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Sugars, organic acids, phenolic composition and antioxidant activity of sweet cherry (*Prunus avium* L.)

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Abstract

Sugars, organic acids, phenolics and anthocyanins in fruits of 13 sweet cherry cultivars: Badascony, Burlat, Early Van Compact, Fercer, Fernier, Ferprime, Lala Star, Lapins, Noire de Meched, Sylvia, Vesseaux, Vigred (red-coloured) and Ferrador (bi-coloured) were quantified by HPLC. Sweet cherry cultivars of different pomological characteristics and different time of ripening were evaluated sensorily. Cultivars were evaluated for their total phenolic content and antioxidant activity. The sum of sugars (glucose, fructose, sucrose and sorbitol) ranged from 125 to 265 g/kg fresh weight (FW) and the sum of organic acids (malic, citric, shikimic and fumaric) ranged from 3.67 to 8.66 g/kg FW. Total phenolic content ranged from 44.3 to 87.9 mg gallic acid equivalents/100 g FW and antioxidant activity ranged from 8.0 to 17.2 mg ascorbic acid equivalent antioxidant capacity mg/100 g FW. The correlation of antioxidant activity with total phenolics content and content of anthocyanins was cultivar dependent.

Keywords: Sweet cherry; Sugars; Organic acids; Phenols; Anthocyanins; Total phenolic content; Antioxidant activity; Sensory evaluation; Fruit weight

1. Introduction

Sweet cherry is one of the most popular of the temperate fruits. Sweetness and skin colour influence consumer acceptance of cherry cultivars (Crisosto, Crisosto, & Metheney, 2003), as well as fruit weight. Skin colour is the most important indicator of quality and maturity of fresh cherry, and depends on the anthocyanidin content (Esti, Cinquanta, Sinesio, Moneta, & Di Matteo, 2002). In numerous fruit production areas sweet cherries are the first fresh fruits of the season, consumed mainly non-processed.

Sweet cherries have been reported to contain various phenolics and anthocyanins (Gao & Mazza, 1995; Gonçalves et al., 2004a; Kim, Heo, Kim, Yang, & Lee, 2005; Mozetič, Simčič, & Trebše, 2006) which contribute to total antioxidant activity (Gonçalves et al., 2004b; Khanizadeh, Tsao, Rekika, Yang, & DeEll, 2007; Serrano, Guillen, Martinez-Romero, Castillo, & Valero, 2005; Vangdal, Sekse, & Slimestad, 2007; Vursavuş, Kebelek, & Selli, 2006). Gao and Mazza (1995) characterised and quantified anthocyanins and colourless phenolics in seven cultivars and four hybrids. (Gonçalves et al. (2004a, 2004b)) quantified the levels of hydroxycinnamates, anthocyanins, flavonols and flavan-3-ols in four cultivars (Burlat, Saco, Summit and Van). Cultivars Hartland, Hedelfingen, Regina and Black Gold showed different contents of total phenolics and total anthocyanins (Kim et al., 2005). Mozetič et al. (2006) analysed Lambert Compact. Vangdal et al. (2007) measured anthocyanins content, phenolics content and antioxidant activity in nine cultivars. Antioxidant activity and phenolic composition were genotype dependent (Khanizadeh et al., 2007) and influenced by climatic conditions (Gonçalves et al., 2004a).

The objectives of our work were to quantify chemical attributes (the content of sugars, acids, individual phenolics, anthocyanins, total phenolic content and antioxidant activity) of 13 sweet cherry cultivars of different

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pomological characteristics and ripening time, and to find correlations between them. Cultivars of sweet cherry have not been analysed from that point of view until now.

2. Experimental

2.1. Plant material

Fruits of sweet cherry cultivars were collected in 2006 from the six-year-old experimental orchard of Fruit Growing Centre Bilje in Slovenia. Fruits of 12 red-coloured cultivars (Slovene: Vigred, French: Burlat (Bigarreau Burlat), Fercer (Arcina), Fernier, Ferprime (Primulat) and Vesseaux, Italian: Lala Star, Canadian: Early Van Compact, Lapins and Sylvia, Hungarian: Badascony, Iranian: Noire de Meched) and one bi-coloured cultivar (French: Ferrador), grafted on Mazzard, were included in the study. Cherry fruits were picked at commercial maturity on the basis of fruit colour: Ferprime 5 days before Burlat; Vigred 10 days after Burlat; Ferrador 15 days after Burlat; Lapins 17 days after Burlat, Lala Star 19 days after Burlat; Fernier and Vesseaux 20 days after Burlat; Early Van Compact, Fercer and Badascony 21 days after Burlat; Sylvia and Noire de Meched 23 days after Burlat. Average fruit weight was calculated from a 40-fruit sample. Six panellists evaluated cherry sensory characteristics (fruit colour, colour of fruit juice, sweetness/sourness and eating quality). Fruit colour was evaluated on a five-step scale from white to black (1 for white, 2 for light red, 3 for bright red, 4 for dark red, 5 for black), fruit juice colour on a five-step scale from colourless to red–violet (1 for colourless, 2 for light red, 3 for red, 4 for dark red, 5 for dark red–violet), sweetness/sourness ratio on a four-step scale from sour to sweet (1 for sour, 2 for sweet–sour, 3 for sour–sweet and 4 for sweet) and eating quality on a five-step scale from unpleasant to excellent (1 for unpleasant, 2 for bad, 3 for fair, 4 for good, 5 for excellent).

