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Antioxidant Capacity, Quality, and Anthocyanin and Nutrient Contents of Several Peach Cultivars [*Prunus persica* (L.) Batsch] Grown in Spain

G. Reig,*[†] I. Iglesias,[†] F. Gatius,[‡] and S. Alegre[†]

[†]Estació Experimental de Lleida, Institut de Recerca i Tecnologia Agroalimentàries (IRTA), Av. Rovira Roure 191, E-25198 Lleida, Spain

[‡]Department de Química, Universitat de Lleida, Av. Rovira Roure 191, E-25198 Lleida, Spain

ABSTRACT: Antioxidant capacity, quality, and anthocyanin and nutrient contents of 106 peach cultivars from different breeding programs were evaluated at the Estació Experimental de Lleida, IRTA (Catalonia, Spain), during two growing seasons (2010 and 2011). High variability was found among cultivars within each quality trait, where different cultivars were scored as the best and the worst. For example, a 5-fold range (2.17−12.07 g of malic acid L^{-1}), 6-fold range (144.20−711.73 μg of Trolox g^{-1} of FW), and 11-fold range (0.70−11.43 mg of cyanidin-3-glucoside kg^{-1} of FW) were observed in titratable acidity, relative antioxidant capacity, and anthocyanin content, respectively. The breeding program within each fruit type (melting peach, nectarine, and flat peach) and qualitative pomological traits also had significant effects on the quality. Nevertheless, each breeding program had specific characteristics that distinguished it from the others. Even so, within each breeding program, there is high variability among cultivars. Therefore, growers should not base their strategy exclusively on the choice of breeding program. Principal component analysis for each fruit type (melting peach, nectarine, nonmelting peach, and flat peach) allowed a selection of a set of cultivars from different breeding programs with the highest quality performance. For example, cultivars such as 'Azurite', 'IFF 1230', 'Amiga', 'Fire Top', 'African Bonnigold', 'Ferlot', 'Mesembrine', and 'Platifirst' had higher sweetness and flavor compared to the others. Therefore, this study could help breeders to make decisions for the selection of new cultivars able to improve the quality features of fruit intake, technicians to know better quality performance of peach cultivars, and consumers to meet their expectations for fruit with high health benefits and a specific taste.

KEYWORDS: *Prunus persica, fruit quality, sweetness, sourness, sucrose, malic acid, relative antioxidant capacity, anthocyanin content*

INTRODUCTION

Peach [*Prunus persica* (L.) Batsch] is the most important stone fruit crop in Spain, which ranks second in European production, after Italy and followed by Greece and France.[1] Peach is also the most dynamic fruit species in terms of new cultivars released per year.[2] New cultivars originate from more than 70 active breeding programs, which are mainly found in the United States, followed by Europe (Italy and France),[2] and are the sources of many of the cultivars grown in Spain.[3] Sometimes, these cultivars show an uncertain agronomic, and so qualitative, performance when they are grown under climatic conditions that are different from those where they were originally developed.[4−6] Breeders have traditionally selected primarily for external quality (fruit size and appearance),[7] with organoleptic and nutritional traits being a secondary goal.[8−10,2] Today, however, health concern is one of the major driving forces of the world food market, and it is the first or second most important concern of consumers, though this varies regionally. Consumers realize the connection between diet and health and therefore tend to associate their diets with the prevention of cardiovascular disease, vision problems, obesity, arthritis/joint pain, and high cholesterol.[11,12]

Fruits and vegetables are excellent functional foods as they are high in antioxidant and nutritional compounds.[13] These naturally occurring substances not only play an important role in visual appearance (pigmentation and browning) and taste (astringency) but also have health-promoting properties, acting as antioxidants by scavenging harmful free radicals, which are implicated in most degenerative diseases.[14] As a result, there is growing interest in fruit quality and nutritional composition in breeding programs worldwide.[15] Many of them, to improve fruit quality, produce cultivars with excellent taste, high sugar levels, and balanced sugar/acid ratios.[16] Others have directed their interest to the identification and quantification of phenolic compounds in fruit to evaluate their potential health-promoting properties[17] and to develop peaches with high levels of compounds potentially beneficial to human health.[18]

The huge peach cultivar supply and fruit health benefits contrast with the decrease of peach consumption in Spain,[5] as is the case in other western countries (Europe and the United States).[19,20] Poor internal fruit quality, perceived when the fruit is consumed, is the main reason claimed by consumers for declining to buy fresh fruit.[2,5] Internal fruit quality is related mainly to two factors: firmness and flavor. Firmness is essential for postharvest management, marketing, and consumer acceptance. Too soft or too firm flesh has a negative impact on quality attributes.[21] High firmness is a consequence of harvesting

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immature fruits and implies less flavor, aroma, texture, and juiciness. As a result, the consumer is disappointed and does not buy peaches again during that season.[3] Many authors[22,23] have suggested that sensory quality attributes and the nutritive value of peach (*P. persica* L.) fruits as well as of other fruits play an important role in consumer satisfaction and influence further consumption.

The high number of new cultivars on the market makes their technical management and their quality performance identification difficult for both growers and technicians. As far as we know, no analyses have been performed on fruit quality (flesh firmness, soluble solids content, titratable acidity), sensory evaluation (sweetness, sourness, and flavor), and nutrient contents and antioxidant capacity (individual and total sugar content, individual and total acid content, relative antioxidant capacity, and anthocyanin content) of peach commercial cultivars from different breeding programs grown under Mediterranean climate conditions. Therefore, the aims of this work were (1) characterization of 106 peach cultivars by measuring fruit quality, sensory, nutrient, and antioxidant capacity traits, (2) to study the influence of the breeding program and pomological traits on the quality, sugar, acid, and anthocynin content, and relative antioxidant capacity profile in *P. persica* fruits, (3) to examine relationships among all variables evaluated, and (4) to select commercial peach cultivars with enhanced fruit quality, sensory, nutrient, and antioxidant capacity traits by principal component analysis (PCA).

