JOURNAL OF AGRICULTURAL AND FOOD CHEMISTRY

Influence of Cultivar on Quality Parameters and Chemical Composition of Strawberry Fruits Grown in Brazil

BEATRIZ ROSANA CORDENUNSI, JOÃO ROBERTO OLIVEIRA DO NASCIMENTO, MARIA INÉS GENOVESE, AND FRANCO MARIA LAJOLO*

Laboratório de Química, Bioquímica e Biologia Molecular de Alimentos, Departamento de Alimentos e Nutrição Experimental, FCF, Universidade de São Paulo, Av. Prof. Lineu Prestes 580, Bloco 14, 05508-900 São Paulo, SP, Brazil

Six strawberry cultivars grown on the same commercial plantation in Brazil were evaluated for their chemical composition and quality attributes at the ripe stage. The profiles of the main soluble sugars, ascorbic acid, and anthocyanins were also obtained during the developmental stages. Results showed significant differences among cultivars in all of the investigated parameters. Cv. Campineiro showed an average value for texture of 0.63 N, half the value found for cv. Oso Grande. Anthocyanin content ranged from 13 (cv. Campineiro) to 55 (cv. Mazi) mg/100 g. Total ascorbic acid found for cv. Campineiro (85 mg/100 g) was twice the amount found in cv. Dover (40 mg/100 g). Fructose was the predominant soluble sugar in almost all cultivars. The proportion among the main soluble sugars (fructose, sucrose, and glucose) was similar for Oso Grande and Toyonoka cultivars. The flavonol content (quercetin plus kaempferol derivatives) ranged from 2.7 to 7.1 mg/100 g, with a mean value of 6.1 mg/100 g, whereas free ellagic acid ranged from 0.9 to 1.9 and total phenolics varied from 159 to 289 (mean 221) mg/100 g.

KEYWORDS: Strawberries; anthocyanins; soluble sugars; antioxidants; vitamin C; flavonoids

INTRODUCTION

Strawberry is a nonclimacteric fruit that usually takes ∼30 days to achieve full size and maturity. This time is highly dependent on light, temperature, soil composition, and other conditions of cultivation (*1*). Besides its attractive color and taste, strawberry is also a good source of carbohydrates, vitamin C, and other antioxidant compounds, such as phenolics and flavonoids (*2*).

Sugars are the main soluble components in ripe strawberry fruit, with glucose, fructose, and sucrose accounting for almost 99% of total sugar content. Glucose and fructose are predominant over sucrose, and the total sugar content can change during the growing period; however, the proportion of each sugar remains constant, even for different growing conditions and cultivars (*3*, *4*). Like sugars, organic acids are important for flavor, and the sugar/acid ratio is calculated to determine the optimum time for strawberry harvesting, because it is considered an index of quality (*5*).

Vitamin C is one of the most important free radical scavengers in plants, animals, and humans (*6*). It is defined as all compounds exhibiting the biological activity of L-ascorbic acid (AA), such as L-dehydroascorbic acid (DHA), usually present in <10% of the total pool of vitamin C (*7*, *8*). The content of vitamin C in fruits and vegetables depends on various factors such as genotypic differences, preharvest climactic conditions, and postharvest handling procedures (*9*).

Flavonoids are widely distributed bioactive compounds found in plant foods and can be grouped in several structural classes including anthocyanins, flavones, flavan-3-ols, flavanones, flavonols, and tannins. Besides being closely associated with the sensory attributes of fruits, flavonoids and phenolic acids have received increased attention due to their potential antioxidant activities, which may also exert cardioprotective effects in humans. Strawberries were recently reported as having the highest antioxidant activity among 12 fruits analyzed, and the contribution of vitamin C to the total antioxidant activity was estimated as being <15% (*10*).

Häkkinen et al. (*11*) reported a total flavonol content of 12−15 mg/kg of fresh weight (FW) in two strawberry varieties, Senga Sengana and Jonsok, represented by quercetin and kaempferol. For six varieties cultivated in Finland, total flavonol content ranged from 5 to 14 mg/kg of FW and ellagic acid content from 396 to 586 mg/kg of FW. Cultivation technique showed no effect on phenolic levels (*12*).

The amount of anthocyanins is important for the maturity evaluation of strawberries. The index of maturity used for harvesting is the red color resulting from anthocyanin synthesis corresponding to half or three-fourths of the fruit (*13*). The main anthocyanin found in strawberries is pelargonidin 3-glucoside, with cyanidin 3-glucoside and pelargonidin 3-rutinoside present as minor components (*14*).

* Corresponding author (fax + 55-11-38154410; e-mail fmlajolo@usp.br).