The samples (0.5 kg) were packed in plastic bags, frozen and kept at −20 °C until extraction. Different compounds (sugars, acids, phenols,...) were analysed from the whole edible part of fruit. For each cultivar 3 replicates were carried out ($n = 3$); each replicate included 5 fruits.

2.2. Extraction and determination of sugars and organic acids

Fruit samples were analysed for the content of individual sugars (glucose, fructose, sucrose and sorbitol) and organic acids (malic, citric, shikimic and fumaric). The fruits were stoned and homogenised with a manual blender (Braun). Mashed (10 g) fruit was dissolved with 50 ml of twice distilled water for 30 min at room temperature. The extracted sample was centrifuged at 12,000*g* for 7 min at 10 °C (Eppendorf 5810 R centrifuge, Hamburg, Germany). The supernatant was filtered through a 0.45 μm cellulose ester filter (Macherey-Nagel), transferred into a vial and used for analyses.

Analysis of sugars was performed using a Thermo Separation Products HPLC with refractive index (RI) detector (Thermo Scientific, Waltham, MA). Separation of sugars was carried out using a Rezex RCM-monosaccharide column (300 × 7.8 mm; Phenomenex, Torrance, CA) with the column temperature maintained at 65 °C. The samples were eluted according to the isocratic method described by Šturm, Koron, and Štampar (2003).

Organic acids were analysed with HPLC, using anAminex HPX-87 H column (300 × 7.8 mm; Bio-Rad, USA) and a UV detector set at 210 nm, according to the method described by Šturm et al. (2003).

The sugars and acids in cherry extracts were identified by their retention time characteristics. Concentrations were expressed as g per kg fresh weight (FW), fumaric and shikimic acids as mg per kg FW.

2.3. Extraction and HPLC analysis of phenolic compounds and anthocyanins

Samples were prepared according to the method of Escarpa and Gonzalez (2000): Five grams of sample was extracted with 25 ml methanol containing 1% HCl and 1% 2.6-di-tert-butyl-4-methylphenol (BHT), using an ultrasonic bath. HPLC analysis was performed using a Surveyor HPLC system with a diode array detector (DAD), controlled by CromQuest 4.0 software (Thermo Finnigan, San Jose, CA). The anthocyanins were analysed at 530 nm and the other phenolics at 280 nm. The column used was a Gemini C_{18} (150 × 4.6 mm 3 μm; Phenomenex) operated at 25 °C. The elution solvents were aqueous 0.01 M phosphoric acid (A) and 100% methanol (B). The samples were eluted according to the linear gradient described by Escarpa and Gonzalez (2000). The injection amount was 20 μl and the flow rate was 1 ml/min. The phenolic compounds in cherry extracts were identified by their spectral and retention time characteristics. The quantities of neochlorogenic acid were assessed from peak areas and calculated as equivalents of chlorogenic acid. *p*-Coumaroylquinic acid is a *p*-coumaric acid derivative, so the area of *p*-coumaroylquinic acid was calculated as equivalents of *p*-coumaric acid (Kim et al., 2005). Concentrations were expressed as mg per 100 g fresh weight (FW).

Anthocyanins in cherry extracts were identified by LC/MS (LCQ Deca XP MAX, Thermo Finnigan). The concentrations of the identified anthocyanins cyanidin 3-glucoside, cyanidin 3-rutinoside, pelargonidin 3-rutinoside and peonidin 3-rutinoside were assessed from peak areas and calculated as equivalents of cyanidin 3-glucoside. The content of total anthocyanins was expressed in mg cyanidin 3-glucoside equivalents (CGE)100 g of fresh cherry.

2.4. Determination of total phenolic content

Five grams of sample were extracted with 25 ml methanol, using an ultrasonic bath (Escarpa & Gonzalez, 2000). The total phenolic content (TPC) of the extracts was

assessed using the Folin-Ciocalteau phenol reagent method (Singleton & Rossi, 1965). The total phenolic content was expressed as gallic acid equivalents (GAE) in mg per kg fresh weight (FW) of edible fruit. To 100 μl of the sample extracts (diluted 1:5 (v/v) with methanol) 6 ml of twice distilled water and 500 μl of Folin-Ciocalteau reagent were added; after waiting between 8 s and 8 min at room temperature, 1.5 ml of sodium carbonate (20% w/v) were added. The extracts were mixed and allowed to stand for 30 min at 40 °C before measuring the absorbance at 765 nm. A mixture of water and reagents was used as a blank.