MATERIALS AND METHODS

Plant Material. The study was carried out during the 2010 and 2011 seasons on fruits of 106 peach cultivars from an experimental collection plot located at the Estació Experimental de Lleida, IRTA (Catalonia, Spain). Their breeding program, fruit type, flesh color, and fruit shape are described in Table 1. To simplify the analysis, both flat peach and flat nectarine cultivars were considered flat peach cultivars.

The experimental orchard contained three trees per cultivar planted in a single block, trained in the central axis system, grafted on INRA®GF677 rootstock, and spaced 4.5 m × 2.5 m. The rows were oriented from northeast to southwest. Trees were trickle-irrigated using drip irrigation with two drips per tree delivering 4 L/h. Standard commercial management practices recommended for the area were followed, including fertilization and plant disease and pest control, in accordance with the guidelines of integrated fruit production. The weather conditions for the period 2010–2011 were usual for this warm Mediterranean area: high summer temperatures (>30 °C) and low rainfall (379 mm per season). Hand thinning in early May was performed each season.

At harvest date, when firmness ranged from 39N to 49N, 24 fruits per cultivar (8 fruits per tree) and season were picked to make the following determinations. The fruits were picked from the periphery of the tree and at 1.5–2.0 m above ground level.

Fruit Quality Determinations. A total of 18 of 24 fruits per cultivar and season were assessed for flesh firmness (FF), soluble solids content (SSC), and titratable acidity (TA). Flesh firmness of two opposing cheeks (the most and least exposed to light) of each fruit was measured using an 8 mm tip penetrometer fixed in a drill stand (Penefel, Copa-Technology, CTIFL, Saint Etienne du Gres, France). SSC and TA were determined on flesh juice extracted by an automatic juicer (Moulinex, type BKA1). SSC was determined using a digital calibrated refractometer (Atago PR-32, Tokyo, Japan), and the results are expressed in °Brix. TA was measured with an automatic titrator (Crison GLP 21, Barcelona, Spain) and determined by titrating 10 mL of juice with 0.1 M NaOH to a pH end point of 8.2. The results are given as grams of malic acid per liter. The ripening index (RI) was then calculated as the SSC/TA ratio. To characterize the cultivars, two groups were established according to the TA value:[24] sweet (<6 g of malic acid L^{-1}); nonsweet (>6 g of malic acid L^{-1}).

Sensory Determinations. A total of 3 of the 24 fruits per cultivar and season were subjected to sensory evaluation by a panel of four experts. On the basis of the work of Oraguzie et al.,[25] the panel was set up using the following criteria: (1) membership in the IRTA—Fruit Growing area, (2) at least 3 years of experience in stone fruit sensory evaluation, and (3) participation in a sensory training exercise. Before the assessments and for each season, the experts undertook a 1 week long course of specific training on peach sensory attributes (Table 2) according to the procedures determined by the International Organization for Standardization (no. 8586-1, 1993) provided by the IRTA sensory group. An overall sensory score, from 1 to 10, was used to understand the influence of all sensorial attributes together, representing a fair and indicative value of threshold acceptability for consumers.[26] Each sample for sensory evaluation consisted of three pieces of 1.5 cm^3 (without skin), one from each of three fruits per cultivar. Peeled fruit samples were identified by a random two-digit code and presented to the expert in white plastic cups in random order. The intensity of each sensory attribute was recorded on 150 mm unstructured line scales, anchored at 0 (absent) and 150 (extreme). The experts were instructed to use mineral water, and crackers were provided as a palate cleanser between each sample assessment.

Extraction and Quantification of Sugars and Organic Acids. To extract and quantify the main soluble sugars and organic acids per cultivar and season, 10 mL of flesh juice were pooled. An aliquot of 5 mL was taken and diluted in ultrapure water (1:1). The mixture was vortexed (10 s) and filtered using triple sterile gauze. A 2 mL volume was extracted, immediately frozen in liquid nitrogen, and stored at −25 °C until analysis. At the moment of analysis, the extracts were defrosted at 4 °C followed by centrifugation at 11 000 rpm for 15 min at 4 °C. A 500 μL volume of supernatant was extracted and clarified by a Whatman polyvinylidene difluoride (PVDF) syringe filter (13 mm, 0.22 μm, reference 6779-1302) and purified using a Sep Pak light 130 mg C18 column (Waters, WAT023501). Sep Pak was previously activated with 1 mL of methanol and conditioned with 1 mL of water. To ensure the total elution of the compounds of interest, 500 μL of Milli-Q water was finally added. A 100 μL volume of filtrate was diluted with ultrapure water (1:10) in a 1 mL HPLC vial. Sugars and organic acids were analyzed by a Waters HPLC system.

In the case of sugars, 10 μL from the HPLC vial was injected and isolated by a strong Hamilton HC-75 (Ca^{2+}) cation-exchange resin column (305 × 7.8, 9 μm Teknokroma, Barcelona, Spain, reference HC-79476) at 90 °C. The flow rate was set at 0.6 mL min^{-1} using ultrapure water as the mobile phase. Compounds were detected by a 2414 refractive index detector (×16) at 30 °C. External calibration was performed at six calibration levels by dilution of a stock solution composed of 2.5 $g{\cdot}L^{-1}$ sucrose, 0.6 $g{\cdot}L^{-1}$ glucose and fructose, and 0.25 $g{\cdot}L^{-1}$ sorbitol. In this case, the lowest calibration level for sorbitol was taken as the instrumental limit of quantification (LOQ) because of its low concentration present in the samples. Calibration curves showed good linearity, and their determination coefficients (R^2) were higher than 0.99. Results from individual sugars are expressed as a mean of the proportion (%) with respect to the total sugar content, and the total sugar content is expressed as grams per liter of flesh juice.