10.1021/jf011421i CCC: $22.00
Published on Web 03/20/2002

Table 1. Physical Characterization of Six Strawberry Cultivars (Mean ± SD of *n* Assays) Harvested at the Ripe Stage

physical characteristic	cultivar					
	Mazi	Oso Grande	Dover	Pajaro	Toyonoka	Campineiro
length (cm)	3.8 ± 0.5	4.4 ± 0.6	4.3 ± 0.6	3.4 ± 0.5	3.4 ± 0.6	3.3 ± 0.5
wide (cm)	3.4 ± 0.3	2.9 ± 0.4	2.9 ± 0.2	2.5 ± 0.4	2.6 ± 0.4	2.9 ± 0.4
weight (g)	14.9 ± 3.5	22.5 ± 7.5	12.6 ± 3.6	11.0 ± 2.1	14.7 ± 4.9	9.5 ± 3.7
texture (N) (n = 10)	0.98 ± 0.2	1.2 ± 0.3	0.85 ± 0.1	ND	0.96 ± 0.2	0.63 ± 0.2
n	58	70	74	38	48	90

In this study, six of the most important cultivars produced in Brazil, produced at the same time on the same commercial plantation, were compared in terms of their physicochemical characteristics. The profiles of the main soluble sugars, ascorbic acid, and anthocyanins were also obtained during fruit development of the six strawberry cultivars.

MATERIALS AND METHODS

Material. Strawberry fruit (*Fragaria ananassa* Duch.) of the cultivars Toyonoka, Pajaro, Mazi, Dover, Campineiro (Brazilian cultivars), and Oso Grande were harvested on the same commercial plantation located in Atibaia (São Paulo State, Brazil). Fruits were classified in five stages: small green (stage 1); medium size green (stage 2); full size green (stage 3); full size white turning red (stage 4); and full size three-fourths red (stage 5). At least 40 fruits in each stage were picked, weighed, and measured in length and diameter. Samples were made into pieces, immediately frozen in liquid nitrogen, and stored at −80 °C. At the time of analysis, samples were thoroughly homogenized by powdering in liquid nitrogen.

Anthocyanin Content. Strawberry samples (2 g of FW) were ground with 20 mL of methanol containing 1% HCl, using a Brinkmann homogenizer (Polytron; Kinematica GmbH, Kriens-Luzern, Sweden), and centrifuged at 2000*g* for 15 min (4 °C). Anthocyanin content was estimated as pelargonidin 3-glucoside at 510 nm, using a molar absorptivity coefficient of 36000 and expressed as milligrams per 100 g of FW.

Carbohydrate Analysis. Soluble sugars were extracted successively with three portions of boiling 80% (v/v) aqueous ethanol. The supernatants were combined, and the ethanol was evaporated under vacuum. The soluble sugar content was analyzed by HPLC-PAD (Dionex, Sunnyvale, CA), using a PA_1 column (Dionex) in an isocratic run, with 18 mM NaOH during 25 min.

Ascorbic Acid Content. AA was extracted with metaphosphoric acid (1% w/v) and analyzed by reversed-phase HPLC in a Hewlett-Packard 1100 system with autosampler and quaternary pump coupled to a diode array detector. The column used was a μ-Bondapak (300 mm × 3.9 mm i.d., Waters, Milford, MA), and elution (flow rate of 1.5 mL/min) was performed in isocratic conditions with 0.2 M sodiun acetate/acetic acid buffer (pH 4.2), monitored at 262 nm. Total AA was estimated after reduction of DHA with 10 mM DTT.

Titratable Acidity (TA), Total Soluble Solids (TSS), and Texture. TSS were measured with an Abbe refractometer (Carl Zeiss, Jena, Germany) calibrated against sucrose. Determination of texture was carried out using pieces (1 × 1 cm) of 10 different fruits from each cultivar, using a texturometer model TA-X12, equipped with a TA-7 USDA Warner-Blatzler knife with triangle cut (SMS Godalming, Surrey, U.K.). Results were expressed in newtons. Titratable acidity was measured according to AOAC Method 942.15 (*15*) and expressed as milligrams of citric acid.

Total Phenolics. Total phenols were determined according to the method of Swain and Hillis (*16*), using the Folin−Ciocalteu reagent. Results were expressed as milligrams of catechin per 100 g of FW.

Flavonol Content. Extraction of flavonols was performed according to the method of Price et al. (*17*), with some modifications. Frozen samples (∼30 g, in duplicate) were extracted three times in a solvent mixture (100 mL the first time, 50 mL the next two times) comprising methanol/water/acetic acid (final solvent composition 70:30:5, including the water of strawberries) at speed 5 for 1 min (Brinkmann homogenizer, Polytron, Kinematica GmbH), while cooled in ice. The homogenate was filtered under reduced pressure through filter paper (Whatman No. 1), and the combined fractions were evaporated under vacuum at 40 °C to ∼20 mL in a Rotavapor RE 120 (Büchi, Flawil, Sweden) and made up to 25 mL with water. An aliquot of 20 mL of the extract was added to a 1 g polyamide SC6 column (Macherey-Nagel Gmbh and Co) preconditioned with methanol (20 mL) and water (60 mL). The column was washed with water (20 mL) and further eluted with methanol (40 mL) to elute the neutral flavonols and with methanol/ammonia (99.5:0.5) to elute the acidic flavonols (*18*). These fractions were evaporated to dryness under reduced pressure at 40 °C, redissolved in methanol (1 mL), and filtered through 0.22 μm PTFE filters (Millipore Ltd., Bedford, MA).