2.5. Determination of antioxidant activity

Samples were prepared as described above (Escarpa & Gonzalez, 2000). The free radical scavenging activity of the extracts was measured using the DPPH (1.1-diphenyl-2-picrylhydrazyl) method of Brand-Williams, Cuvelier, and Berset (1995) with some modifications. A 50 μl methanolic solution of each extract (diluted 1:6) was placed in 96-well microplates, and 200 μl of 0.1 mM methanolic solution of DPPH was added and allowed to react in the dark at room temperature. The decrease in absorbance of DPPH at 520 nm was measured in 5 min intervals until the absorbance stabilised (30 min). All samples were analysed in triplicate. The DPPH radical scavenging activity of extracts was expressed as mg of ascorbic acid equivalents per 100 g of fruit (ascorbic acid equivalent antioxidant capacity, AEAC) after 30 min reaction time. Determination of AEAC values of the samples at various concentrations was made using ascorbic acid standard curves (Leong & Shui, 2002).

2.6. Statistical analysis

Statistical analysis was conducted with the program Statgraphics Plus 4.0 (Statgraphics, Herndon, VA). One-way analysis of variance was used for analysis of the effect of cultivar on the content of sugars, acids, phenolics, etc. Differences between cultivars were estimated with the HSD test ($p < 0.05$). Linear regression was performed between measured variables. Correlations were tested at $p \leqslant 0.05$.

3. Results and discussion

3.1. Fruit weight and sensory attributes

The average fruit weight and sensory attributes of sweet cherry cultivars are shown in Table 1. Fruit colour and fruit size are the most useful parameters for visual liking of sweet cherries (Romano, Cittadini, Pugh, & Schouten, 2006). The highest average fruit weight was measured in Lapins and the lowest in Ferprime which was the earliest cultivar in the study. Our results show a low fruit weight for Sylvia and a high weight for Lapins compared to the results of Dever, MacDonald, Cliff, and Lane (1996). Fruit weight, beside cultivar genotype (Gonçalves et al., 2006) also depends on crop load.

Table 1
The average fruit weight and sensory properties of different cultivars of sweet cherry

	Fruit weight (g)	Colour of fruit	Colour of fruit juice	Sweetness/ sourness ratio	Eating quality
Badascony	7.6	4.0 ± 0.36	3.3 ± 0.21	3.5 ± 0.22	4.3 ± 0.21
Burlat	8.6	4.0 ± 0.26	3.5 ± 0.22	2.5 ± 0.22	4.5 ± 0.22
Early Van Compact	9.5	3.8 ± 0.17	2.7 ± 0.21	3.0 ± 0.36	4.5 ± 0.22
Fercer	8.8	4.4 ± 0.24	2.0 ± 0.00	2.2 ± 0.37	4.8 ± 0.20
Fernier	7.7	4.6 ± 0.24	2.2 ± 0.20	2.4 ± 0.24	4.8 ± 0.20
Ferprime	6.3	3.8 ± 0.17	3.5 ± 0.22	2.5 ± 0.22	4.5 ± 0.22
Ferrador	8.3	1.4 ± 0.24	1.0 ± 0.00	2.2 ± 0.20	4.0 ± 0.32
Lala Star	8.9	4.4 ± 0.24	3.0 ± 0.45	2.4 ± 0.24	4.8 ± 0.20
Lapins	12.5	2.2 ± 0.20	1.4 ± 0.24	3.4 ± 0.24	3.0 ± 0.32
Noire de Meched	9.8	4.8 ± 0.20	3.6 ± 0.24	2.6 ± 0.24	5.0 ± 0.00
Sylvia	8.3	3.8 ± 0.20	2.8 ± 0.20	2.8 ± 0.37	4.4 ± 0.24
Vesseaux	9.2	4.6 ± 0.24	2.8 ± 0.37	2.4 ± 0.24	5.0 ± 0.00
Vigred	8.2	4.2 ± 0.20	3.6 ± 0.24	2.4 ± 0.24	4.6 ± 0.24

Cultivars Badascony, Early Van Compact and Lapins were rated as sour–sweet and other cultivars as sweet–sour. Cultivars were arranged according to the fruit colour from bi-colour, yellow–red (Ferrador), light red (Lapins), bright red (Early Van Compact, Ferprime and Sylvia), dark red (Badascony, Burlat, Vigred and Fercer) and dark red to black (Fernier, Noire de Meched and Vesseaux). Cultivars Fercer, Fernier, Lala Star, Noire de Meched, Vesseaux and Vigred were rated as excellent in eating quality. Fruits of Lapins were rated lowest. Sweetness and flavour intensity are the most useful parameters for flavour/texture liking of sweet cherries (Romano et al., 2006).

3.2. Sugars

Glucose, fructose, sorbitol and sucrose contents of the sweet cherry fruits are shown in Table 2. Generally, glucose was found to have the highest content, followed by fructose, sorbitol and sucrose, confirming the results of Serrano et al. (2005) and Usenik, Štampar, Šturm, and Fajt (2005). Cultivar Early Van Compact had the highest and Sylvia the lowest glucose content. The content of fructose varied from 47.6 g/kg FW (Sylvia) to 102 g/kg FW (Lala Star). The content of sorbitol varied from 4.45 g/kg FW (Ferprime) to 26.7 g/kg FW (Early Van Compact). Cultivar Lala Star had the highest and Sylvia the lowest sucrose content. The highest sum of sugars was found in Lala Star and Early Van Compact and the lowest in Sylvia.