To determine the organic acids, 20 μL from the HPLC vial was injected and isolated by a reversed-phase strong Hamilton HC-75 (Ca^{2+}) cation-exchange resin column (305 × 7.8, 9 μm Teknokroma, Barcelona, Spain, reference HC-79476) at 90 °C. The flow rate was set at 1 $mL{\cdot}min^{-1}$ using ultrapure water as the mobile phase buffered at pH 3. Compounds were detected by a 2414 refractive index detector (×16) at 30 °C. External calibration was performed at six calibration levels by dilution of a stock solution composed of 1.0 $g{\cdot}L^{-1}$ malic acid, citric acid, and quinic acid and 0.05 $g{\cdot}L^{-1}$ shikimic acid. The lowest calibration level for sorbitol was taken as the LOQ because of its low concentration present in the samples. Calibration curves showed good linearity, and their determination coefficients (R^2) were higher than 0.99. Results from individual organic acids are expressed as a mean of the proportion (%) with respect to total acid content, and the total acid content is expressed as grams per liter of flesh juice.

Table 1. Characteristics of the Cultivars Evaluated: Breeding Program, Fruit Type, Flesh Color, and Fruit Shape[a]

cultivar	Unscrambler code	breeding program	fruit type	flesh color	fruit shape
African Bonnigold	1	ARC	NME	Y	R
Alice	2	Martorano di Cesena	NE	Y	R
Amiga	3	A. Minguzzi	NE	Y	R
ASF 05–25	4	ASF	NE	W	R
ASF 05–93	5	ASF	FP	W	F
ASF 06–88	6	ASF	FP	W	F
ASF 06–90	7	ASF	FP	W	F
August Red	8	Bradford	NE	YR	R
Azurite	9	Monteuax-Callet	ME	Y	R
Big Bel	10	Zaiger	NE	WR	R
Big Nectared	11	ASF	NE	Y	R
Big Sun	12	Europepinieres	ME	Y	R
Big Top	13	Zaiger	NE	YR	R
Catherina	14	L. Houg	NME	Y	R
Country Sweet	15	Zaiger	ME	YR	R
Diamond Bright	16	Bradford	NE	Y	R
Diamond Ray	17	Bradford	NE	YR	R
Donutnice	18	ASF	FP	W	F
Early Top	19	Zaiger	NE	Y	R
Endogust	20	ASF	NE	WR	R
Extreme July	21	Provedo	ME	YR	R
Extreme Red	22	Provedo	NE	Y	R
Extreme Sweet	23	Provedo	ME	Y	R
Fairlane	24	USDA	NE	Y	R
Feraude	25	INRA	NME	Y	R
Fercluse	26	INRA	NME	Y	R
Ferlot	27	INRA	NME	Y	R
Fire Top	28	Zaiger	NE	YR	R
Flataugust	29	ASF	FP	W	F
Flatpretty	30	ASF	FP	W	F
Flatprincess	31	ASF	FP	WR	F
Fullred	32	ASF	ME	Y	R
Garcica	33	PSB	NE	WR	R
Gardeta	34	PSB	NE	Y	R
Grenat	35	Monteuax-Callet	ME	Y	R
Hesse	36	University of California	NME	Y	R
Honey Blaze	37	Zaiger	NE	Y	R
Honey Fire	38	Zaiger	NE	Y	R
Honey Glo	39	Zaiger	NE	Y	R
Honey Kist	40	Zaiger	NE	Y	R
IFF 1182	41	CRA	NE	WR	R
IFF 1190	42	CRA	ME	Y	R
IFF 1230	43	CRA	ME	WR	R
IFF 1233	44	CRA	ME	YR	R
IFF 331	45	CRA	ME	W	R
IFF 813	46	CRA	NE	Y	R
IFF 962	47	CRA	ME	Y	R
Latefair	48	Zaiger	NE	Y	R
Luciana	49	PSB	NE	Y	R
Magique	50	Europepinieres	NE	WR	R
Mesembrine	51	INRA	FP	YR	F
Nectabang	52	ASF	NE	Y	R
Nectabelle	53	ASF	NE	Y	R
Nectabeauty	54	ASF	NE	Y	R
Nectabigfer	55	ASF	NE	W	R
Nectadiva	56	ASF	NE	Y	R
Nectaearly	57	ASF	NE	W	R
Nectafine	58	ASF	NE	Y	R
Nectagala	59	ASF	NE	Y	R
Nectajewel	60	ASF	NE	W	R
Nectalady	61	ASF	NE	Y	R
Nectaperla	62	ASF	NE	WR	R
Nectapi	63	ASF	NE	Y	R
Nectapink	64	ASF	NE	Y	R
Nectaprima	65	ASF	NE	Y	R
Nectareine	66	ASF	NE	YR	R
Nectariane	67	ASF	NE	Y	R
Nectarjune	68	ASF	NE	WR	R
Nectarlight	69	ASF	NE	W	R
Nectaroyal	70	ASF	NE	Y	R
Nectarreve	71	ASF	NE	W	R
Nectatop	72	ASF	NE	Y	R
Nectavanpi	73	ASF	NE	Y	R
NG 4/720	74	A. Minguzzi	NE	YR	R
NG-187	75	A. Minguzzi	NE	Y	R
Noracila	76	PSB	NE	YR	R
O'Henry	77	G. Merril	ME	YR	R
Onyx	78	Monteuax-Callet	ME	WR	R
Oriola	79	INRA	FP	W	F
PG 3/1312	80	A. Minguzzi	ME	Y	R
PG 3/138	81	A. Minguzzi	ME	YR	R
PG 3/719	82	A. Minguzzi	ME	Y	R
PI 2/84	83	A. Minguzzi	NME	Y	R
Pink Ring	84	CRA	FP	W	F
Platibelle	85	INRA	FP	W	F
Platifirst	86	INRA	FP	WR	F
Platifun	87	INRA	FP	W	F
Rich lady	88	Zaiger	ME	YR	R
Romea	89	CRA	NME	Y	R
Rose Diamond	90	Bradford	NE	Y	R
Subirana	91	Agromillora	FP	W	F
Summersun	92	ARC	NME	Y	R
Summersweet	93	Zaiger	ME	WR	R
Surprise	94	INRA	ME	WR	R
Sweet Dream	95	Zaiger	ME	Y	R
Sweetbella	96	ASF	ME	WR	R
Sweetlove	97	ASF	ME	WR	R
Sweetmoon	98	ASF	ME	W	R
Sweetprim	99	ASF	ME	WR	R
Sweetstar	100	ASF	ME	WR	R
UFO 3	101	CRA	FP	W	F
UFO 4	102	CRA	FP	W	F
UFO 7	103	CRA	FP	Y	F
UFO 8	104	CRA	FP	Y	F
Very Good	105	ASF	ME	Y	R
Zee Lady	106	Zaiger	ME	Y	R

[a]Abbreviations: PE, peach; NE, nectarine; NMP, nonmelting peach; FP, flat peach; Y, yellow; YR, yellow-red, W, white; WR, white-red; R, round; F, flat.