Identification and quantification of flavonols was achieved using analytical reversed-phase HPLC in a Hewlett-Packard 1100 system with autosampler and quaternary pump coupled to a diode array detector. The column used was a Prodigy 5u ODS3 reversed-phase silica (250 mm × 4.6 mm i.d., Phenomenex Ltd.), and elution solvents were (A) water/tetrahydrofuran/trifluoroacetic acid 98:2:0.1 and (B) acetonitrile. The solvent gradient was the same one used by Price et al. (*17*), except for the separation of acidic flavonols, where the initial % B was 25% in order to allow separation of ellagic acid from quercetin glucuronide. Samples were injected in duplicate, and flavonols were quantified using quercetin-3-rhamnoglucoside (rutin) (Apin Chemicals Ltd., Abingdon, U.K.) as an external standard. Calibration was performed by injecting the standard three times at five different concentrations. Results were expressed as milligrams of quercetin (aglycon) per 100 g.

RESULTS AND DISCUSSION

Physical Characteristics. The average weight of the fruits ranged from 9.5 to 22 g, with Pajaro and Campineiro cultivars being the smallest ones and cv. Oso Grande the largest (**Table 1**). Considering that the number of fruits per pack can be affected by regularity of fruit weight, the coefficient of variation (CV) from the average weight was calculated. Two cultivars showed a CV of ∼20% (Mazi and Pajaro), whereas cv. Oso Grande and Toyonoka showed CV values of 33%. Cv. Campineiro was the most irregular one (CV = 39%).

Fruits of the Campineiro cultivar were the softest ones, with an average value of 0.63 N, which is half the value observed for cv. Oso Grande. This result is consistent with the empirical observation that cv. Campineiro strawberries are extremely prone to mechanical damage and bruising, which limits their postharvest shelf life.

Water content of the fruits can also make a contribution to the firmness, because cell turgor can affect the mechanical resistance of the tissue. However, as shown in **Table 2**, the water contents of the six cultivars studied are quite similar, ranging from 89.7 to 93.1%. Even when one considers that the value of water content of cv. Campineiro fruits was one of the highest, and water can contribute to cell turgor, differences in composition of cell wall are more likely to be the reason for the contrasting behaviors in relation to firmness.

Acidity and pH. Strawberry flavor is conditioned in part by the balance between sugars and acids expressed in ripe fruits, and the organic acids are the second contributors (after sugars)

Table 2. Chemical Composition (Mean ± SD of Triplicate Assays) of Six Strawberry Cultivars Harvested at the Ripe Stage[a]

	cultivar					
constituent	Mazi	Oso Grande	Dover	Pajaro	Toyonoka	Campineiro
water (%)	91.2 ± 0.2	90.5 ± 0.3	93.1 ± 0.1	90.8 ± 1.3	89.7 ± 0.2	92.8 ± 0.2
soluble solids (%)	7.5	8.0	5.4	9.0	9.4	6.0
glucose (mg/100 g)	713 ± 108	1713 ± 23	1520 ± 82	951 ± 52	1495 ± 271	1371 ± 389
fructose (mg/100 g)	1327 ± 353	1928 ± 37	1852 ± 99	1232 ± 66	1591 ± 182	1547 ± 372
sucrose (mg/100 g)	661 ± 120	1803 ± 67	908 ± 30	807 ± 48	1316 ± 212	847 ± 298
citric acid (mg/100 g)	600	590	680	ND	590	710
total ascorbic acid (mg/100 g)	50.9 ± 0.4	63.3 ± 2.3	40.1 ± 5.5	69.3 ± 2.1	55.6 ± 3.8	85.3 ± 0.8
anthocyanin (mg/100 g)	54.9 ± 5.6	42.2 ± 8.3	52.2 ± 6.6	21.2 ± 2.0	19.1 ± 1.5	13.4 ± 2.3
total phenolics (mg/100 g)	174.3 ± 2.3	249.8 ± 0.7	219.7 ± 0.6	233.1 ± 2.1	158.6 ± 3.0	289.2 ± 8.7

[a] Values of SD for citric acid were under 2%.