3.3. Organic acids

The results show variations between cultivars (Table 3). Malic, citric, shikimic and fumaric acids were all detected in sweet cherry cultivars. The predominant organic acid

Table 2
Mean sugars content (g/kg FW) ± standard error of different sweet cherry cultivars

	Glucose	Fructose	Sorbitol	Sucrose
Badascony	106.7 ± 7.82 ab	91.2 ± 7.28 abc	21.7 ± 2.05 abc	8.91 ± 0.35 abc
Burlat	68.9 ± 4.46 bcd	57.6 ± 4.05 cde	6.70 ± 0.71 fg	8.57 ± 0.24 abc
Early Van Compact	123 ± 4.02 a	97.1 ± 3.73 ab	26.7 ± 1.11 a	8.96 ± 2.05 abc
Fercer	84.4 ± 5.71 abcd	64.2 ± 5.12 bcde	18.9 ± 1.26 bcd	9.43 ± 0.64 abc
Fernier	105 ± 2.65 ab	92.0 ± 2.62 abc	22.0 ± 0.89 ab	11.8 ± 0.48 ab
Ferprime	62.2 ± 7.11 cd	51.5 ± 5.68 de	4.45 ± 0.63 g	5.82 ± 0.57 cd
Ferrador	99.6 ± 5.09 abcd	88.0 ± 5.40 abc	17.8 ± 0.82 bcde	9.70 ± 0.43 abc
Lala Star	118 ± 4.73 a	101.5 ± 5.14 a	23.3 ± 1.09 ab	12.5 ± 0.28 a
Lapins	93.7 ± 3.13 abcd	79.9 ± 3.40 abcde	14.4 ± 0.27 cde	7.54 ± 0.28 bcd
Noire de Meched	101 ± 16.67 abc	84.4 ± 16.35 abcd	20.2 ± 2.98 abc	9.74 ± 1.47 abc
Sylvia	61.8 ± 6.67 d	47.6 ± 3.89 e	11.0 ± 0.63 efg	3.57 ± 1.48 d
Vesseaux	85.1 ± 9.79 abcd	71.2 ± 9.18 abcde	18.1 ± 1.89 bcde	9.73 ± 0.91 abc
Vigred	74.6 ± 9.51 bcd	61.1 ± 7.81 bcde	12.3 ± 1.47 def	8.11 ± 0.67 abcd

Different letters indicate significantly different values at $p < 0.05$.

Table 3
Mean organic acids content ± standard errors of different sweet cherry cultivars

	Malic acid	Citric acid	Shikimic acid	Fumaric acid
	(g/kg FW)		(mg/kg FW)	
Badascony	4.71 ± 0.31 bcd	0.32 ± 0.01 bc	6.98 ± 0.68	2.96 ± 0.35 bc
Burlat	3.55 ± 0.15 d	0.12 ± 0.02 e	7.21 ± 0.57 e	7.56 ± 1.32 a
Early Van Compact	5.84 ± 0.15 abcd	0.28 ± 0.02 bcd	17.7 ± 0.16 b	2.00 ± 0.16 b
Fercer	8.12 ± 0.97 a	0.54 ± 0.07 a	26.7 ± 1.27 a	6.63 ± 0.44 ab
Fernier	6.56 ± 0.40 abc	0.27 ± 0.03 bcde	10.0 ± 0.41 de	1.38 ± 0.17 b
Ferprime	3.60 ± 0.73 d	0.12 ± 0.01 de	6.56 ± 1.35 e	3.85 ± 2.25 abc
Ferrador	5.27 ± 0.21 bcd	0.32 ± 0.03 bc	7.05 ± 0.60 e	1.33 ± 0.79 b
Lala Star	5.83 ± 0.26 abcd	0.24 ± 0.04 cde	11.40 ± 0.64 cde	2.79 ± 0.13 bc
Lapins	3.53 ± 0.22 d	0.16 ± 0.00 de	8.38 ± 0.20 e	1.68 ± 0.13 b
Noire de Meched	6.61 ± 0.65 ab	0.42 ± 0.05 ab	15.2 ± 1.72 bcd	5.10 ± 0.17 abc
Sylvia	4.00 ± 0.08 cd	0.12 ± 0.00 de	9.46 ± 0.54 e	0.97 ± 0.58 b
Vesseaux	5.38 ± 0.61 bcd	0.11 ± 0.00 e	15.5 ± 1.75 bc	1.94 ± 0.29 b
Vigred	6.48 ± 0.70 abc	0.26 ± 0.04 cde	9.90 ± 1.48 e	2.09 ± 1.28 b

Different letters indicate significantly different values at $p < 0.05$.

in sweet cherry was malic acid, which is in agreement with Serrano et al. (2005). The content differed among cultivars: malic acid 3.53–8.12 g/kg FW, citric acid 0.11–0.54 g/kg FW, shikimic acid 6.56–26.7 mg/kg FW and fumaric acid 0.97–7.56 mg/kg FW. Cultivar Fercer had the highest content of malic, citric and shikimic acid and a high content of fumaric acid. The lowest content of malic acid was measured in Lapins and the lowest content of citric acid in Vesseaux. Similar content of acids for cultivars Burlat, Vigred and Lapins were measured in the study of Šturm and Štampar (1998).

