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Sensory, Nutritive and Functional Properties of Sweet Cherry as Affected by Cultivar and Ripening Stage

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In this article 11 commercial sweet cherry cultivars were selected to evaluate sensory, nutritive and functional properties over the maturation process on tree. Fruit quality was significantly different among cultivars and maturity stages at harvest, with the highest quality scores being found in the harvest which was 4 days beyond current commercial harvest maturity for all the cultivars tested. Taking into account all of the measured parameters (weight, firmness, color, acidity and total soluble solids), 'NY-6479', 'Prime Giant' and 'Sunburst' could be classified as having the highest quality in terms of sensory attributes. However, 'Cristalina' and 'Sonata' had the highest functional quality, as determined by the measurement of bioactive compound content and antioxidant capacity. We conclude that a delay of a few days in harvesting of sweet cherries would lead to achieve maximal nutritional (highest sugar and organic acid contents), sensory (greatest firmness and color development) and functional (greatest phenolics content, anthocyanins and antioxidant capacity) quality to provide both eating enjoyment and health benefits to the consumer.

Key Words: sweet cherry, ripening, antioxidants, phenolics, quality

INTRODUCTION

Sweet cherry is one of the most appreciated fruits by consumers due to its precocity and excellent quality. Spain is one of the main cherry producers in Europe, with a production of 115,000 ton in 2003, which represents 20% of the total in the European Union (FAO, 2005). The concept of 'quality' depends on the product itself and the consumer's preferences, and for sweet cherry it is widely accepted that the main characteristics related to fruit quality are fruit weight, color, firmness, sweetness, sourness, flavor and aroma (Romano et al., 2006). In sweet cherry, the ripening process is characterized by color changes, from green to red, which can be followed by the evolution of L^*, a^* and b^* parameters and the color indices Chroma and Hue. However, the industry has a standard color chart used for this purpose, the most common being that from the Centre Technique Interprofessionel de Fruits et Légumes (CTIFL, Paris). Red color development in sweet cherry is used as indicator of quality and ripening, and is due to accumulation and profile of anthocyanins (Gao and Mazza, 1995; Mozetič et al., 2004; Serrano et al., 2005a). Sweetness in cherry fruit is mainly due to glucose and fructose, while sourness is primarily due to the presence of malic acid (Serrano et al., 2005a; Usenik et al., 2008). Fruit firmness is also appreciated by consumers, together with green color and freshness of the stems. However, the overall acceptance by consumers seems to be dependent on the ratio between sugar and acid concentrations (Crisosto et al., 2003).

Nowadays, especially in developed countries, fruits and vegetables are appreciated not only by their sensory and nutritional properties, but also by their additional health benefits. In fact, critical and epidemiological studies have established an inverse correlation between the intake of fruit and vegetables and the occurrence of several degenerative diseases, such as cancer, cardiovascular illness and even Alzheimer's disease, due to their content in some bioactive compounds (Kris-Etherton et al., 2002; Scalbert et al., 2005; Schreiner and Huyskens-Keil, 2006). Among these compounds there are vitamins (A, C and E), carotenoids and phenolics,

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including anthocyanins, due to their antioxidant properties (Kaur and Kapoor, 2001; Tomás-Barberán and Espín, 2001).

There are some papers about sensory, nutritive and functional properties of sweet cherry at harvest time, showing important differences among cultivars (Girard and Koop, 1998; Gonçalves et al., 2004; Kim et al., 2005; Usenik et al., 2008). In addition, some parameters related to fruit quality, such as fruit weight, color and anthocyanins, firmness, and sugar and acid content have been also evaluated on different cultivars during fruit development on tree (Crisosto et al., 2002; Mozetič et al., 2004; Usenik et al., 2005; Muskovics et al., 2006). Harvesting is usually performed based on the attainment of acceptable fruit size, color and concentration of soluble solids. However apart from our previous paper, with sweet cherry cultivar '4–70' (Serrano et al., 2005a), there is no available information about the changes in the content of health-promoting compounds during sweet cherry development and ripening on tree. In this sense, the aim of this work was to analyze sensory, nutritive and functional properties during the ripening on tree of 11 sweet cherry cultivars with interest in Spain, the majority of them being studied for the first time. This information could be useful to pick each cultivar with the maximum overall quality, in order to satisfy the demand of consumers for taste, nutrition and health beneficial effects. In addition, results would also serve as a basis for selection of sweet cherry cultivars with both high quality fruits and health beneficial effects, since in the last decades cultivars have been screened mainly on the basis of field growth factors and on a few fruit quality attributes such as size, color, texture and flavor.