Table 3. Flavonol and Free Ellagic Acid Content (Milligrams per 100 g of FW) (Mean ± SD of Duplicate Assays) of Six Strawberry Cultivars at the Ripe Stage

	cultivar					
constituent	Mazi	Oso Grande	Dover	Pajaro	Toyonoka	Campineiro
free ellagic acid	1.36 ± 0.01	1.87 ± 0.08	1.01 ± 0.01	0.90 ± 0.04	0.98 ± 0.03	1.62 ± 0.03
neutral flavonols						
quercitin derivative	0.39 ± 0.02	0.45 ± 0.02	0.32 ± 0.01	0.46 ± 0.02	0.30 ± 0.01	0.29 ± 0.01
kaempferol derivative	0.25 ± 0.01	0.28 ± 0.01	0.75 ± 0.02	0.67 ± 0.02	0.14 ± 0.01	0.56 ± 0.02
acidic flavonols						
quercitin derivative	5.32 ± 0.06	4.82 ± 0.11	4.14 ± 0.10	4.14 ± 0.14	1.90 ± 0.09	4.08 ± 0.12
kaempferol derivative	1.01 ± 0.04	1.56 ± 0.05	1.31 ± 0.04	1.51 ± 0.05	0.33 ± 0.02	1.57 ± 0.03
total quercitin	5.71	5.27	4.46	4.6	2.20	4.37
total kaempferol	1.26	1.84	2.06	2.18	0.47	2.13
total flavonols	6.97	7.11	6.52	6.78	2.67	6.50

to the soluble solids of strawberries. Besides their importance in flavor, acids are important in processing because they affect the gelling properties of pectin. Citric acid contributes 92% and malic acid 9% of acidity (*5*). The acidity (calculated as percent w/w) of a typical ripe strawberry is ~1.01, with a minimum of 0.57 and a maximum of 2.26. For the cultivars tested, citric acid contents are all near the minimum, with a variation between 0.59 and 0.71 (**Table 2**). The sugar/acid ratio in all cultivars, except Mazi, was >5.3, which is the value mentioned in the literature (*5*), probably because of the low acid content. In the case of cv. Oso Grande, the ratio was 9.2 and for cv. Mazi it was 4.5, because of the low sugar contents.

Total Ascorbic Acid. Strawberries are considered to be a good source of vitamin C, having an average AA content of 60 mg/100 g (*5*). The values of AA content for the six varieties studied were around this average value (**Table 2**); cv. Campineiro is the richest in AA, with 85 mg/100 g of FW, twice the amount found in cv. Dover strawberries (40 mg/100 g of FW).

All of the cultivars showed an increase in total AA content from the early stages of development to full maturity, but followed different patterns (**Figure 1**). Whereas the AA contents of cv. Toyonoka and Oso Grande increased continuously during development, the levels of AA in cv. Mazi and Campineiro increased significantly at the transitions from stages 1 to 2 and from 2 to 3, respectively. Because there was no information about stages 1 and 2 of cv. Dover and Pajaro fruits, any interpretation of changes in AA content of these cultivars is limited. In Mazi and Campineiro cultivars there was no increase in total AA associated with ripening (change in color from white-green to red). Because cv. Campineiro and Mazi are the AA-rich and AA-poor cultivars, respectively, it appears that there is no relationship between final AA content and pattern of accumulation in the tissue during fruit development.

Soluble Sugars. As shown in **Figure 1**, the total sugar content of strawberries during development changed in a similar way to that of AA, reaching maximum values at full maturity. Sucrose, fructose, and glucose were the main soluble sugars detected in all cultivars studied, and they showed similar profiles during development and ripening (**Figure 2**). There was a close relationship between fructose and glucose content and also between the proportion of these two sugars during development. At the full maturity stage, the proportion among sugars was very similar in all strawberry cultivars except for Dover and Pajaro fruits, which presented a significantly higher amount of fructose. In general, the proportion of sucrose in the cultivars was higher than that described by Wrostade and Shallenberger (*19*), who found a sucrose maximum of 17% of total sugars. The sucrose profile shown in **Figure 2** for all cultivars is different from that found in cv. Brighton (*4*), because a decrease of sucrose content concomitantly with the color appearance was found at ripening time. The results presented here point to values of ~33% for each sugar in cv. Oso Grande and Toyonoka. The other cultivars showed at least 22% of sucrose.

Together with color and vitamin C content, sweetness is another important attribute of strawberries, and because the relative sweetness in relation to sucrose can be equal or higher for fructose and lower for glucose, it is obvious that it can be affected by changes or differences in sugar composition. However, because taste is a complex phenomenon, which is also related to acids and volatiles and is dependent on food matrix, it is not possible to establish a simple relationship between sugar content and sweetness of the six cultivars of strawberries studied based only on chemical analysis. Soluble solids (**Table 2**) were also different among cultivars; whereas cv. Dover has 5.4%, cv. Pajaro has almost twice the amount, 9.4%.

