and is presented in Table 3. All of them showed the same trends between obtained products. Among the analysed semi-products the highest antioxidant activity was determined in FQJ: 6.41 mmol TE/100 ml by the ABTS method; 2.89 mmol TE/100 ml by the FRAP method; and 7.47 mmol TE/100 ml of juice by the ORAC method. In contrast, the lowest antioxidant activity characterized AJ and PJ, respectively: 0.55 and 0.54 mmol TE (ABTS); 0.33 and 0.17 mmol TE (FRAP), and 0.37 and 0.58 mmol TE (ORAC) in 100 ml of juice. Therefore, the smoothies prepared on the basis of apple and pear juice were characterized by the lowest antioxidant activity. In these products antioxidant activity (ABTS) ranged from 2.83 mmol TE/100 g smoothie (20% SCP:80% PJ) to 3.50 mmol/100 g smoothie with 80% SCP. Smoothies with the highest antioxidant activity were SCP–FQJ. The highest value was determined in 100 g of 50% SCP:50% FQJ (12.67 mmol TE), then in 80% SCP:20% FQJ (9.07 mmol TE), and 20% SCP:80% FQJ (6.87 mmol TE/100 g).

The results suggest that antioxidant activity of the smoothies is related to the presence of total polyphenols (Pearson correlation = 0.448, 0.690, and 0.656 for ABTS, FRAP, and ORAC, respectively). Significant positive correlations were also found between the results of total antioxidant activity and polymeric procyanidins (Pearson correlation = 0.502, 0.620, and 0.784 for ABTS, FRAP, and ORAC, respectively). It was confirmed by other authors, who suggest that not only the total content of

Table 3 Effect of mixing different kinds of fruit juice with sour cherry puree on antioxidant activity (mmol TE/100 g of in final product)

Product composition	Type of product	ABTS	FRAP	ORAC
SCP	Puree	5.71 ± 0.21 ^{d7}	2.82 ± 0.08ab	3.57 ± 0.09b
AJ	Juice	0.55 ± 0.02h	0.33 ± 0.00e	0.37 ± 0.02d
80% SCP ÷ 20% AJ	Smoothie	4.85 ± 0.28e	1.72 ± 0.16c	2.78 ± 0.14bc
50% SCP ÷ 50% AJ		5.71 ± 0.23d	1.80 ± 0.04d	3.14 ± 0.03bc
20% SCP ÷ 80% AJ		4.49 ± 0.22e	0.98 ± 0.04de	1.69 ± 0.15c
PJ	Juice	0.54 ± 0.03h	0.17 ± 0.00e	0.58 ± 0.02d
80% SCP ÷ 20% PJ	Smoothie	3.50 ± 0.45f	0.61 ± 0.38de	3.97 ± 0.07b
50% SCP ÷ 50% PJ		3.43 ± 0.38f	0.37 ± 0.03de	2.31 ± 0.01bc
20% SCP ÷ 80% PJ		2.83 ± 0.13g	0.22 ± 0.02e	1.75 ± 0.02c
QJ	Juice	3.24 ± 0.09fg	0.68 ± 0.01e	1.36 ± 0.04c
80% SCP ÷ 20% QJ	Smoothie	5.04 ± 0.01h	1.93 ± 0.03bc	4.61 ± 0.12b
50% SCP ÷ 50% QJ		4.64 ± 0.16e	1.17 ± 0.04d	2.76 ± 0.04bc
20% SCP ÷ 80% QJ		2.70 ± 0.20e	1.48 ± 0.10d	2.36 ± 0.02bc
FQJ	Juice	6.41 ± 0.05c	2.89 ± 0.02de	7.47 ± 0.05a
80% SCP ÷ 20% FQJ	Smoothie	9.07 ± 0.28b	2.18 ± 0.34bc	5.15 ± 0.04ab
50% SCP ÷ 50% FQJ		12.67 ± 0.92a	3.32 ± 0.91a	8.26 ± 0.48a
20% SCP ÷ 80% FQJ		6.87 ± 0.10c	2.77 ± 0.17de	6.71 ± 0.05ab

SCP sour cherry puree, AJ apple juice, PJ pear juice, QJ quince juice, FQJ flowering quince juice

Mean value (three repetitions) ± SD. Mean values followed by different letters are statistically different at $p < 0.05$

polyphenolic compounds, but primarily the type of phenolic compounds played a very important role in antioxidant activity (Ou et al. 2002; Toydemir et al. 2013; Wojdyło et al. 2014b). In addition, it was observed, that antioxidant activity of 50% SCP:50% FQJ smoothie was higher than those of SCP and FQJ separately. It was probably caused by the synergistic effect of some polyphenols or other compounds (vitamins, minerals, pectins, acids) found in sour cherry and flowering quince fruits. Generally, it is very interesting effect, which requires additional studies.