MATERIALS AND METHODS

Materials

Plant Material and Experimental Design

The experiment was carried out along the developmental cycle during the 2007 spring period, in a commercial plot located at 'Finca Los Frutales' (Villena, Alicante, Spain). Eleven different sweet cherry cultivars (Table 1) from 10 year old trees on 'Santa Lucía' rootstock were selected. After fruit set, three trees were selected for each cultivar and then 10 fruits were labeled around the equatorial perimeter of each tree. These marked fruits served to evaluate the growth by measuring three linear dimensions of the fruit: polar, suture and cheek diameters. At 3–4 day intervals along the development process, 30 similar fruits to those labeled on tree were taken, and then immediately transferred to laboratory for further analytical determinations. The commercial harvest date (CH) for each cultivar was determined according to the Technician's company and based on size and color using the CTIFL chart. Thus, the scores at CH were 3 for 'Brooks' and 'Somerset', 5 for 'Cristalina' and 'Sonata' and 4 for the remaining cultivars. In addition, some fruits were kept 4 days further on tree to take the last sample (CH + 4 days). Fruit weight, firmness, and color were measured individually in each fruit, and data are the mean ± SE ($n = 30$). When the fruit had an appropriate size (the last six sampling dates) five subsamples of six fruits were made at random, and then the edible portion was cut in small pieces to obtain five homogenous subsamples for each cultivar and sampling date. Five grams were used for total soluble solids and titratable acidity determination and the remaining tissue was immediately frozen in liquid N_2 and milled for total phenolics, anthocyanins and antioxidant activity determination at the last four sampling dates.

Table 1. Dates of full blossom and harvesting and total days from full blossom to reach harvest ripening stage for sweet cherry cultivars in 2007 year.

Cultivar	Date of full blossom	Date of commercial harvesting	Total days
Brooks	23 March	4 June	74
Cristalina	12 April	14 June	63
Newstar	24 March	4 June	73
No. 4 or Santina	8 April	11 June	60
Somerset or no. 52	6 April	11 June	66
No. 57 or 13N 7-19	9 April	14 June	66
NY-6479 or Picota	3 April	14 June	69
Prime Giant	20 March	11 June	83
Sonata	12 April	14 June	63
Sunburst	15 April	14 June	57
Sweetheart	30 March	21 June	79

Methods

Fruit Weight, Firmness and Color

The weight for each fruit was determined using a digital balance (ST-360 Gram Precision) with two significant figures and results were the mean ± SE. Fruit firmness was determined using a TX-XT2i Texture Analyzer (Stable Microsystems, Godalming, UK) interfaced to a personal computer, with a flat steel plate mounted on the machine. For each fruit, the cheek diameter was measured and then a force that achieved a 3% deformation of the fruit diameter was applied. Results were expressed as the ratio between this force and the covered distance (N/mm) and were the mean ± SE. This determination of firmness as the slope of the force-deformation curve has been chosen as the most characteristic parameter for textural changes in cherry fruits (Serrano et al., 2005a; Muskovics et al., 2006). Three color determinations were made on each

fruit at 120° interval along the equatorial perimeter using the Hunter Lab System (L^*, a^*, b^*) in a Minolta colorimeter CR200 model (Minolta Camera Co., Osaka, Japan). In addition, a/b, Chroma index (Chroma $= (a^2 + b^2)^{1/2}$) and Hue angle (Hue $=$ arctan (b/a)) were calculated. Results were the mean ± SE.

Total Soluble Solids and Total Acidity

Total Soluble Solids (TSS) were determined in duplicate from the juice obtained from each subsample with a digital refractometer Atago PR-101 (Atago Co. Ltd., Japan) at 20 °C and results expressed as °Brix. Total acidity (TA) was determined from the above juice by potentiometric titration with 0.1 N NaOH up to pH 8.1, using 1 mL of diluted juice in 25 mL distilled H_2O and results were the mean ± SE expressed as g of malic acid equivalent per 100g fresh weight.

Total Anthocyanins, Total Phenolics and Antioxidant Activity

Total anthocyanins were determined as previously reported (Serrano et al., 2005a). Two grams of fruit tissue were homogenized in 4 mL methanol and left 1 h at −18 °C. Extracts were centrifuged at 10,000 × *g* for 15 min at 4 °C and the supernatant was loaded onto a C18 Sep-Pak® cartridge, previously conditioned with 5 mL methanol, 5 mL pure water and then with 5 mL 0.01 N HCl. Cartridge was washed with 5 mL pure water and then eluted with acidified MeOH (0.01% HCl). Absorbance of the collected fraction was measured at 530 nm and total anthocyanins were calculated using cyanidin-3-glucoside (molar absorption coefficient of 23,900 L/cm · mol and molecular weight of 449.2 g/mol). Results were expressed as mg cyanindin 3-glucoside equivalent per 100g fresh weight, and were the mean ± SE of determinations made in duplicate in each one of the five subsamples.