3.4. Phenolic compounds

The content of phenolic compounds detected in sweet cherry fruits is shown in Table 4. Neochlorogenic acid, *p*-coumaroylquinic acid and chlorogenic acid (hydroxycinnamic acids), epicatechin (flavan-3-ol) and rutin (flavonol) were analysed in the study. Generally, the same phenolic compounds were present in each cultivar, but there were differences in relative levels. Neochlorogenic acid was the major hydroxycinnamic acid derivative ranging from 4.74 to 11.9 mg/100 g FW, followed by *p*-coumaroylquinic acid (0.77–7.20 mg/100 g FW) and chlorogenic acid (0.60–2.61 mg/100 g FW). The contents of neochlorogenic acid, *p*-coumaroylquinic acid and chlorogenic acid are similar to those of Kim et al. (2005). Our results for phenolic acids content, are low compared to those of Gonçalves et al. (2004a), but the proportions are similar. Neochlorogenic acid comprised 24–65%, *p*-coumaroylquinic acid 5–31% and chlorogenic acid 3–15% of the phenolics.

Cultivar Early Van Compact was found to have a significantly higher content of neochlorogenic acid, compared to Badascony, Burlat, Fercer, Noire de Meched, and Vigred. Cultivars Early Van Compact, Fernier, Ferrador and Lapins had a significantly lower content of *p*-coumaroylquinic acid, compared to cultivars Burlat, Ferprime, Noire de Meched and Sylvia. Cultivars Fernier, Lala Star, Early Van Compact and Vesseaux had a significantly higher content of chlorogenic acid, compared to cultivars Badascony, Burlat, Fercer, Ferprime, Ferrador, Noire de Meched, Sylvia and Vigred. The highest contents of epicatechin (from 0.43 to 4.51 mg/100 g FW) were found in cultivars with early ripening time (Ferprime, Burlat, Vigred). Gonçalves

Table 4
Phenolics content of different sweet cherry cultivars (mg/100 g FW)

	Neochlorogenic acid	*p*-Coumaroylquinic acid	Chlorogenic acid	Epicatechin	Rutin
Badascony	4.74 ± 0.20 c	4.20 ± 0.13 abcd	1.12 ± 0.04 cd	1.99 ± 0.02 bcde	5.78 ± 0.58 a
Burlat	6.80 ± 1.12 bc	6.41 ± 0.79 ab	1.10 ± 0.26 cd	3.05 ± 0.60 abc	4.54 ± 0.51 ab
Early Van Compact	11.9 ± 1.11 a	1.24 ± 0.08 d	2.26 ± 0.11 ab	1.31 ± 0.06 cde	3.53 ± 0.38 abc
Fercer	5.78 ± 0.39 bc	5.17 ± 0.34 abcd	1.02 ± 0.03 cd	3.01 ± 0.07 abcd	4.47 ± 0.61 abc
Fernier	8.72 ± 0.29 abc	1.23 ± 0.11 d	2.61 ± 0.26 a	0.95 ± 0.04 e	3.79 ± 0.44 abc
Ferprime	8.75 ± 1.57 abc	6.32 ± 2.89 ab	0.60 ± 0.06 d	4.51 ± 0.00 a	2.81 ± 0.34 bc
Ferrador	8.55 ± 0.38 abc	1.29 ± 0.17 d	1.18 ± 0.04 cd	0.83 ± 0.10 e	2.74 ± 0.36 bc
Lala Star	10.6 ± 2.09 ab	1.75 ± 0.07 cd	2.49 ± 0.02 a	1.01 ± 0.16 e	4.37 ± 0.34 abc
Lapins	8.70 ± 0.88 abc	0.77 ± 0.06 d	1.69 ± 0.15 bc	0.43 ± 0.09 e	2.06 ± 0.28 c
Noire de Meched	6.76 ± 1.02 bc	6.10 ± 0.74 abc	0.62 ± 0.13 d	0.75 ± 0.14 e	4.97 ± 0.56 ab
Sylvia	7.31 ± 0.23 abc	7.20 ± 0.36 a	0.77 ± 0.02 d	2.89 ± 0.23 abcd	3.66 ± 0.22 abc
Vesseaux	8.29 ± 0.82 abc	2.11 ± 0.06 bcd	2.32 ± 0.17 ab	1.22 ± 0.07 de	4.03 ± 0.48 abc
Vigred	6.50 ± 0.34 bc	4.96 ± 0.36 abcd	1.07 ± 0.07 cd	3.70 ± 0.41 ab	5.68 ± 0.80 a

Different letters indicate significantly different values at $p < 0.05$.

et al. (2004a) detected from 4 to 11 mg/100 g FW of epicatechin and from 2.8 to 13.7 mg/100 g FW of rutin. The content of rutin (range from 2.06 to 5.78 mg/100 g FW) was similar in cultivars Badascony, Burlat, Noire de Meched and Vigred and significantly higher, compared to cultivars Ferprime, Ferrador and Lapins. Veberič and Štampar (2005) found rutin in a range from 1.0 to 2.6 mg/100 g FW in sweet cherries.