Vitamin C content

Analysing the vitamin C content, the tested products can be divided into two major groups. The content of vitamin C was very low (<1 mg/100 g of smoothies), and among these were SCP–AJ and SCP–QJ smoothies, including semi-products and SCP. In the second were products with a higher content of vitamin C, including SCP–PJ and SCP–FQJ smoothies. The content of vitamin C in SCP–PJ ranged from 5.39 mg (80% SCP:20% PJ) to 19.41 mg (20% SCP:80% PJ) in 100 g of product. High content of vitamin C in SCP–PJ smoothies was due to the addition of L-ascorbic acid solution to pear fruit while shredding, to prevent enzymatic browning. In turn, flowering quince was a rich source of vitamin C, so in the products with addition of FQJ content of vitamin C ranged from 6.71 to 40.22 mg/100 g of products, depending on the amount of FQJ. Based on the results of the study, a significant correlation was only found between the antioxidant activity measured by the ORAC method and vitamin C content (Pearson correlation = 0.563). In the case of the other methods, ABTS and FRAP, these relationships were 0.242 and 0.303, respectively.

Physicochemical parameters of smoothies

The main physicochemical characteristics of obtained smoothies were evaluated in this study. Differences were found among the analysed mixed fruit products in total titratable acidity, pectins, soluble solids, sugar content and also viscosity and colour parameters (Tables 4, 5).

The highest content of titratable acidity was determined in smoothies with addition of FQJ. The titratable acidity in these products ranged from 2.43% in the smoothies with the lowest addition of FQJ to 3.65% in the case of the 20% SCP:80% FQJ smoothie. In other samples, content of malic acid was at a comparable level, from 0.70 to 1.60, and was positively correlated with the amount of SCP. Both sour cherry and flowering quince were characterized by a high

content of acids (Tarko et al. 2014; Wojdyło et al. 2014b); therefore these two semi-products resulted in final acidity of smoothies.

Interesting results were obtained by analysing the sugar content of the smoothie products. The studies showed that mixing the various fruits can be used to design specific quality values of the final product. For example, the addition of AJ to SCP enriched the final product in sucrose, while the QJ enriched smoothies in arabinose. Generally, the highest sugar content was determined in SCP–AJ and SCP–PJ smoothies (average 10%). In contrast, the lowest content of sugar characterized FQJ products (from 1.40 to 7.03%). The soluble solids value depend on the content of non-volatile organic acids (malic, citric, or tartaric acids), but first of all on the total sugar content. Therefore, the highest content of soluble solids was found in the smoothies with addition of AJ and PJ. In all these products the soluble solids had a sugar content of more than 13°Bx. In turn, the higher contribution of QJ and FQJ resulted in a decrease of the soluble solids value.

One compound which determines the nutritional value of the fruit is pectin. Pectin is one form of soluble fibre responsible for the prevention of obesity, diabetes and cardiovascular disease (Tetens and Alinia 2009). In the analysed products content of pectins ranged from 0.10% (FQJ) to 0.72% (SCP). It was observed that the highest content of SCP, and thereby contribution of solids content, affects the increase of pectins. Thus the smoothies were characterized by a higher content of soluble fibre than juice (semi-products of smoothies).

In this study, was also determined viscosity, which is influenced by the presence of solid particles and their size. Therefore, purees have a higher value of this factor than do juices. The study confirmed this relationship. It has been shown that the SCP was characterized by the highest viscosity: 287.90 mPa·s. Generally, it was possible to discriminate two groups of products. The first of them comprised SCP and smoothies with 80 and 50% contribution of puree. In these smoothies was observed higher viscosity from 120 (50% SCP:50% QJ) to 245 (80% SCP:20% PJ) mPa·s. In the second group were liquid juices and smoothies with 20% addition of SCP. The viscosity in these products ranged from 12 (AJ) to 46 (20% SCP:80% PJ) mPa·s. Another quality parameter, analysed in the resulting products, was colour. The three main determinants of colour: lightness (L^*), redness (a^*), and yellowness (b^*) were tested (Table 5). The studies showed that the colour of the mixed fruit products differed significantly.