Sweetener potency was defined as the number of times the compound was sweeter than sucrose, on the basis of its equisweetness.[27] The equisweet concentrations used were 1, 1.75, and 0.75 for sucrose, fructose, and glucose, respectively,[28] and 0.6 for sorbitol.[29]

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Table 2. Sensory Attributes Corresponding to 106 Peach Cultivars[a]

attribute	definition	ref std	intensity (150 mm scale)[c]
sweetness	characteristic of sugar	50% juice[b]	taste 75
sourness	characteristic of acid	50% juice	taste 80
flavor	characteristic of peach flavor	puree of canned peach	75

[a]Definitions and references used for each attribute and their position on the intensity scale (ref 68). [b]Commercial peach juice diluted to 50% with filtered water. [c]Conversion: 1 mm = 0.0394 in.

Relative Antioxidant Capacity (RAC) and Anthocyanin Content. A total of 3 of the 24 fruits were chosen from each cultivar and season to measure anthocyanin content and RAC as described by Cantín et al.[17] RAC was quantified by the 2,2-dipyridyl-1,1-diphenyl-2-picrylhydrazyl (DPPH) radical method adapted from Brand-Williams et al.[30] The results are expressed in micrograms of Trolox per gram of fresh weight (FW). Total anthocyanin content analysis was determined by the method of Fuleki and Francis[31] adapted to peach tissue. Anthocyanins were quantified as milligrams of cyanidin-3-glucoside per kilogram of FW using a molar extinction coefficient of 25 965 cm^{-1} M^{-1} and a molecular weight of 494.[32]

Statistical Analysis. Three replications for each parameter evaluated and season were used for each cultivar. To obtain basic statistics for the entire plant material studied, the number of observed cultivars, maximum, minimum, and mean values, mean standard error, and standard deviation for each trait were recorded. All data were treated by means of analysis of variance (GLM procedure) using the SAS program package.[33] Differences between fruit type were tested with Tukey's honestly significant difference (HSD) test at a significance level of 0.05 ($p \leq 0.05$). Differences between flesh color, fruit shape, and TA range were tested with Student's test at the 0.05 significance level ($p \leq 0.05$). For this, mean values of the proportion of sugars and organic acids were transformed to an arcsine distribution. Correlations between traits to reveal possible relationships were calculated from raw data of the 2 years using the Pearson correlation coefficient at $p \leq 0.05$. PCA was performed using the Unscrambler 7.6 program package.[34]

■ RESULTS AND DISCUSSION

Cultivar. The cultivars evaluated in this study exhibited considerable phenotypic variation in fruit quality, sensory, nutrient content, and antioxidant capacity traits (Table 3), as reported by several authors.[17,35,36] Mean values obtained per cultivar are not shown, but the names of the cultivars with the highest and lowest values are reported.

The evaluated fruit quality traits showed a wide range of variability. SSC ranged from 9.55 to 19.83 °Brix, with a mean of 12.99 °Brix, which is higher than the minimum (8 °Brix) established by the EU to market peaches and nectarines (R-CE no. 1861/2004). 'Nectapink' (19.83 °Brix), 'Nectafine' (19.03 °Brix), and 'Nectalady' (18 °Brix) showed the highest SSC and 'Nectabang' (9.55 °Bx), 'Nectaprima' (9.73 °Brix), and 'Sweetprim' (9.65 °Brix) the lowest, mainly because the latter are early maturity season varieties, which are reported to have less SSC.[37,38] SSC is an important quality trait in peaches and nectarines due to its reported relationship with consumer acceptance and satisfaction. However, this relationship is cultivar dependent, as there is no single reliable SSC that ensures consumer satisfaction, which is also influenced by other quality traits, such as TA.[39] With respect to TA, important differences among cultivars were observed, with the minimum levels found for 'PG 3/719' (2.17 g of malic acid L^{-1}), 'Nectadiva' (2.26 g of malic acid L^{-1}), and 'Platifirst' (2.28 g of malic acid L^{-1}) and the maximum levels for 'August Red' (12.07 g of malic acid L^{-1}), 'Fire Top' (10.92 g of malic acid L^{-1}), and 'Early Top' (10.72 g of malic acid L^{-1}). RI is also a major instrumental quality trait of the mature peach fruit. It is commonly used as a quality index[40] because it is related to taste perception,[35,41] is a potential indicator of sweetness,[21,42] and plays an important role in consumer acceptance of some peach, nectarine, and plum cultivars in ripe fruits.[39] RI ranged from 1.07 to 6.19. 'Sweetbella' (6.19), followed by 'PG 3/719' (6.08) and 'Nectadiva' (6.02), had the highest value, and 'Sweetprim' (1.07), 'Early Top' (1.07), and 'Fire Top' (1.09) had the the lowest values, due to high TA (about 10 g of malic acid L^{-1}) and quite low SSC (11 °Brix).