Total phenolics were extracted according to Tomás-Barberán et al. (2001) using water: methanol (2:8) containing 2 mM NaF (1:5 w/v) and quantified using the Folin-Ciocalteu reagent (Singleton et al., 1999). Briefly, a suitable volume (25–100 µL) of extracts was mixed with 2.5 mL of water-diluted Folin-Ciocalteau. The mixture was incubated for 2 min at room temperature and 2 mL of sodium carbonate (75 g/L) were added and shaken. Finally, mixture was incubated at 50 °C for 15 min and absorbance was measured at 760 nm. A calibration curve was performed with gallic acid and results were expressed as mg gallic acid equivalent per 100g fresh weight. Results were the mean ± SE of determinations made in duplicate in each one of the five subsamples.

For antioxidant activity quantification 1 g of cherry flesh was homogenized with 5 mL of 50 mM Na-phosphate buffer pH 7.5 and 3 mL of ethyl acetate, centrifuged at 10,000 × *g* for 15 min at 4 °C and then the aqueous and organic phases were separated and used to quantify hydrophilic and lipophilic total antioxidant activity (H-TAA and L-TAA), respectively, according to Arnao et al., (2001). The method is based on the capacity of different fruit components to scavenge the $ABTS^{\bullet+}$ radicals (2,2′-azino-bis-(3-ethylbenzothiazoline-6-sulfonic acid) diammonium salt), which have been previously generated by the horse radish peroxidase enzyme (HRP) and its oxidant substrate (hydrogen peroxide). The reaction mixture contained 1.5 mM ABTS, 15 µM hydrogen peroxide and 0.25 µM HRP in a total volume of 2 mL of 50 mM glycine-HCl buffer (pH 4.5), for H-TAA or in ethyl acetate for L-TAA. The assay temperature was 25 °C and the reaction was monitored at 414 nm until a stable absorbance was obtained using a UNICAM Helios α spectrophotometer (Cambridge, UK). After that, a suitable amount of cherry fruit extract was added and the observed decrease in absorbance was determined. A calibration curve was performed with Trolox ((R)-(+)-6-hydroxy-2,5,7,8-tetramethylchroman-2-carboxylic acid), as standard antioxidant for both H-TAA and L-TAA and results are expressed as mg of Trolox equivalent per 100g fresh weight. Results were the mean ± SE of determinations made in duplicate in each one of the five subsamples.

Statistical Analysis

Data for the analytical determinations were subjected to a two-way analysis of variance (ANOVA). Sources of variation were cultivar and developmental sampling dates. LSDs ($p < 0.05$) were calculated for mean separations and are shown in the Figures. Polynomial linear or quadratic regressions were performed between color parameters and anthocyanin concentration, as well as among anthocyanins or phenolics and H-TAA. The regressions were carried out taking into account data for all cultivars and sampling dates. All analyses were performed with SPSS software package v. 12.0 for Windows (2001).

RESULTS AND DISCUSSION

Changes in Sensory and Nutritional Parameters

It is known that environmental factors and orchard management (choice of rootstock, pruning, fertilization and irrigation) affect cherry fruit quality, in terms of different concentration of nutritive and bioactive compounds (Predieri et al., 2004; Gonçalves et al., 2006). However, in this work all cherry cultivars were in the same farm, under similar environmental conditions and cultural practices and even on similar rootstocks and tree age. Then, differences in quality parameters

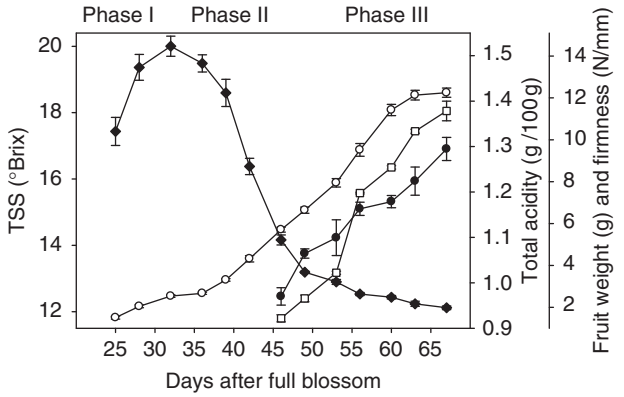

Figure 1. Evolution of fruit weight, firmness, total acidity and TSS content during development and ripening on tree of 'Sonata' cultivar. Data are the mean ± SE ($n = 30$ for firmness and fruit weight; $n = 5$ for acidity and TSS). LSD $_{(P<0.05)} = 0.14$ for fruit weight, 0.21 for total acidity, 0.27 for TSS and 0.28 for firmness. (○) Fruit weight, (□) TSS, (●) Total acidity, (◆) Firmness.

among cultivars that will be commented below should be attributed to genetic characteristics of each cultivar.