The value of L^* ranged from 31.05 (QJ) to 53.58 (PJ). Therefore, the smoothies with addition of PJ were the brightest, while the addition of QJ caused a decrease in the brightness of the smoothies. In the case of the a^* parameter, which is responsible for the red colour of samples, the

Table 4 Chemical composition of analyzed smoothies, juices and puree

Product composition	Type of product	TA	Pectins	Vitamin C	SS	Sugar content					Total
						Arabinose	Fructose	Sorbitol	Glucose	Sucrose	
SCP	Puree	1.88 ± 0.01e ^a	0.72 ± 0.13a	0.58 ± 0.03i	13.75 ± 0.07b	nd	3.06 ± 0.04i	0.91 ± 0.02d	5.27 ± 0.21a	nd	9.24 ± 0.27d
AJ	Juice	0.50 ± 0.01 l	0.15 ± 0.01c	0.59 ± 0.00i	14.10 ± 0.00a	nd	7.74 ± 0.01a	0.00 ± 0.00l	2.87 ± 0.11e	1.37 ± 0.08a	11.98 ± 0.20a
80% SCP ÷ 20% AJ	Smoothie	1.61 ± 0.02f	0.56 ± 0.01ab	0.61 ± 0.01i	13.45 ± 0.07bc	nd	3.80 ± 0.00 g	0.67 ± 0.01fg	4.37 ± 0.04c	nd	8.84 ± 0.05d
50% SCP ÷ 50% AJ	Smoothie	1.23 ± 0.01g	0.53 ± 0.11ab	0.73 ± 0.21i	13.50 ± 0.00bc	nd	5.57 ± 0.00c	0.56 ± 0.03hi	4.38 ± 0.13c	nd	10.51 ± 0.16b
20% SCP ÷ 80% AJ	Smoothie	0.75 ± 0.04i	0.14 ± 0.04c	0.90 ± 0.01i	13.40 ± 0.00bc	nd	6.26 ± 0.11b	0.36 ± 0.00j	3.86 ± 0.00d	0.09 ± 0.00c	10.57 ± 0.11b
PJ	Juice	0.38 ± 0.01l	0.63 ± 0.20a	29.87 ± 1.24c	13.05 ± 0.07d	nd	5.50 ± 0.06c	1.75 ± 0.00a	1.14 ± 0.02h	0.81 ± 0.05b	9.21 ± 0.13d
80% SCP ÷ 20% PJ	Smoothie	1.57 ± 0.06f	0.61 ± 0.10a	5.39 ± 0.09h	13.40 ± 0.00bc	nd	4.11 ± 0.17f	1.09 ± 0.06c	4.62 ± 0.01b	nd	9.82 ± 0.24c
50% SCP ÷ 50% PJ	Smoothie	1.13 ± 0.02h	0.57 ± 0.26ab	18.10 ± 0.08f	13.25 ± 0.07cd	nd	4.88 ± 0.14e	1.50 ± 0.02b	3.83 ± 0.04d	nd	10.21 ± 0.20bc
20% SCP ÷ 80% PJ	Smoothie	0.68 ± 0.00j	0.61 ± 0.16a	19.41 ± 0.04e	13.35 ± 0.07bc	nd	5.14 ± 0.00d	1.46 ± 0.11b	2.59 ± 0.0f	nd	9.19 ± 0.11d
QJ	Juice	0.50 ± 0.01k	0.30 ± 0.11bc	0.76 ± 0.02i	8.80 ± 0.00h	0.07 ± 0.01a	3.86 ± 0.00g	0.61 ± 0.00hi	0.65 ± 0.01i	nd	5.12 ± 0.02h
80% SCP ÷ 20% QJ	Smoothie	1.62 ± 0.01f	0.61 ± 0.11a	0.59 ± 0.01i	12.40 ± 0.00e	nd	3.04 ± 0.12i	0.88 ± 0.02de	4.39 ± 0.01c	nd	8.31 ± 0.15e
50% SCP ÷ 50% QJ	Smoothie	1.21 ± 0.00g	0.55 ± 0.01ab	0.59 ± 0.01i	10.80 ± 0.00f	0.03 ± 0.00b	2.94 ± 0.04i	0.72 ± 0.00fg	2.42 ± 0.00f	nd	6.08 ± 0.04g
20% SCP ÷ 80% QJ	Smoothie	0.79 ± 0.02i	0.27 ± 0.06c	0.58 ± 0.01i	9.50 ± 0.00g	0.06 ± 0.01ab	3.52 ± 0.00h	0.76 ± 0.10ef	2.01 ± 0.00g	nd	6.30 ± 0.11g
FQJ	Juice	3.91 ± 0.01a	0.10 ± 0.03c	48.25 ± 0.95a	7.80 ± 0.00i	nd	0.12 ± 0.00m	0.07 ± 0.00l	0.09 ± 0.02j	nd	0.27 ± 0.02k
80% SCP ÷ 20% FQJ	Smoothie	2.43 ± 0.05d	0.62 ± 0.01a	6.71 ± 0.24g	12.45 ± 0.07e	nd	2.32 ± 0.00j	0.71 ± 0.03fg	3.99 ± 0.06d	nd	7.03 ± 0.09f
50% SCP ÷ 50% FQJ	Smoothie	2.96 ± 0.01c	0.60 ± 0.14a	25.20 ± 0.49d	10.90 ± 0.00f	nd	1.60 ± 0.01k	0.52 ± 0.07i	2.43 ± 0.05f	nd	4.55 ± 0.13i
20% SCP ÷ 80% FQJ	Smoothie	3.65 ± 0.01b	0.16 ± 0.08c	40.22 ± 0.00b	9.40 ± 0.00g	nd	0.42 ± 0.01l	0.21 ± 0.01k	0.78 ± 0.00i	nd	1.40 ± 0.02j