3.5. Total phenolic content

The total phenolic contents (TPC) of 13 sweet cherry cultivars are shown in Table 5. Total phenolics were in a range from 44.3 to 87.9 mg GAE/100 g FW while Kim et al. (2005) measured 110 mg GAE/100 g FW the average total phenolics content of sweet cherry cultivars Hartland, Hedelfingen, Regina and Black Gold. Also Gonçalves et al. (2004a) measured higher values for cultivars Burlat, Saco, Summit and Van (from 92.7 to 264 mg GAE/100 g FW); for cultivar Burlat values were 119 and 141 mg GAE/100 g FW in 2001 and 2002, respectively. In the nine sweet cherry cultivars (Sue, Merton Glory, Sunburst, Chelan, Lapins, Van, Ulster, Kordia and Agila), total phenolics content ranged from 23 to 168 (Vangdal & Slimestad, 2006) and in cultivars Van, Noir de Guben and 0-900 Ziraat from 115 to 147 mg GAE/100 g FW (Vursavuş et al., 2006).

The highest content of TPC was found in Ferprime (87.9 mg GAE/100 g FW), a cultivar with early ripening time; the content was significantly different from Badascony, Lapins and Ferrador. TPC was significantly correlated with the individual phenolic content ($r^2 = 0.54$). Cultivar Ferprime with the highest TPC was found to have the highest sum of the individual phenolic compounds. This trend was true also for cultivar Lapins with the lowest content of TPC.

Table 5
Mean antioxidant capacity AEAC (mg ascorbic acid equivalents/100 g FW) and total phenolic content (TPC) (mg GAE/100 g FW) ± standard errors of different sweet cherry cultivars

	AEAC	TPC
Badascony	15.5 ± 0.09 a	62.2 ± 0.48 bcd
Burlat	17.2 ± 0.30 a	83.8 ± 4.18 ab
Early Van Compact	11.4 ± 2.28 bc	70.9 ± 3.62 abc
Fercer	15.2 ± 0.09 ab	75.6 ± 1.61 ab
Fernier	13.4 ± 0.43 ab	79.6 ± 4.53 ab
Ferprime	14.8 ± 0.44 ab	87.9 ± 9.11 a
Ferrador	16.3 ± 0.37 a	47.4 ± 1.22 cd
Lala Star	7.99 ± 0.38 c	76.2 ± 5.05 ab
Lapins	15.5 ± 0.09 a	44.3 ± 3.42 d
Noire de Meched	13.8 ± 0.44 ab	74.9 ± 7.97 ab
Sylvia	14.9 ± 0.40 ab	76.6 ± 5.13 ab
Vesseaux	14.1 ± 0.47 ab	81.2 ± 3.11 ab
Vigred	14.2 ± 0.24 ab	74.6 ± 4.51 ab

Different letters indicate significantly different values at $p < 0.05$.

3.6. Antioxidant activity

The antioxidant activity, expressed as ascorbic acid equivalent antioxidant capacity (AEAC), is shown in Table 5. AEAC of 13 sweet cherry cultivars was in a range from 8.00 to 17.2 mg ascorbic acid equivalents/100 g FW. The highest AEAC was measured in Burlat and the lowest in Lala Star. Our results were not comparable with other authors because of the method used. The methods used to measure antioxidative capacity vary widely (Vangdal & Slimestad, 2006). One of the methods used is the FRAP assay. In nine sweet cherry cultivars antioxidative capacity (FRAP) ranged from 0.44 to 2.67 mmol/100 g FW (Vangdal & Slimestad, 2006), and from 0.62 to 1.42 mmol/100 g FW for six samples (Halvonsen et al., 2002).

Antioxidant capacity in sweet cherry was higher in cultivars with dark fruits (Vangdal & Slimestad, 2006), which partly agrees with our results. AEAC of bi-coloured Ferrador was very high (16.3 mg ascorbic acid equivalents/100 g FW) but not significantly different from the highest value of cultivar Burlat. Burlat has a very high anthocyanin concentration and the highest antioxidant activity. The lowest values of AEAC were measured in Lala Star, followed by Early Van Compact, both with dark red-coloured fruits.

Our results are in agreement with the results of Vangdal et al. (2007) who reported the highest antioxidant activity of the lighter coloured Victoria plum cultivar.

3.7. Anthocyanins

The anthocyanins identified in sweet cherry cultivars are shown in Table 6. Four anthocyanins were identified; Wu and Prior (2005) found six anthocyanins, Gao and Mazza (1995); Gonçalves et al. (2004a) found five, Mozetič et al. (2006) four anthocyanins, and Kim et al. (2005) found three anthocyanins in sweet cherries.