Cherry fruit weight increased along development on tree, as it is shown in Figure 1 for 'Sonata' as an example, in which the second and third phases of double sigmoid curve for stone fruit growth can be observed. The final fruit weight and the time from full blossom to harvesting were significantly different depending on cultivar (Tables 1 and 2). Thus, 'Sunburst' had faster development, with only 57 days from full blossom to harvesting, while 'Prime Giant' had the slowest with 83 days. Final fruit weight was also different among cultivars, ranging from 9 g in 'Sweetheart' to 14 g in 'Sunburst' and 'No. 57', although for all cultivars similar values were obtained in CH and CH + 4 days. This means that at CH all cherry fruits had reached their final size (Table 2), which were higher as than the majority of other cultivars studied by others (Usenik et al., 2008). According to morphological properties, Beyer et al. (2002) distinguished five typical shape characteristics of cherries: kidney, flat-round, round, oblong and chordate. In this study, most cultivars had chordate shape ('Santina', 'Somerset', 'No. 57', 'NY-6479', 'Prime Giant' and 'Sunburst'), 3 had round shape ('Newstar', 'Sonata' and 'Sweetheart'), while 'Brooks' and 'Cristalina' had kidney and flat-round shape, respectively.

Texture is one of the most important attributes in sweet cherry and it is often used as quality assessment, although there are considerable genotypic differences, as can be observed in Table 2. In previous reports, it has been found that late cultivars were generally firmer than early ones (Chistesen, 1995; Esti et al., 2002). This was true for 'Sweetheart', which was both the firmest (3.15 ± 0.12 N/mm at CH) and the latest cultivar, while 'Brooks' and 'Newstar' were early-season cultivars and showed an intermediate firmness, and the softest was 'No 57', with 1.85 ± 0.10 N/mm at CH and considered mid-season cultivar (Tables 1 and 2). For all cultivars, fruit firmness reached the highest value at the second phase of fruit growth, which has been associated to pit hardening in sweet cherry (Muskovics et al., 2006). After that, fruit firmness decreased sharply as fruit weight increased, as it is shown in Figure 1 for 'Sonata', which simply reflects cell enlargement during fruit growth. However, softening in the last days of ripening has been attributed to increases in β-galactosidase activity (Gerardi et al., 2001), unlike in most of fruits, in which softening is dependent on pectin depolymerization due to polygalacturonase activity (Batisse et al., 1996).

For all sweet cherry cultivars, TSS and TA started to increase when fruit had around 40–50% of its final size and went on until the last sampling date, as it is shown for 'Sonata' in Figure 1. However, significant differences were found among cultivars and between CH and CH + 4 days for each cultivar (Table 2). At CH the highest TSS content was found in 'Sunburst' (19.90 ± 0.12 °Brix) followed by 'NY-6479' and 'Prime Giant' (≈19.5 °Brix) and the lowest in 'Santina' (15.95 ± 0.15 °Brix). Nevertheless, at CH + 4 days the higher levels were found in 'Sweetheart' and 'NY-6479' (≈21.5 °Brix) while 'Santina' still had the lowest TSS (16.62 ± 0.15 °Brix). The TSS levels found for these cultivars were in agreement with those reported for other sweet cherries harvested at commercial ripening stage, for which values between 11 and 25 °Brix have been reported (Girard and Kopp, 1998; Esti et al., 2002; Serrano et al., 2005a and b). The main sugars found in cherry cultivars have been glucose and fructose, followed by sorbitol and sucrose (Girard and Koop, 1998; Serrano et al., 2005a; Usenik et al., 2008). TA reached the highest levels, close to 1.30 g per 100g at CH + 4 days in 'Newstar', 'NY-6479' and 'Sonata, while 'Brooks' and 'Santina' showed the lowest acidity, ≈0.80 g per 100g (Table 2). In sweet cherry as well as in other *Prunus* species, such as plum, peach, apricot and nectarines, malic acid has been found to be the major organic acid contributing to total acidity, which differed greatly among cultivars (Crisosto, 1994; Girard and Koop, 1998; Zuzunaga et al., 2001). However, in stone fruits apart from cherries, acidity decreased over the development and ripening, while an accumulation was observed for all cherry cultivars, in agreement with the reported increase in total acidity as harvesting date was delayed in 'Lapins' and '4–70' cherries (Drake and Elfving, 2002; Serrano et al., 2005a).

The color indices (Hue angle, Chroma and a/b) of the skin showed similar evolutions for all sweet cherry cultivars which are displayed in the 'Sonata' example in

Table 2. Fruit properties at CH and CH + 4 days.