Table 3. Values of Quality, Antioxidant Capacity, and Anthocyanin and Nutrient Content Traits of 106 Commercial Peach Cultivars[a]

trait	min	max	mean	MSE	SD
SSC (°Brix)	9.55	19.83	12.99	0.19	2.00
TA (g of malic acid L^{-1})	2.17	12.07	5.13	0.24	2.46
RI	1.07	6.19	3.18	0.14	1.46
sweetness	4.30	9.67	7.08	0.11	1.12
sourness	2.78	10.39	6.26	0.19	1.91
flavor	3.32	7.71	5.84	0.10	1.04
overall score	2.67	7.50	5.01	0.09	0.89
sucrose content (%)	55.74	72.96	67.35	0.32	3.26
glucose content (%)	6.65	15.42	10.26	0.15	1.57
fructose content (%)	6.77	16.82	10.78	0.16	1.69
sorbitol content (%)	1.07	15.99	5.24	0.30	3.07
sucrose/glucose ratio	3.74	10.75	6.86	0.13	1.32
glucose/fructose ratio	0.80	1.30	0.96	0.01	0.08
total sugar content (g L^{-1})[b]	89.16	184.49	126.71	2.13	21.89
sweetening power	91.02	102.46	97.06	0.18	1.84
malic acid content (%)	42.92	84.30	59.30	0.73	7.55
citric acid content (%)	3.72	31.61	14.23	0.70	7.18
quinic acid content (%)	14.56	57.54	27.36	0.73	7.49
shikimic acid content (%)	0.14	1.89	0.59	0.02	0.25
total acid content (g L^{-1})[c]	5.59	18.50	9.33	0.23	2.40
RAC (μg of Trolox g^{-1} of FW)	144.20	711.73	338.32	8.99	92.52
anthocyanin content (mg of C3G kg^{-1} of FW)	0.70	11.43	3.50	0.22	2.24

[a]For each trait, the minimum, maximum, and mean values, mean standard error (MSE), and standard deviation (SD) are given. Abbreviations: SSC, soluble solids content; RI, ripening index; TA; titratable acidity; RAC, relative antioxidant capacity; C3G, cyanidin-3-glucoside. [b]Sum of sucrose, glucose, fructose and sorbitol for each cultivar. [c]Sum of malic, citric, quinic and shikimic acids for each cultivar.

Sensorial traits varied among cultivars in the range of 4.30−9.67 for sweetness, 2.78−10.39 for sourness, 3.32−7.71 for flavor, and 2.67−7.50 for the overall score (Table 3). 'Nectapink' (9.67), 'Nectatop' (9.33), and 'IFF 331' (8.80) had the highest sweetness values, while the lowest were for 'IFF 1230' (4.30), 'Amiga' (4.43), and 'Onyx (4.82). The highest sourness values were obtained for 'Onyx' (10.39), 'Endogust' (9.33), and 'Fire Top' (9.87) and the lowest for 'Platifirst' (2.78), 'UFO 4' (2.95), and 'Sweetstar' (3.13). 'Nectapink' (7.71), 'Gardeta' (7.66), and 'Garcica' (7.61) had the highest flavor values, and 'African Bonnigold' (3.32), followed by 'Onyx' (3.39) and 'IFF 1230' (3.68), had the lowest value. Finally, the highest overall scores were for 'Platifun' (7.50), 'Zee Lady' (6.63), and 'Garcica' (6.58) and the lowest for 'Onyx' (2.67), 'IFF 1230' (3.00), and 'Fire Top' (3.08).

Sucrose, glucose, fructose, and sorbitol contents were analyzed separately, as they play an important role in peach flavor quality.[41] Sucrose is important as an energy source and as a preservative of fruit flavors.[43] As with other studies in peaches,[16,23,35,36,41,44] we found sucrose was the major soluble sugar (Table 3), ranging from 55.74% to 72.96% of the total sugar content, followed by the reducing sugars (fructose and glucose) and sorbitol. 'Pink Ring' (72.96%), 'Nectabelle' (72.90%), and 'Nectabigfer' (72.15%) had the highest sucrose concentration and 'Fairlane' (55.74%), 'August Red' (56.28%), and 'Endogust' (59.54%) the lowest. 'Amiga' (15.42%) and 'Fairlane' (15.31%), followed by 'IFF 331' (13.27%), had the highest glucose concentration and 'Nectavanpi' (6.65%), 'Nectapi' (6.75%), and 'Nectalady' (6.89%) the lowest. 'Amiga' (16.82%), together with 'Azurite' (15.11%) and 'IFF 331' (13.51%), had the highest fructose concentration and 'Nectalady' (6.77%), 'Nectavanpi' (7.09%), and 'UFO 3′ (7.13%) the lowest. Glucose and fructose had comparable concentrations, which supports the findings of other studies.[44,45] Since fructose is rated higher (1.75) than sucrose (1) and glucose (0.75) in terms of sweetness,[28] those cultivars which in general had a high fructose percentage presented the highest sweetening power (R^2 = 0.80). These cultivars were 'Amiga' (102.46), 'Mesembrine' (100.51), and 'Azurite' (100.45). 'Nectalady' (91.02), 'Nectavanpi' (91.91), and 'UFO 8' (92.33) showed the lowest sweetening power. Finally, the levels of sorbitol, a polyalcohol sugar, were very low and relatively variable in terms of total sugar content (from 1.07% to 15.99% of the total sugar content). Sorbitol plays an important role in the texture and flavor of peach nectarine fruits.[36] Sorbitol is also an interesting polyalcohol in terms of nutrition for special dietary purposes, such as diet control or dental health.[46,47] Therefore, those genotypes with the highest sorbitol percentage, namely, 'Nectalady', 'August Red', and 'Nectafine' (15.99%, 14.60%, and 14.20%, respectively), could be of interest for peach breeders[47] to use as genitors to transmit this trait. The fact that the sorbitol content is always low in peach and nectarine fruit suggests that sorbitol is metabolized into reducing sugars.[48]