TA titratable acidity [g of malic acid/100 g products], pectins [g/100 g products]; Vitamin C [mg/100 g products]; SS soluble solids [° Brix]; sugar content [g/100 g products]; SCP sour cherry puree, AJ apple juice, PJ pear juice, QJ quince juice, FQJ flowering quince juice

Mean value (three repetitions) ± SD followed by different letters are statistically different at $p < 0.05$

Table 5 Viscosity and colour parameters of analyzed smoothies, juices and puree

Product composition	Type of product	Viscosity	Colour parameters			
			L^*	a^*	b^*	ΔE
SCP	Puree	288 ^a a ^b	32.09de	20.10de	5.79d	—
AJ	Juice	12m	35.78b	0.35g	5.03d	20.11
80% SCP ÷ 20% AJ	Smoothie	228c	32.61de	20.75d	6.03cd	0.87
50% SCP ÷ 50% AJ	Smoothie	156g	32.23de	20.32d	6.58bc	0.83
20% SCP ÷ 80% AJ	Smoothie	24k	35.89b	21.71c	8.17a	4.76
PJ	Juice	16l	53.58a	−3.41i	2.66e	32.00
80% SCP ÷ 20% PJ	Smoothie	245b	32.56de	21.63c	6.49bc	1.75
50% SCP ÷ 50% PJ	Smoothie	168f	33.66cd	22.31b	6.78bc	2.89
20% SCP ÷ 80% PJ	Smoothie	46j	36.22b	22.13b	6.55bc	4.66
QJ	Juice	18l	31.05e	0.66g	2.38e	19.76
80% SCP ÷ 20% QJ	Smoothie	192e	32.33de	20.79d	6.40bc	0.95
50% SCP ÷ 50% QJ	Smoothie	120i	32.66de	19.45e	5.40d	0.95
20% SCP ÷ 80% QJ	Smoothie	26k	32.27de	16.70f	4.86d	3.53
FQJ	Juice	18l	36.78b	−1.46h	4.36d	22.11
80% SCP ÷ 20% FQJ	Smoothie	216d	32.60de	22.22b	6.97b	2.48
50% SCP ÷ 50% FQJ	Smoothie	150h	33.57cd	23.39a	7.51ab	4.00
20% SCP ÷ 80% FQJ	Smoothie	26k	35.00bc	23.67a	8.20a	5.20

Viscosity [mPas], L^* lightness, a^* indicates red for positive value and green for negative value, b indicates yellow for positive value and blue for negative value, SCP sour cherry puree, AJ apple juice, PJ pear juice, QJ quince juice, FQJ flowering quince juice

^a Values are means of three repetitions

^b Mean values followed by different letters are statistically different at $p < 0.05$

greatest decrease was observed in the smoothies supplemented with QJ (from 16.70 to 20.79). In contrast, the most intense red colour was found in the SCP–FQJ smoothies; the value of a^* ranged from 22.22 (80% SCP:20% FQJ) to 23.67 (20% SCP:80% FQJ). This trend was probably due to the very low pH of the FQJ that stabilized the content of polyphenols, especially anthocyanins, by inhibiting their oxidation. A similar effect was observed in new products obtained by osmotic dehydration of sour cherry fruits in FQJ juice (Nowicka et al. 2015).