Variations were found in the anthocyanin composition between cultivars (Table 6). The major anthocyanin was cyanidin 3-rutinoside, which ranged from 1.09 to 14.8 mg CGE/100 g FW, followed by cyanidin 3-glucoside in range from 0.03 to 2.3 mg/100 g FW, pelargonidin-3-rutinoside in range from 1.08 to 0.01 mg CGE/100 g FW and peonidin 3-rutinoside in range from 0.02 to 0.31 mg CGE/100 g FW. The cultivar with the lowest content of anthocyanins was Ferrador, with 0.03 mg of cyanidin 3-glucoside, 1.09 mg CGE of cyanidin 3-rutinoside, 0.01 mg CGE of pelargonidin 3-rutinoside and 0.02 mg CGE of peonidin 3-rutinoside (1.15 mg CGE/100 g of total anthocyanins). The highest content of anthocyanins was measured in Fernier with 16.2 mg CGE/100 g FW. Kim et al. (2005) detected from 25.3 to 77.4 mg CGE/100 g in cultivars Hartland, Hedelfingen, Regina and Black Gold.

The major anthocyanin was cyanidin 3-rutinoside (from 77.0% to 96.2%) followed by cyanidin-3-glucoside (from 1.99% to 19.9%), pelargonidin 3-rutinoside (from 0.49% to 8.09%) and peonidin 3-rutinoside (from 0.92% to 1.88%) (Table 7). The anthocyanins of Lambert Compact cherries comprised 91.4% cyanidin 3-rutinoside, 4.3% cyanidin 3-glucoside, 3.8% peonidin 3-rutinoside and 0.5% pelargonidin 3-rutinoside (Mozetič et al., 2006).

The lowest anthocyanin content was measured in bi-colour Ferrador (Tables 6 and 7) (96.2% of the total anthocyanins was cyanidin 3-rutinoside). The highest proportions of cyanidin 3-glucoside (compared to the total anthocyanins) were found in cultivars which ripen very early (Ferprime and Burlat; 16.8% and 19.9%) and the lowest in Ferrador.

3.8. Relations between measured attributes

The relations between antioxidant capacity and total phenolics content (Table 8) varried between cultivars (r^2 from 0.27 to 0.99), was significant only in Early Van Compact and Fernier. Our results show strong correlations ($r^2 > 0.90$) between antioxidant capacity and total phenolic content only with Early Van Compact, Fernier, Ferprime and Lapins. Weak correlations were found between Noire de Meched and Sylvia, where there was a strong correlation between AEAC and anthocyanin content ($r^2 > 0.80$). There were strong correlations between antioxidant capacity and total phenolic content for sweet cherry (Vangdal & Slimestad, 2006), and blackberry and hybrid berry cultivars (Connor, Finn, & Alspach, 2005).

The relations between antioxidant activity and total anthocyanins content (Table 8) varied between cultivars (r^2 from 0.01 to 0.99), and were only significant in Ferprime. There were strong correlations between antioxidant capacity and anthocyanins content (Vangdal & Slimestad, 2006), but our results confirm this statement only partially (Table 7). Strong correlations ($r^2 > 0.80$) were found in our research with cultivars Burlat, Early van Compact, Fercer, Ferprime, Noire de Meched and Sylvia, but with bi-coloured Ferrador and Lala Star, which has dark fruits, the correlations were very weak. The negative correlation between antioxidant capacity and cyanidin 3-rutinoside levels in the cherry extracts (Gonçalves et al., 2004b) was confirmed with our results.

Highly positive correlations were found between antioxidant activity and both ascorbic acid, total phenolic compounds and also with the anthocyanin concentration (Serrano et al., 2005), but the correlations were made only for one cultivar. The content of ascorbic acid was not analysed in our study but it would be useful to include it in analyses in the future. Gonçalves et al. (2004b) found that

Table 6
Anthocyanin composition and sum of the anthocyanins of different sweet cherry cultivars, presented as mg CGE/100 g ± standard errors