Anthocyanins. Besides size and shape, color is another important component of strawberry fruit appearance, and it is defined by the anthocyanin content. Although all cultivars have started accumulating anthocyanin at the first stage, they showed

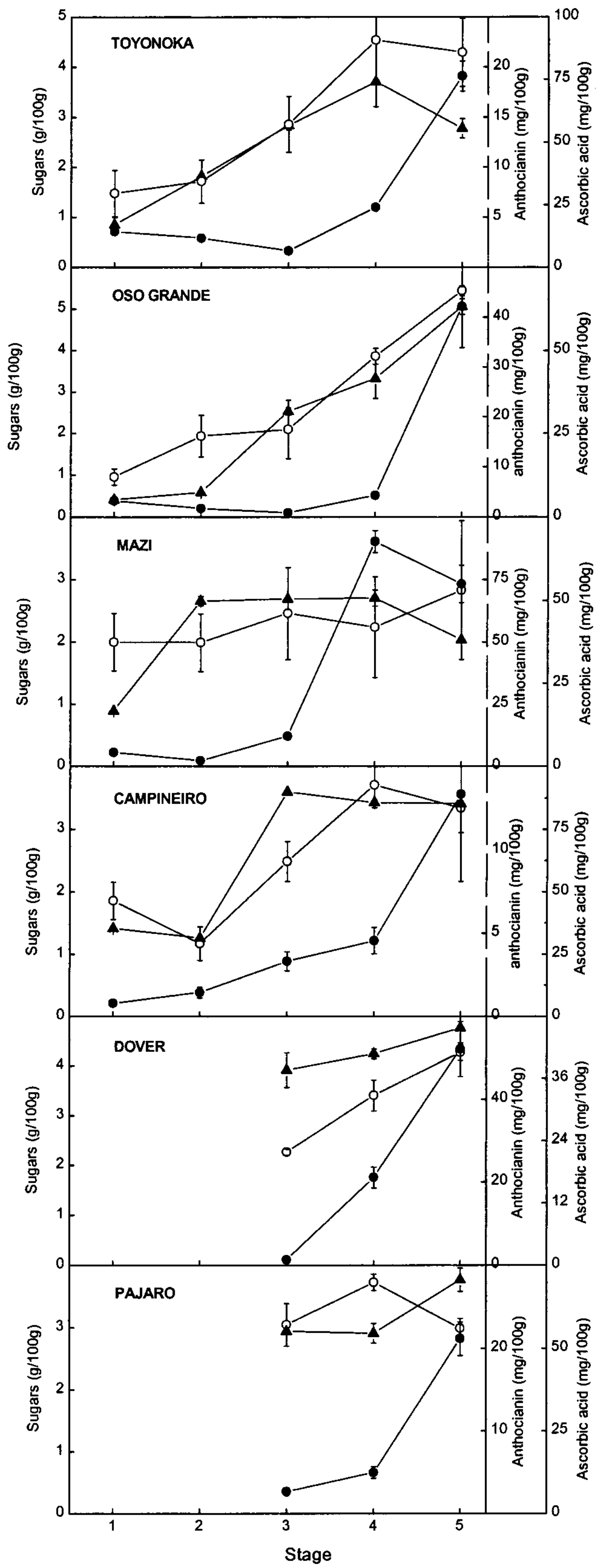

Figure 1. Time course of total soluble sugars (○), anthocyanin (●), and total ascorbic acid (▲) contents of Toyonoka, Oso Grande, Campineiro, Mazi, and Dover strawberry cultivars during development and ripening. Fruits were classified in five stages: small green (stage 1); medium size green (stage 2); full size green (stage 3); full size white turning red (stage 4); and full size three-fourths red (stage 5). Points represent means of triplicate (± standard error).