	Fruit weight		TSS (°Brix)		Total acidity		Firmness	
Cultivar	CH	CH + 4 days	CH	CH + 4 days	CH	CH + 4 days	CH	CH + 4 days
Brooks	11.93 ± 0.42 a A	11.95 ± 0.33 a A	19.05 ± 0.21 a A	20.82 ± 0.19 b A	0.75 ± 0.02 a A	0.84 ± 0.02 b A	2.47 ± 0.08 a A	2.38 ± 0.10 a A
Cristalina	10.55 ± 0.29 a B	10.60 ± 0.44 a B	17.54 ± 0.31 a B	19.37 ± 0.51 b B	0.85 ± 0.03 a B	0.89 ± 0.01 a B	2.26 ± 0.09 a B	2.17 ± 0.04 a B
Newstar	11.75 ± 0.33 a A	11.81 ± 0.44 a A	18.14 ± 0.24 a C	20.72 ± 0.06 b A	1.21 ± 0.02 a C	1.29 ± 0.02 b C	2.24 ± 0.09 a B	2.10 ± 0.04 a B
Santina	10.14 ± 0.33 a B	10.22 ± 0.21 a B	15.95 ± 0.15 a D	16.62 ± 0.15 b C	0.79 ± 0.04 a A	0.81 ± 0.03 a A	2.58 ± 0.09 a A	2.27 ± 0.11 a A
Somerset	10.90 ± 0.20 a B	10.92 ± 0.24 a B	17.84 ± 0.12 a B	19.4 ± 0.11 b B	0.92 ± 0.02 a BD	0.96 ± 0.05 a BD	2.24 ± 0.11 a B	2.11 ± 0.09 a B
No 57	13.91 ± 0.44 a C	13.82 ± 0.32 a C	18.55 ± 0.24 a C	19.70 ± 0.35 b B	0.99 ± 0.02 a D	1.04 ± 0.03 a D	1.85 ± 0.10 a C	1.62 ± 0.09 b C
NY-6479	9.40 ± 0.20 a D	9.42 ± 0.15 a D	19.60 ± 0.06 a E	21.42 ± 0.10 b D	1.25 ± 0.03 a C	1.32 ± 0.02 a C	2.83 ± 0.13 a D	2.60 ± 0.2 a D
Prime Giant	13.36 ± 0.53 a C	13.45 ± 0.55 a C	19.55 ± 0.14 a E	19.90 ± 0.12 b B	1.12 ± 0.01 a E	1.14 ± 0.01 a E	2.42 ± 0.13 a A	2.31 ± 0.09 a A
Sonata	12.13 ± 0.23 a E	12.25 ± 0.22 a E	17.44 ± 0.06 a B	18.05 ± 0.29 b E	1.20 ± 0.03 a C	1.29 ± 0.02 b C	2.17 ± 0.12 a B	1.98 ± 0.09 a B
Sunburst	13.96 ± 0.26 a C	13.99 ± 0.21 C a	19.90 ± 0.12 a E	20.62 ± 0.05 b A	0.92 ± 0.01 a B	0.93 ± 0.02 a B	2.23 ± 0.10 a B	2.08 ± 0.08 b B
Sweetheart	9.02 ± 0.23 a D	9.15 ± 0.21 a D	17.90 ± 0.20 a B	21.77 ± 0.45 b D	1.18 ± 0.03 a CE	1.19 ± 0.05 a CE	3.15 ± 0.12 a E	2.82 ± 0.09 b E

Mean values followed by different small letters within a row are significantly different at $p < 0.05$ level.
Mean values followed by different capital letters within columns are significantly different at $p < 0.05$ level.

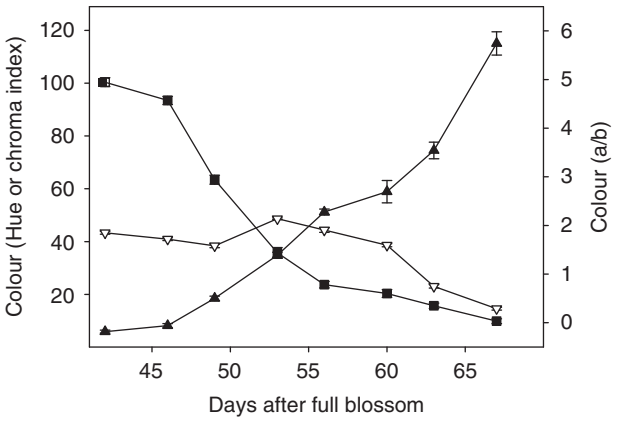

Figure 2. Evolution of color indices (Hue angle, Chroma and a/b) in 'Sonata' sweet cherry along the ripening process on tree. Data are the mean ± SE ($n = 30$). $LSD_{(P<0.05)} = 2.45$ for Hue angle, 1.67 for Chroma and 0.34 for a/b. (■) Hue angle, (▽) Chroma, (▲) Color a/b.