In general, the studies showed that the physicochemical parameters depend on the amount and type of compounds used for the production of smoothies.

Principal component analysis (PCA)

To better understand the relationship and trends among the smoothies, principal component analysis (PCA) was applied (Fig. 1). When considering the first two dimensions of the biplot (PCA1 and PCA2), bioactive compounds and physicochemical parameters explained 65.35% of the variation. The results obtained from PCA indicated the presence of four main clusters. The first contained smoothies with 50% (16) and 80% (17) addition of FQJ, characterized by the high content of polymeric

procyanidins (PP), titratable acidity (TA) and also high total antioxidant activity measured by ORAC, ABTS and FRAP methods. The second cluster contained QJ (10), FQJ (14) and smoothies with 80% QJ (13). These products were positively correlated with monomer and dimer flavan-3-ols (mF3ol) and vitamin C (Vit C) content. In the third group were AJ (2) and smoothie with 80% (5) addition of AJ and also PJ (6) and its smoothies: 50% SCP:50% PJ (8) and 20% SCP:80% PJ (9). They were characterized by high content of hydroxycinnamic acids (HA), total sugar (TS) and soluble solids (SS), but also were the brightest (L^*). The fourth cluster contained SCP (1), and all the smoothies with 80% contain SCP (3, 7, 11, 15), except for the 50% SCP:50% AJ smoothie (4) and 50% SCP:50% QJ (12). In these products high contents of flavonols (F), anthocyanins (Ant) and pectins (P) were found. In addition, samples in the fourth group were characterized by high viscosity, redness (a^*), yellowness (b^*) and a positive correlation with antioxidant activity.

Figure 1 also presents the directions of changes of quality and quantitative parameters in the tested products. It was observed that all the products with 80% SCP were in the same cluster—number 4. Increasing the content of juices in the final smoothies significantly affected the properties of the products and hence also their spatial position in the space defined by two dimensions of the

Fig. 1 PCA map showing the relationship among the physicochemical profile and smoothies, juices and puree. 1 sour cherry puree (SCP); 2 apple juice (AJ); 3 smoothie (80% SCP ÷ 20% AJ); 4 smoothie (50% SCP ÷ 50% AJ); 5 smoothie (20% SCP ÷ 80% AJ); 6 pear juice (PJ); 7 smoothie (80% SCP ÷ 20% PJ); 8 smoothie (50% SCP ÷ 50% PJ); 9 smoothie (20% SCP ÷ 80% PJ); 10 quince juice (QJ); 11 smoothie (80% SCP ÷ 20% QJ); 12 smoothie (50%

SCP ÷ 50% QJ); 13 smoothie (20% SCP ÷ 80% QJ); 14 flowering quince juice (FQJ); 15 smoothie (80% SCP ÷ 20% FQJ); 16 smoothie (50% SCP ÷ 50% FQJ); 17 smoothie (20% SCP ÷ 80% FQJ); mF3ol–flavan-3-ols (monomeric and dimeric). VitC Vitamin C, PP polymeric procyanidins, HA hydroxycinnamic acids, F flavonols, Ant anthocyanins, TS total sugar, SS soluble solids, P pectins, L* lightness, a* redness, b* yellowness, TA titratable acidity

biplot (PCA1 and PCA2). Thus, it was confirmed that mixing of fruit allows one to obtain smoothies with pre-designed properties.

Conclusion

The study showed that the use of SCP in the production of smoothies affected product attractiveness in terms of physicochemical properties and antioxidant activity. Mixing fruit with each other especially determined the content of bioactive compounds in the final product. The addition of SCP to QJ, AJ, FQJ and PJ enriched smoothies with anthocyanins, hydroxycinnamic acids and flavonols. A particularly interesting polyphenol profile characterized smoothies with flowering quince, where were detected 20 different compounds. In these products were also found the highest content of total polyphenols, and antioxidant activity. Analysing the other sour cherry products with AJ, PJ and QJ demonstrated that increasing the proportion of SCP increased the polyphenol content and activity of final smoothies.

There are not many reports on the effects of mixing different fruit products on the content of bioactive compounds and antioxidant activity in the final product. Despite this, the present study showed that mixing various fruit products could be interesting from a nutritional as well as commercial perspective. A detailed analysis of similar products and their promotion is extremely important to increase the range of food products with high nutritional value.

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