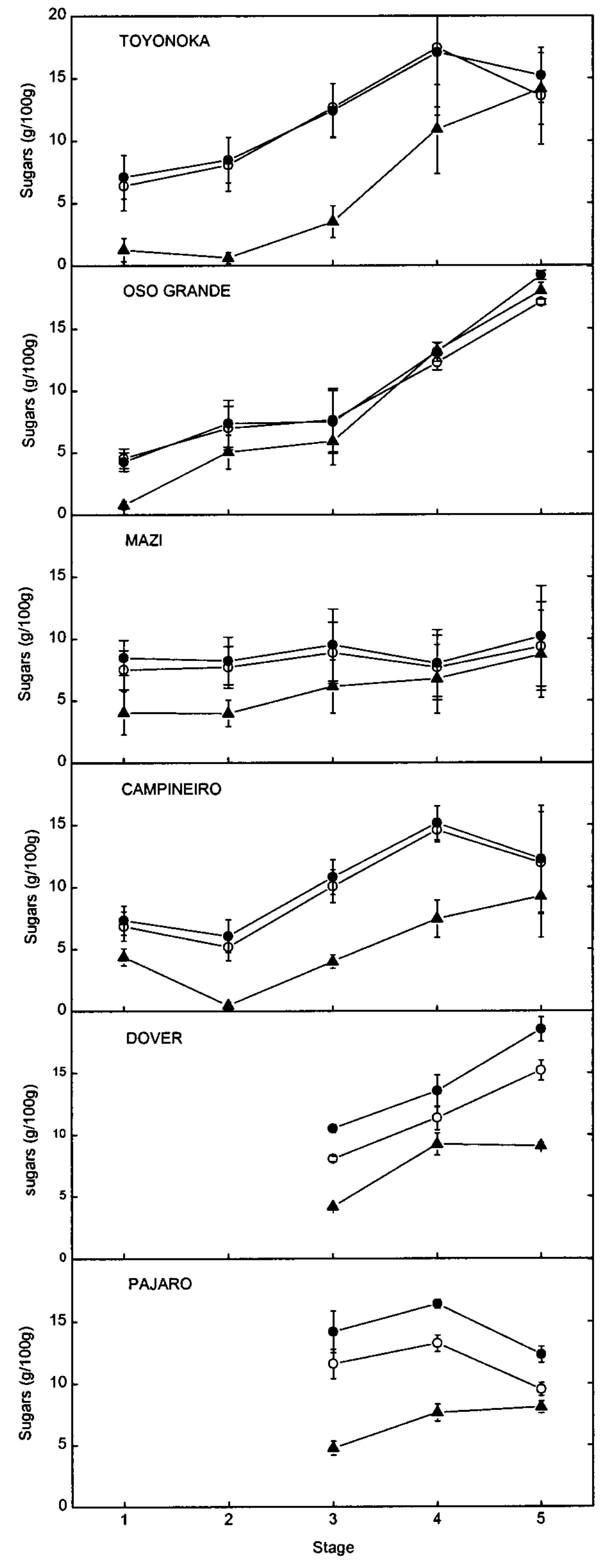

Figure 2. Time course of glucose (○), fructose (●), and sucrose (▲) contents of Toyonoka, Oso Grande, Campineiro, Mazi, and Dover strawberry cultivars during development and ripening. Fruits were classified in five stages: small green (stage 1); medium size green (stage 2); full size green (stage 3); full size white turning red (stage 4); and full size three-fourths red (stage 5). Points represent means of triplicate (± standard error).

a great increase in anthocyanin content between stages 4 and 5, associated with the ripening process (**Figure 1**). Cv. Mazi was an exception because it showed a dramatic increase in anthocyanins from stage 3 to 4 and had a higher content of anthocyanin. It was observed that the inner part of cv. Mazi fruits is strongly colored, giving them a more homogeneous appearance. In contrast, in cv. Campineiro fruits anthocyanins are predominantly distributed on the surface, resulting in fruits slightly colored red in the surface and pink to white in the inner parts.

The amount of anthocyanin determined for the six cultivars ranged from 13 to 55 mg/100 g of fresh fruit (**Table 2**). These values are compatible with other cultivars described in the literature such as Chandler [80 mg/100 g of FW (*20*)] and Red Gauntlet with [30 mg/100 g of fresh fruit (*3*)]. On the basis of the data presented here, groups of strawberries can be clearly defined in relation to the anthocyanin content. One group would be composed of the Mazi, Oso Grande, and Dover cultivars, which showed 2 times more anthocyanin than the group composed of cv. Pajaro, Toyonoka, and Campineiro fruits at the full ripening stage. This difference in anthocyanin composition can be reflected not only in the color of the fruits or their attractiveness but also in the benefits to the consumer's health, as a consequence of its antioxidant activity. However, besides anthocyanins, other flavonoids, phenolic acids, and vitamins can contribute to the protective effect against oxidative damage to cells. Considering the AA and anthocyanin contents together, there might be an inverse relationship between the levels of these compounds in strawberry (**Table 2**). Cv. Campineiro fruits were the richest in AA but showed a poor red color, as indicated by the lower anthocyanin content. On the other hand, Mazi and Dover cultivars showed high levels of anthocyanin and the lowest levels of AA, whereas the other cultivars had intermediate contents. It would be possible that AA and anthocyanin have a complementary or superimposing action in strawberry, probably as antioxidant agents, acting to protect cells against oxidative damage. This would explain why fruits that are rich in one of these two compounds are relatively poor in the other one.

Total Phenols. Total phenolics content varied from 159 (cv. Toyonoka) to 289 (cv. Campineiro) mg/100 g of FW and was not correlated to anthocyanin or flavonol content (**Tables 2** and **3**). This finding was expected because, as previously reported, strawberries are characterized by a very high content of ellagic and *p*-coumaric acids, which together represent ∼85% of total phenols, excluding anthocyanins (*21*). The variation found here in total phenolics content among cultivars, of 1.8 at maximum, was not as extensive as that found for flavonoids (4.1 for anthocyanins). According to their biological activities and influence on consumer acceptance, the content of anthocyanins would be a more significant parameter of quality than the content of total phenols.