Figure 2. Hue angle decreased sharply between 45 and 55 days from full blossom while the decrease was at much slow rate afterwards. Contrarily, Chroma index increased, reaching a plateau and decreased afterwards during the last days of ripening, which means an increase in the tonality of the fruit color. However, *a*/*b* could be a better index to describe the ripening process in sweet cherry, since it showed a continuous increase until the last sampling date. Significant differences were found among the studied cultivars in the final values of *a*/*b* index, which ranged from 3.07 ± 0.03 in 'Brooks' to 7.23 ± 0.14 in 'Cristalina', which had the highest bright red (score 3 of CITFL chart) and dark red (score 5 of CITFL chart) colors, respectively (Figure 3). The results about parameters related to fruit ripening, such as soluble solids and total acidity accumulation, decrease in firmness and skin color changes, showed that some ripening processes in sweet cherry started to change at an early stage during development of phase III.

Evolution on Functional Properties

Total anthocyanins were determined at the four last sampling dates in all cultivars, since it has been shown that the main anthocyanins accumulation occurred in the last two weeks of cherry development (Mozetič et al., 2004). Anthocyanin concentration increased sharply in all cultivars, reaching final concentration between 39.55 ± 2.58 and 224.65 ± 5.57 mg cyanidin-3-glucoside per 100g for 'Brooks' and 'Cristalina', respectively (Figure 4). Taking into account the data obtained at CH, the lowest anthocyanin concentration was found for 'Brooks', 'Somerset', 'Prime Giant' and 'Sweetheart' which are considered as light-colored cultivars, with a 3 score of the CTIFL color chart.

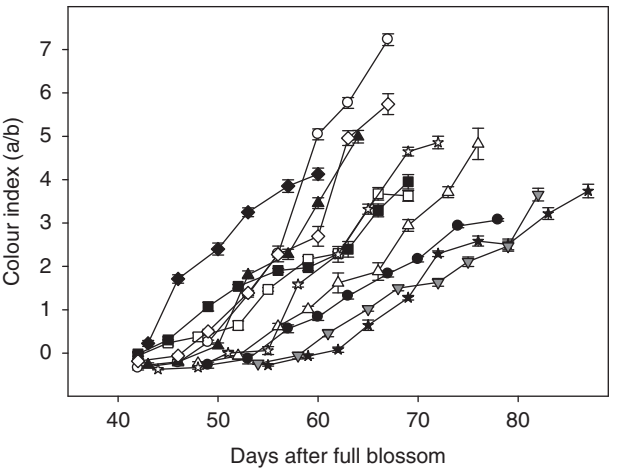

Figure 3. Evolution of color index (a/b) in the different sweet cherry cultivars along the ripening process on tree. Data are the mean ± SE ($n = 30$). $LSD_{(P<0.05)} = 0.31$. (●) Brooks, (○) Cristalina, (△) Newstar, (▲) Santina, (□) Somerset, (■) No 57, (☆) NY-6479, (★) Prime Giant, (◇) Sonata, (◆) Sunburst, (▼) Sweetheart.

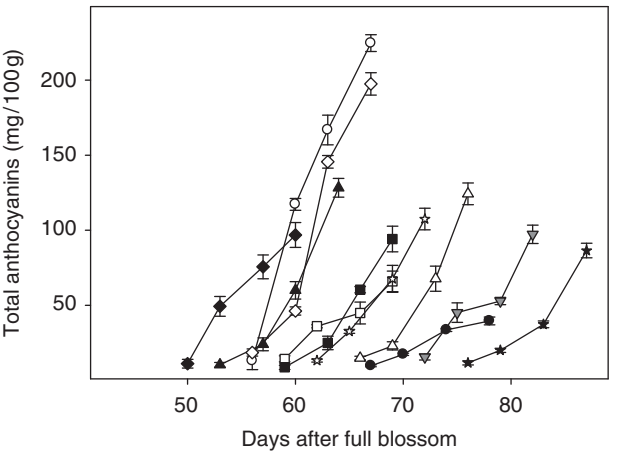

Figure 4. Evolution of total anthocyanin concentration (mg cyanidin 3-glucoside equivalent per 100g) in the different sweet cherry cultivars along the ripening process on tree. Data are the mean ± SE ($n = 5$). $LSD_{(P<0.05)} = 8.95$. (●) Brooks, (○) Cristalina, (△) Newstar, (▲) Santina, (□) Somerset, (■)No. 57, (☆) NY-6479, (★) Prime Giant, (◇) Sonata, (◆) Sunburst, (▼) Sweetheart.