	Cyanidin 3-glucoside	Cyanidin 3-rutinoside	Pelargonidin 3-rutinoside	Peonidin 3-rutinoside	Sum of anthocyanins
Badascony	0.55 ± 0.05 bcde	12.8 ± 0.99 ab	0.21 ± 0.01 de	0.22 ± 0.01 abc	13.8 ± 0.96 a
Burlat	2.30 ± 0.28 a	8.28 ± 2.00 abc	0.25 ± 0.03 de	0.11 ± 0.00 bcde	12.9 ± 2.31 ab
Early Van Compact	0.24 ± 0.02 de	8.06 ± 0.76 bc	0.84 ± 0.11 abc	0.15 ± 0.02 bcd	9.30 ± 0.90 ab
Fercer	0.54 ± 0.05 bcde	8.87 ± 0.14 abc	0.37 ± 0.03 cde	0.17 ± 0.01 bcd	9.95 ± 0.24 ab
Fernier	0.95 ± 0.13 b	14.8 ± 2.07 a	0.23 ± 0.09 de	0.23 ± 0.05 ab	16.2 ± 2.31 a
Ferprime	1.78 ± 0.06 a	7.44 ± 0.72 bcd	0.35 ± 0.03 cde	0.10 ± 0.00 cde	9.66 ± 0.79 ab
Ferrador	0.03 ± 0.01 e	1.09 ± 0.27 d	0.01 ± 0.00 e	0.02 ± 0.00 e	1.15 ± 0.29 c
Lala Star	0.56 ± 0.10 bcde	11.2 ± 0.57 ab	1.08 ± 0.07 a	0.21 ± 0.02 abc	13.0 ± 0.52 a
Lapins	0.10 ± 0.02 e	3.07 ± 0.48 cd	0.31 ± 0.08 de	0.04 ± 0.01 de	3.52 ± 0.58 bc
Noire de Meched	0.62 ± 0.14 bcde	9.38 ± 2.32 abc	0.88 ± 0.29 ab	0.23 ± 0.05 ab	11.1 ± 2.77 ab
Sylvia	0.34 ± 0.04 cde	9.77 ± 0.85 abc	0.36 ± 0.02 cde	0.14 ± 0.01 bcde	10.6 ± 0.91 ab
Vesseaux	0.83 ± 0.07 bcd	13.1 ± 0.67 ab	0.38 ± 0.03 bcde	0.20 ± 0.00 abc	14.5 ± 0.72 a
Vigred	0.91 ± 0.20 bc	13.5 ± 2.16 ab	0.71 ± 0.07 abcd	0.31 ± 0.04 a	15.4 ± 2.46 a

Different letters indicate significantly different values at $p < 0.05$.

Table 7
Anthocyanin composition (% of total anthocyanins), presented as mg CGE/100 g ± standard errors of different sweet cherry cultivars

	Cyanidin 3-glucoside	Cyanidin 3-rutinoside	Pelargonidin 3-rutinoside	Peonidin 3-rutinoside
Badascony	3.62 ± 0.49 b	93.6 ± 0.62 ab	1.37 ± 0.17 cd	1.45 ± 0.04 abc
Burlat	19.9 ± 0.09 a	77.0 ± 2.41 g	2.14 ± 0.16 bcd	1.01 ± 0.18 cd
Early Van Compact	2.34 ± 0.13 b	88.1 ± 0.22 def	8.09 ± 0.36 a	1.49 ± 0.10 abc
Fercer	4.86 ± 0.38 b	90.3 ± 0.63 bcdef	3.28 ± 0.24 bc	1.54 ± 0.05 ab
Fernier	5.26 ± 0.47 b	92.3 ± 0.56 abcd	1.19 ± 0.31 cd	1.24 ± 0.08 bcd
Ferprime	16.8 ± 0.77 a	79.0 ± 1.02 g	3.30 ± 0.37 bc	0.92 ± 0.06 d
Ferrador	1.99 ± 0.35 b	96.2 ± 0.28 a	0.49 ± 0.06 d	1.29 ± 0.12 bcd
Lala Star	3.88 ± 0.66 b	87.2 ± 1.30 ef	7.50 ± 0.81 a	1.46 ± 0.08 abc
Lapins	2.58 ± 0.08 b	88.71 ± 0.73 cdef	7.59 ± 0.70 a	1.12 ± 0.02 bcd
Noire de Meched	5.08 ± 0.24 b	86.2 ± 0.78 f	6.86 ± 0.94 a	1.88 ± 0.15 a
Sylvia	2.83 ± 0.12 b	93.0 ± 0.25 abc	3.03 ± 0.24 bc	1.17 ± 0.05 bcd
Vesseaux	5.04 ± 0.19 b	91.4 ± 0.15 bcde	2.35 ± 0.29 bcd	1.23 ± 0.05 bcd
Vigred	5.19 ± 0.40 b	88.8 ± 0.27 bcdef	4.19 ± 0.31 b	1.79 ± 0.09 a

Different letters indicate significantly different values at $p < 0.05$.

Table 8
Coefficients of correlation (r^2) between antioxidant capacity (AEAC), and total phenolic content and total anthocyanins (sum of anthocyanins) of sweet cherry cultivars

	Total phenolic content	Total anthocyanins
Badascony	0.40	0.34
Burlat	0.77	0.90
Early Van Compact	0.99*	0.99
Fercer	0.39	0.82
Fernier	0.99*	0.42
Ferprime	0.96	0.99*
Ferrador	0.39	0.01
Lala Star	0.82	0.04
Lapins	0.98	0.63
Noire de Meched	0.27	0.88
Sylvia	0.33	0.81
Vesseaux	0.63	0.67
Vigred	0.55	0.33

* Significant at $p < 0.05$.

the antioxidant activity of cherries correlated with *p*-coumaroylquinic acid and also tended to correlate with catechin concentration, which was not analysed in our study.

4. Conclusions

The results of our research show large variability between cultivars in sensory and chemical attributes. Our results suggest that the antioxidant activity of sweet cherries is not related only with phenolics or anthocyanins. Fruits of cultivar Ferrador contained low values of phenolics and anthocyanins but had a very high antioxidant activity. Antioxidant activity depended on different chemical attributes and is specific for cultivar. Antioxidant activity in some cultivars depends on phenolics, in others on anthocyanins and also with some other compounds.

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