Flavonols. Total flavonol content of cv. Toyonoka was much lower than those of the other five cultivars (**Table 3**), corresponding to only 38−41% of their contents. Myricetin was not found, and quercetin derivatives were present in higher amounts than kaempferol derivatives, with a practically constant ratio between quercetin and kaempferol for four of the cultivars (∼2−3) and a higher ratio for cv. Mazi (4.5) and for Toyonoka (4.7). Also, the main derivatives present seem to be glucoronides because a much higher content of flavonols was present in the fraction eluted from the polyamide column with $MeOH/NH_3$. The presence of quercetin and kaempferol glucosides and glucoronides in strawberries was previously reported, although the amounts of each derivative were not determined (*14*). The contents of quercetin (4 mg/100 g of FW) and kaempferol (1.4 mg/100 g of FW) derivatives found by these authors for the cv. Selva were similar to those reported here, except for the Toyonoka cultivar. However, these results are different from those reported by Häkkinen et al. (*11*), who found a similar and much lower content of quercetin and kaempferol for the varieties Senga Sengana and Jonsok. Häkkinen and Törrönen (*12*) found a kaempferol content ranging from 0.2 to 0.9 mg/100 g of FW and a quercetin content from 0.3 to 0.5 mg/100 g of FW for nine strawberry cultivars grown in Finland. According to these results, the cultivars analyzed here would be more promising in relation to beneficial effects on health, due to their much higher content of flavonols. However, besides varieties and environmental conditions, some discrepancies in flavonol contents could be related to maturity stage and/or to the methodology used (sample preparation, determination of aglycons after acid hydrolysis vs glycosyl derivatives, etc.). In this sense, Häkkinen and Törrönen (*12*) observed that the conditions used by them for sample storage (−20 °C/8−9 months) could lead to some losses, kaempferol being more susceptible than quercetin. In any case, the differences found could not be explained solely on the basis of differences of methodology and are most probably inherent to the cultivars used.

Ellagic Content. There is an increasing interest in the amounts of ellagic acid in fruits due to the evidence of its supposed anticarcinogenicity. The main sources of ellagic acid in our diet are by far strawberries, raspberries, and blackberries (*22*). For the six cultivars analyzed, free ellagic acid ranged from 0.9 to 1.9 (mean = 1.3) mg/100 g of FW, similar to the values reported by Amakura et al. (*23*) and Gil et al. (*14*). However, most of the ellagic acid in berries is present as an ellagitannin esterified with glucose, demanding an acid hydrolysis step to liberate it (*24*). The total ellagic acid content of red pulp was previously reported as ranging from 43 to 464 mg/100 g of DW (*25*), which, considering a mean water content of 90%, would correspond to 4−46 mg/100 g of FW. A lower variation was found by Hakkinen et al. (*12*) for six strawberry cultivars analyzed, which had ellagic acid contents ranging from 39.6 to 52.2 mg/100 g of FW.

The overall results indicated that, depending on the intended use of the fruits, different cultivars could be more or less suitable. Cv. Toyonoka had the lowest values for vitamin C, anthocyanins, soluble solids, total phenolics, and total flavonols. However, it had a good texture, a high amount of total sugars, and a low amount of citric acid, counting for a good taste. Cv. Oso Grande had the best values concerning weight, texture, total flavonols, free ellagic acid, total phenolics, and total soluble sugars and had good amounts of anthocyanins and vitamin C, being the most suitable cultivar for fresh consumption in terms of nutritional value and quality parameters. Cv. Mazi had the highest amounts of anthocyanins and flavonols but had some of the lowest values of vitamin C, citric acid, and total soluble sugars.

ACKNOWLEDGMENT

We appreciate the technical assistance of Marcia Morais, Alberto Bernal, Lucia Justino da Silva, and Ricardo José dos Santos.

LITERATURE CITED

(1) Klein, B. P.; Perry, A. K. Ascorbic acid and vitamin A activity in selected vegetables from different geographical areas of the United States. *J. Food Sci.* **1982**, *47*, 941−945.
(2) Robards, K.; Prenzler, P. D.; Tucker, G.; Swatsitang, P.; Glover, W. Phenolic compounds and their role in oxidative processes in fruits. *Food Chem.* **1999**, *66*, 401−436.
(3) Woodward, J. R. Physical and chemical changes in developing strawberry fruits. *J. Sci. Food Agric.* **1972**, *23*, 465−473.

(4) Forney, C. F.; Breen, P. J. Sugar content and uptake in the strawberry fruit. *J. Am. Soc. Hortic. Sci.* **1986**, *111* (2), 241−247.

(5) Green, A. Soft fruits. In *The Biochemistry of Fruits and Their Products*; Hulme, A. C., Ed.; Academic Press: London, U.K., 1971; Vol. 2, pp 375−410.