'Cristalina' and 'Sonata' had the highest anthocyanin content and were dark-colored (5 score of the CTIFL color chart), while the remaining had intermediate anthocyanin concentration and a value of 4 (medium-colored cultivars). The predominant anthocyanins in cherry are cyanidin-3-rutinoside and

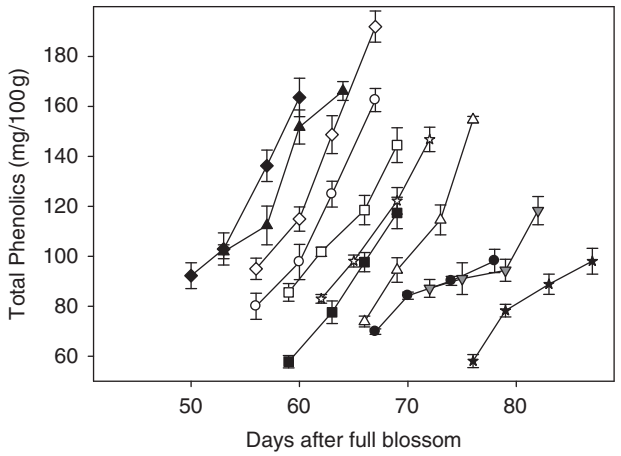

Figure 5. Evolution of total phenolic concentration (mg gallic acid equivalent per 100g) in the different sweet cherry cultivars along the ripening process on tree. Data are the mean ± SE ($n = 5$). $LSD_{(P<0.05)} = 7.42$. (●) Brooks, (○) Cristalina, (△) Newstar, (▲) Santina, (□) Somerset, (■) No. 57, (☆) NY-6479, (★) Prime Giant, (◇) Sonata, (◆) Sunburst, (▼) Sweetheart.

cyanidin-3-glucoside, while peonidin- and pelargonidin-(3-glucoside and 3-rutinoside) have been found at very low concentrations (Gonçalves et al., 2004; Mozetič et al., 2004; 2006; Chaovanalikit and Wrolstad, 2004; Usenik et al., 2008).

When linear regression was performed between anthocyanin concentration and color index a/b taking into account data from all cultivars and sampling dates, a positive linear correlation was found ($r^2 = 0.899$) and this could be considered as an easy and reliable index for anthocyanin concentration in cherries, in general. In addition, the measurement of this color index could be a good tool to predict the levels of anthocyanins in sweet cherry cultivars.

Total phenolics increased in a similar way with anthocyanins. A sharp increase during the last sampling dates was observed, with significant differences among cultivars (Figure 5). The highest phenolic concentration at the last sampling date was found in 'Sonata' (191.90 ± 6.23 mg gallic acid equivalent per 100g) and the lowest in 'Brooks' (98.14 ± 4.64 mg/100 g). These levels of total phenolics were within the same concentration range to those found in other cherry cultivars at commercial harvesting, in which concentration from 90 to 200 mg/100 g have been reported (Mozetič et al., 2002; Kim et al., 2005). The major polyphenols in sweet cherry are anthocyanins followed by the hydroxycinnamic acid's derivatives neochlorogenic acid and 3′-*p*-coumaroylquinic acid (Mozetič et al., 2002, Chaovanalikit and Wrolstad, 2004). Since phenolic compounds contribute to fruit quality in terms of modifying color, taste, aroma and flavor (Tomás-Baberán and Espín, 2001), those cultivars with higher phenolics content will have higher quality. In addition, taking into account data from all cultivars and the last four harvest dates, a highly positive correlation was found between total anthocyanins and total phenolics concentration using a polynomial quadratic equation ($r^2 = 0.813$). Thus, it could be concluded that in these sweet cherry cultivars, anthocyanins are the major phenolics, according to previous reports in other cultivars (Gao and Mazza, 1995; Chaovanalikit and Wrolstad, 2004).

TAA was quantified in hydrophilic (H-TAA) and lipophilic (L-TAA) extracts separately. It could be observed that both H-TAA and L-TAA increased along the ripening process for all sweet cherries. For all of them, H-TAA was higher than L-TAA (ca. 80% of TAA in 'Cristalina' and ≈50% in 'Prime Giant'), showing that the major contributors to antioxidant activity are hydrophilic compounds (Figure 6). Nevertheless, important differences were found among cultivars. Thus, at the last sampling date, the highest levels of H-TAA were found in 'Sonata' and 'Cristalina' (≈130 mg/100 g) and the lowest in 'Brooks' (69.67 ± 2.50 mg/100 g), while for L-TAA 'Sonata' showed the highest level (74.66 ± 2.68 mg/100 g) and the lowest (≈35 mg/100 g) were found in 'Brooks', 'Santina', 'Cristalina' and 'NY-6479'. However, no correlations were found between H-TAA and L-TAA in these cherry cultivars. This is the first time that antioxidant activity in both hydrophilic and lipophilic extracts has been measured during sweet cherry fruit ripening on tree and no literature is available for comparative purposes. The only reports in which L-TAA and H-TAA have been quantified separately are those of Wu et al. (2004), in a wide range of fruits and vegetables at CH (including 4 cherry cultivars although no names or maturity stages were reported), and Arnao et al. (2001), in vegetable soups, showing that H-TAA contributed about 70–90% of the total antioxidant activity.