The main acids in stone fruits are malic acid, citric acid, quinic acid, and traces of shikimic acid.[44] For all cultivars evaluated, malic acid was, in general, the most abundant acid at maturity (42.92−84.30% of the total acid content), followed by quinic acid (14.56−57.54%), citric acid (3.72−31.61%), and traces of shikimic acid (0.14−1.89%) (Table 3), as also reported by several authors.[44,49,50] However, some studies have reported citric acid to be the second[35,44] and quinic acid[35,50] the third most abundant organic acid in most peach and nectarine cultivars. Among cultivars, 'Nectaroyal' (84.30%), 'Nectafine' (77.90%), and 'IFF 813' (75.63%) presented the highest malic acid content and 'Nectabigfer' (42.92%), 'ASF 06−90' (43.92%), and 'Platifirst' (45.82%) the lowest. The range found in quinic acid was 4-fold, while in citric and shikimic acids it was 10-fold. 'Nectareine' (57.54%), followed by 'IFF 331' (48.62%) and 'UFO 4' (43.26%), showed the highest quinic acid content and 'Fire Top' (14.56%), 'NG-187' (15.76%), and 'Big Bel' (15.80%) the lowest. Wu et al.[51] reported that quinic acid imparts a slightly sour and bitter taste and has antibacterial properties beneficial to health. 'IFF 1182' (31.61%), 'Noracila' (31.02%), and 'Amiga' (30.84%) had the highest citric acid content and 'UFO 8' (3.72%), 'Ferlot' (3.73%), and 'Hesse' (3.74%) the lowest. Finally, 'UFO 3′ (1.89%), 'UFO 4' (1.09%), and 'Platifirst' (1.06%) had the highest shikimic acid content and 'PI 2/84' (0.14%), 'Catherina' (0.21%), and 'Alice' (0.23%) the lowest.

RAC and anthocyanin content also showed a wide range of variability (Table 3). RAC varied from 144.20 to 711.73 μg of Trolox g^{-1} of FW among cultivars. 'Nectapink' (711.73 μg of Trolox g^{-1} of FW), followed by 'Fercluse' (568.64 μg of Trolox g^{-1} of FW) and 'Grenat' (566 μg of Trolox g^{-1} of FW), had the highest RAC value, and 'Azurite' (144.20 μg of Trolox g^{-1} of FW), 'Nectadiva' (184.42 μg of Trolox g^{-1} of FW), and 'Sweetbella' (191.46 μg of Trolox g^{-1} of FW) had the lowest values. Values in a similar range were obtained in other studies with peach cultivars,[17,52] but lower than in other studies where peel was included in the test sample (700−6000 μg of Trolox g^{-1} of FW)[53,54] due to unequal distribution of phenolic compounds in the flesh (∼30%) and skin (∼70%).[55] On average, unpeeled fruit contains 1.5-fold higher levels of phenolics than peeled fruit.[56] Cyanidin-3-glucoside has been identified as the main anthocyanin in *P. persica* along with a smaller amount of cyanidin-3-rutinoside.[56−59] The total anthocyanin content varied greatly among cultivars, ranging from 0.7 to 11.43 mg of C3GE kg^{-1} of FW (C3GE = cyanidin-3-glucoside equivalents), depending on the percentage of red pigmentation of the flesh. In this study, cultivars with red endocarp flesh such as 'Nectareine' (11.43 mg of C3GE kg^{-1} of FW), 'Onyx' (10.15 mg of C3GE kg^{-1} of FW), and 'IFF 1233' (9.92 mg of C3GE kg^{-1} of FW) had higher anthocyanin content than nonmelting peach cultivars of pure yellow flesh such as 'PI 2/84' (0.94 mg of C3GE kg^{-1} of FW), 'Feraude' (0.92 mg of C3GE kg^{-1} of FW), 'Ferlot' (0.89 mg of C3GE kg^{-1} of FW), and 'African Bonnigold' (0.70 mg of C3GE kg^{-1} of FW).

In this work it was also observed that the fruit type and flesh color had no direct effect on the cultivar for all quality traits evaluated, except for anthocyanin content in the case of flesh color. One example of this was observed in the case of RAC (Figure 1).

All cultivars were grown under the same environmental conditions and cultivation practices; thus, the differences observed in all quality traits should be attributable to the cultivar effect. This indicated that adequate genetic variability is present for the potential development of new cultivars with enhanced fruit quality.

Breeding Program. A comparison between cultivars depending on the breeding program selected and for a given fruit type (melting peach, nectarine, and flat peach) was carried out for fruit quality, sensorial, nutritional, and antioxidant capacity traits (Table 4). The nonmelting peach type was not included in this section due to the limited number of breeding programs; a minimum of three cultivars were required for statistical comparisons to be possible.

ASF melting peaches showed in general higher SSC compared to the others (Table 4). Moreover, together with Mounteaux-Callet and CRA, they had the highest TA, followed by Zaiger and A. Minguzzi melting peaches. In spite of these differences, great variability was observed in TA within each breeding program (data not shown), mainly due to the fact that each breeding program had sweet and nonsweet cultivars. A. Minguzzi, Zaiger, and ASF melting peaches had the highest sweetness scores, followed by INRA, CRA, and Monteaux-Callet melting peaches. The last one also showed the highest sourness and lowest flavor and were the least rated melting peaches and together with CRA melting peaches showed the highest percentage of fructose compared to the others. Owing to the important role of sorbitol in the texture and flavor of peach and nectarine fruits,[36] this interesting trait was valued, among others, in the Zaiger breeding program. In general, high malic acid content coincided with low quinic acid content when