(6) Agar, I. T.; Streif, J.; Bangerth, F. Effect of high CO_2 and controlled atmosphere (CA) on the ascorbic and dehydroascorbic acid content of some berry fruits. *Postharvest Biol. Technol.* **1997**, *11*, 47−55.

(7) Smirnoff, N. The function and metabolism of ascorbic acid in plants. *Ann. Bot.* **1996**, *78*, 661−669.

(8) Loewus, F. A. Biosynthesis and metabolism of ascorbic acid in plants and of analogs of ascorbic acid in fungi. *Phytochemistry* **1999**, *52*, 193−210.

(9) Lee, K. S.; Kader, A. A. Preharvest and postharvest factors influencing vitamin C content of horticultural crops. *Postharvest Biol. Technol.* **2000**, *20*, 207−220.

(10) Wang, H.; Cao, G.; Prior, R. L. Total antioxidant capacity of fruits. *J. Agric. Food Chem.* **1996**, *44*, 701−705.

(11) Häkkinen, S. H.; Kärenlampi, S. O.; Heinonen, I. M.; Mykkänen, H. M.; Törrönen, A. R. Content of the flavonols quercetin, myricetin, and kaempferol in 25 edible berries. *J. Agric. Food Chem.* **1999**, *47*, 2274−2279.

(12) Häkkinen, S. H.; Törrönen, A. R. Content of flavonols and selected phenolic acids in strawberries and *Vaccinium* species: influence of cultivar, cultivation site and technique. *Food Res. Int.* **2000**, *33*, 517−524.

(13) Manning, K. Soft fruits. In *Biochemistry of Fruit Ripening*; Seymour, G. B., Taylor, J. E., Tucker, G. A., Eds.; Chapman and Hall: London, U.K., 1996.

(14) Gil, M. I.; Holcroft, D. M.; Kader, A. A. Changes is strawberry anthocyanins and other polyphenols in response to carbon dioxide treatments. *J. Agric. Food Chem.* **1997**, *45*, 1662−1667

(15) AOAC. *Official Methods of Analysis*, 16th ed.; Association of Official Analytical Chemists: Washington, DC, 1995.

(16) Swain, T.; Hillis, W. E. The phenolic constituents of *Prunus domestica*. I. The quantitative analysis of phenolic constituents. *J. Sci. Food Agric.* **1959**, *10*, 63−68.

(17) Price, K. R.; Prosser, T.; Richetin, A. M. F.; Rhodes, M. J. C. A comparison of the flavonol content and composition in dessert, cooking and cider-making apples; distribution within the fruit and effect of juicing. *Food Chem.* **1999**, *66*, 489−494.

(18) Price, K. R.; Colquhoun, I. J.; Barnes, K. S.; Rhodes, M. J. C. Composition and content of flavonol glycosides in green beans and their fate during processing. *J. Agric. Food Chem.* **1998**, *46*, 4898−4903.

(19) Wrolstad, R. E.; Challenberger, R. S. Free sugars and sorbitol in fruits—a compilation from the literature. *J. Assoc. Off. Anal. Chem.* **1981**, *64*, 91−100.

(20) Montero, T. M.; Mollá, E. M.; Esteban, R. M.; López-Andréu, F. J. Quality attributes of strawberry during ripening. *Sci. Hortic.* **1996**, *65*, 239−250.

(21) Häkkinen, S. H.; Heinonen, I. M.; Kärenlampi, S.; Mykkänen, H. M.; Ruuskanen, J.; Törrönen, R. Screening of selected flavonoids and phenolic acids in 19 berries. *Food Res. Int.* **1999**, *32*, 345−353.

(22) Tomás-Barberán, F.; Clifford, M. N. Dietary hydroxybenzoic acid derivatives—nature, occurrence and dietary burden. *J. Sci. Food Agric.* **2000**, *80*, 1024−1032.

(23) Amakura, Y.; Okada, M.; Tsuji, S.; Tonogai, Y. High-performance liquid chromatographic determination with photo-diode array detection of ellagic acid in fresh and processed fruits. *J. Chromatogr.* **2000**, *896*, 87−93.

(24) Daniel, E. M.; Krupnick, A. S.; Heur, Y. H.; Blinzler, J. A.; Nins, R. W.; Stoner, G. D. Extraction, stability, and quantitation of ellagic acid in various fruits and nuts. *J. Food Compos. Anal.* **1989**, *2*, 338−349.

(25) Maas, J. L.; Wang, S. Y.; Galleta, G. J. Evaluation of strawberry cultivars for ellagic acid content. *HortScience* **1991**, *26*, 66−68.

Received for review October 29, 2001. Revised manuscript received January 28, 2002. Accepted January 30, 2002. This work was supported by FAPESP.

JF011421I