A high positive correlation was obtained between H-TAA and both, phenolic and anthocyanin concentrations ($y = 1.33\,x - 9.83$; $r^2 = 0.841$ and $y = 0.41\,x + 45.7$; $r^2 = 0.753$, respectively) taking into account data for all cultivars and the four last sampling dates. Thus, in sweet cherry the main contributors to H-TAA are phenolic compounds and especially anthocyanins. The correlation between antioxidant activity and phenolic compounds has been also found in several studies comparing a wide range of fruits and vegetables (Wang et al., 1996; Kaur and Kapoor, 2001; Wu et al., 2004). Specifically, in sweet cherry cultivars, it has also been found that there is a good correlation between total phenolics and TAA (Serrano et al., 2005a; Usenik et al., 2008), although they were determined only in hydrophilic extracts. This indicates that when sweet cherry is developing the intensity of red color, the anthocyanins and other phenolic compounds could also account for

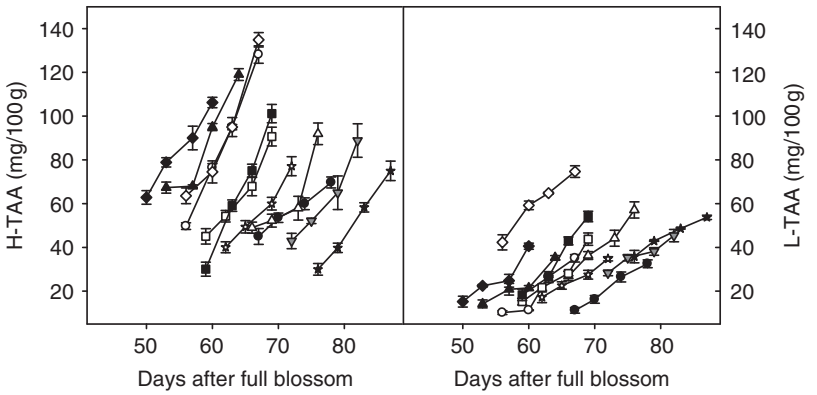

Figure 6. Hydrophilic (H-TAA) and lipophilic (L-TAA) total antioxidant activity (mg Trolox equivalent per 100g) evolution in the different sweet cherry cultivars along the ripening process on tree. Data are the mean ± SE ($n = 5$). $LSD_{(P<0.05)} = 6.94$ for H-TAA and 4.15 for L-TAA. (●) Brooks, (○) Cristalina, (△) Newstar, (▲) Santina, (□) Somerset, (■)No. 57, (☆) NY-6479, (★) Prime Giant, (◇) Sonata, (◆) Sunburst, (▼) Sweetheart.

their antioxidant activity and health beneficial effects (Scalbert et al., 2005).

It has been shown that sour and sweet cherry anthocyanins have the potential to directly interfere with intestinal tumor development (Kang et al., 2003), a strong antidegenerative activity in neuronal cells (Kim et al., 2005) and a beneficial role in the treatment of inflammatory pain (Tall et al., 2004). Thus, cherry can serve as a good source of biofunctional phytochemicals in our diet, providing health beneficial effects in humans. Moreover, ascorbic acid is a hydrophilic compound with antioxidant activity which could also account for H-TAA, as has been shown in sweet cherry '4–70' (Serrano et al., 2005a) and in other fruits, such as oranges (Pretel et al., 2004).

CONCLUSIONS

Results show that there are significant differences among sweet cherry cultivars in quality parameters related to sensory, nutritive and functional properties, and between ripening stages. Taking into account data from fruit weight, color, firmness, acidity and TSS (sensory and nutritive parameters), the cultivars more appreciated could be 'NY-6479', 'Prime Giant' and 'Sunburst'. However, 'Cristalina' and 'Sonata' exhibited the highest values of total anthocyanins and total phenolic compounds that seemed to be the main responsible for antioxidant activity properties. Finally, it is interesting to point out that for all cultivars a delay in harvesting (CH + 4 days) led to significant increases in functional compounds and antioxidant activity. In future, it would be necessary to determine the best conditions in handling, storage and commercialization to ensure that the overall cherry quality does not decrease until they reach the consumer.

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