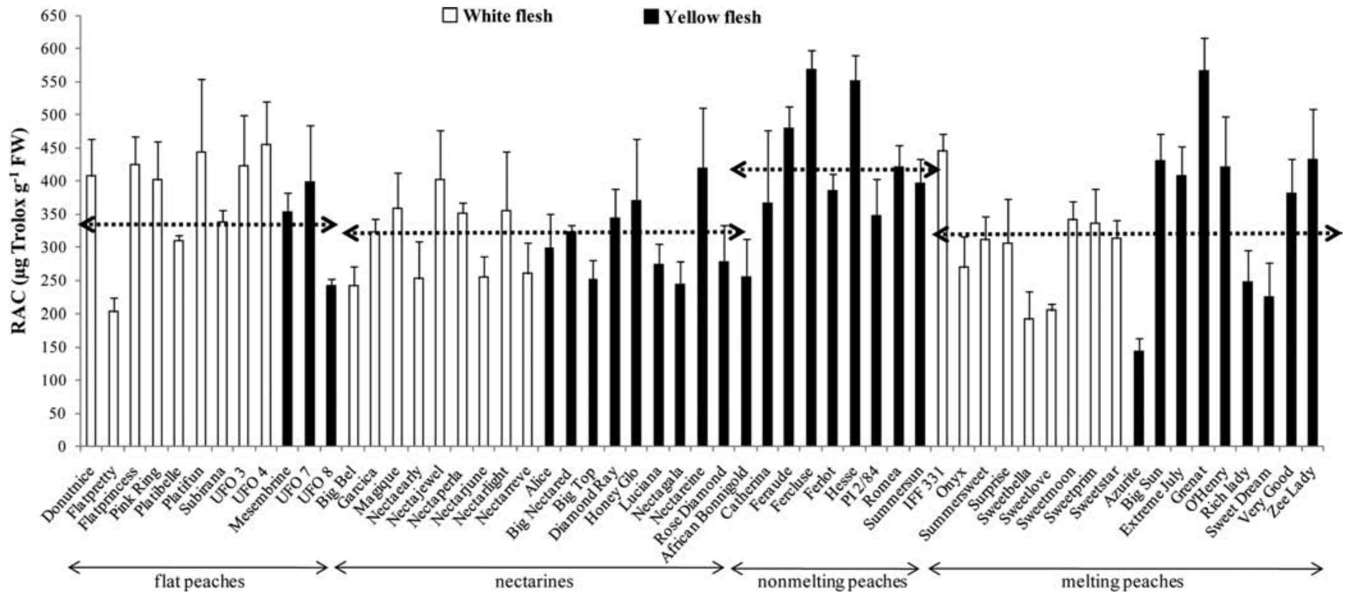

Figure 1. Fruit RAC (DPPH method) of flat peach, nectarine, nonmelting peach, and melting peach cultivars: white bars, white flesh; black bars, yellow flesh. Values are the mean ± standard error (n = 6). Lines show averages for flat peaches, nectarines, nonmelting peaches, and melting peaches.

melting peach breeding programs were compared. Monteaux-Callet melting peaches showed the highest citric acid and anthocyanin contents.

Among nectarine breeding programs, SSC was higher in ASF compared to the other programs (Table 4). Significantly higher TA was observed for Bradford cultivars compared to the others. ASF and PSB nectarines had the highest sweetness. PSB nectarines showed the lowest sourness, highest flavor, highest overall scores, and highest percentage of sucrose and sucrose/glucose ratio. The high glucose and fructose values from A. Minguzzi nectarines gave them the highest sweetener potency. In contrast, despite high sorbitol percentage and high total sugar content, ASF nectarines had the lowest sweetener potency. In general, high citric and malic acid contents coincided with low quinic acid content. ASF nectarines had the highest shikimic acid content and Bradford and Zaiger nectarines the highest total acid content, followed by A. Minguzzi, ASF, and PSB nectarines. The last one also showed the highest anthocyanin content.

ASF flat peaches had significantly higher SSC, TA, and sourness values than the CRA and INRA flat peaches (Table 4). This was due to the higher mean TA (11 g of malic acid L^{-1}) from 'Donutnice' compared to the mean TA (3.25 g of malic acid L^{-1}) from the remaining ASF cultivars. Moreover, ASF flat peaches had the highest total sugar content and sweetener potency as a result of their high glucose, fructose, and sorbitol percentages.

The breeding program had a significant influence on these quality traits; however, each breeding program had specific characteristics that distinguished it from the others. Even so, within each breeding program there is high variability among cultivars. Therefore, growers should not base their strategy exclusively on the choice of breeding program.

Qualitative Trait Effect. Significantly differences were observed among fruit types (Table 5). Yellow melting peaches showed the highest fructose content compared to the others. White melting peaches were the best rated by the expert panel. Yellow nectarines showed the highest sorbitol content and white nectarines the highest citric acid content. Nonmelting peaches showed the highest malic acid and RAC mean value. Finally, white flat peaches showed the highest sucrose and shikimic acid contents compared to the others. The results from this study were partly in agreement with the study of 14 peach progenies carried out by Cantín et al.,[36] who reported that nectarine fruits showed higher SSC, glucose content, total sugar content, and glucose/fructose ratio than melting peach fruits, probably because more subacid cultivars were selected. Kader [60] considered mean values of SSC over 10 °Brix as the minimum value for consumer acceptance for yellow-flesh nectarines. In this study, all fruit types provided values above 12 °Brix, which is common in warm climates and considering the entire range of cultivars.

Yellow-fleshed cultivars showed the highest sorbitol and malic acid content (Table 5). Yellow-red-fleshed cultivars had the highest glucose and fructose mean values. White-fleshed cultivars had the highest flavor and sucrose, citric acid, and shikimic acid contents and were the best rated. White-red-fleshed cultivars had the highest glucose/fructose ratio, and together with yellow-red-fleshed cultivars, they showed the highest anthocyanin content. These results were in agreement with those obtained by Vizzoto et al.,[18] who reported that peach cultivars with red-colored flesh had higher anthocyanin content than light-colored flesh cultivars. Cantín et al.[17] and Gil et al.[54] reported that white-fleshed cultivars showed higher antioxidant capacity than yellow-fleshed ones. In addition, Vizzotto et al.[18] reported that the antioxidant activity of red-fleshed cultivars was higher than that of light-colored flesh cultivars of peach. Nevertheless, this study was not in agreement with theirs. On the other hand, Cantín et al.[36] and Robertson et al.[61] reported higher SSC and individual and total sugar contents in white-fleshed fruits than in yellow-fleshed cultivars. It is assumed that white- and yellow-fleshed cultivars differ in acidity and sugar composition, and this may contribute to the different preferences shown by groups of consumers.[36] Nevertheless, this study showed similar results in glucose and fructose between white- and yellow-fleshed cultivars.

Flat peach cultivars have been reported to have excellent flavor with a sweet taste, low TA, and high sugar content,

Table 4. Mean Values of Quality, Antioxidant Capacity, and Anthocyanin and Nutrient Content Traits by Fruit Type and Origin (Nonmelting Peach Is Not Included) over the 2010 and 2011 Seasons[a]

		melting peach					nectarine					flat peach		
quality trait	mean ± MSE[b]	A. Minguzzi (3)[c]	ASF (7)	CRA (5)	Monteaux-Callet (3)	Zaiger (5)	A. Minguzzi (3)	ASF (25)	Bradford (4)	PSB (4)	Zaiger (9)	ASF (7)	CRA (5)	INRA (5)
SSC (°Brix)	13.01 ± 0.10	11.79 ab	12.57 a	11.72 ab	11.02 b	12.34 ab	11.73 b	14.01 a	12.55 ab	12.37 b	12.91 ab	14.28 a	12.44 b	13.03 b
TA (g of malic acid L^{-1})	4.93 ± 0.11	2.94 b	5.01 a	5.39 a	6.37 a	4.71 ab	6.78 b	4.46 c	9.20 a	4.31 c	6.69 b	4.34 a	2.53 b	3.16 b
RI	3.33 ± 0.07	4.18 a	3.43 ab	2.79 ab	2.34 b	3.31 ab	2.00 bc	3.48 a	1.43 c	2.96 ab	2.36 b	4.33	5.98	4.24
sweetness	7.22 ± 0.07	7.47 a	6.89 a	6.60 ab	5.82 b	7.32 a	6.38 b	7.55 a	6.21 b	7.84 a	6.71 b	7.76	7.69	7.63
sourness	6.04 ± 0.10	4.85 b	6.43 ab	6.31 ab	7.42 a	6.08 ab	7.14 ab	5.96 bc	8.51 a	5.25 c	7.37 a	5.14 a	3.79 b	4.49 ab
flavor	5.92 ± 0.07	5.77 ab	5.51 ab	5.24 bc	4.38 c	6.30 a	4.88 c	6.15 b	5.65 bc	7.24 a	5.49 bc	6.57 a	5.77 b	6.32 ab
overall score	5.07 ± 0.05	5.12 ab	4.71 b	4.63 b	3.43 c	5.55 a	4.18 c	5.18 b	4.75 bc	6.13 a	4.79 bc	5.45	5.15	5.67
sucrose content (%)	6.48 ± 0.18	68.70	68.00	66.81	66.12	67.22	63.09 d	67.94 b	63.70 cd	70.65 a	66.29 bc	67.24 b	70.81 a	67.67 b
glucose content (%)	10.10 ± 0.09	10.41	10.27	10.93	10.41	10.44	13.20 a	9.37 d	11.31 b	9.0 cd	10.33 bc	10.41 a	8.31 b	10.90 a
fructose content (%)	10.61 ± 0.10	11.58 ab	10.69 ab	11.71 a	12.41 a	10.07 b	14.08 a	9.65 d	11.74 b	9.73 cd	11.00 cd	10.94 a	8.61 b	11.60 a
sorbitol content (%)	5.35 ± 0.16	2.73 c	4.39 ab	3.83 bc	3.63 c	5.54 a	4.12 bc	6.66 ab	7.74 a	3.22 c	6.16 ab	5.65 a	4.45 ab	3.48 b
sucrose/glucose ratio	7.00 ± 0.08	6.89	6.87	6.33	6.63	6.74	4.94 c	7.63 a	5.65 bc	7.89 a	6.60 b	6.55 b	8.79 a	6.37 b
glucose/fructose ratio	0.97 ± 0.01	0.92 ab	0.90 ab	0.94 a	0.87 b	1.05 a	0.94	0.98	0.98	0.94	0.94	0.95	0.97	0.94
total sugar content[d] ($g\ L^{-1}$)	127.54 ± 1.27	120.15 ab	122.51 a	112.19 ab	101.03 b	110.75 a	108.55 b	142.02 a	122.67 b	122.32 b	124.49 b	135.60 a	127.96 ab	118.87 b
sweetener potency	96.84 ± 0.11	98.42 a	97.06 ab	97.82 a	97.84 a	96.00 b	100.12 a	95.86 c	97.38 b	96.44 bc	97.00 b	97.59 a	94.80 b	98.25 a
malic acid content (%)	56.85 ± 0.48	57.72 a	61.99 a	48.48 b	56.66 a	61.42 a	58.22	57.84	59.22	56.82	57.05	54.94	52.55	51.94
citric acid content (%)	14.19 ± 0.36	14.49 ab	13.00 b	11.74 b	20.16 a	12.26 b	21.7 a	11.97 b	20.07 a	19.94 a	18.25 a	11.821 b	8.09 c	15.84 a
quinic acid content (%)	0.60 ± 0.02	27.21 ab	24.40 b	31.70 a	22.68 b	25.66 b	19.63 b	28.00 a	18.74 b	22.66 b	22.74 b	32.48 b	38.33 a	31.42 b
shikimic acid content (%)	27.20 ± 0.38	0.57	0.59	0.38	0.48	0.64	0.40 ab	0.60 a	0.35 b	0.56 ab	0.47 ab	0.74	1.01	0.78
total acid content[e] ($g\ L^{-1}$)	9.60 ± 0.16	7.10 b	8.95 b	11.73 a	9.98 ab	8.77 b	10.62 ab	9.51 b	13.39 a	8.51 b	11.70 a	9.11 a	7.19 ab	7.46 b
RAC (μg of Trolox g^{-1} of FW)	325.24 ± 6.76	347.12	289.61	321.55	326.43	319.1	275.34	328.12	343.57	307.77	316.88	334.73	383.72	329.23
anthocyanin content (mg of C3G kg^{-1} of FW)	3.67 ± 0.16	2.91 b	3.50 b	3.72 ab	6.75 a	2.89 b	5.39 ab	3.29 b	4.02 ab	6.36 a	3.80 ab	3.37	2.19	3.23

[a]Abbreviations: SSC, soluble solids content; TA, titratable acidity; RI, ripening index; RAC, relative antioxidant capacity; C3G, cyanidin-3-glucoside. Mean separation within rows by Tukey's test ($p \leq 0.05$). In each row by fruit type values with the same letter are not significantly different. [b]Mean value and mean standard error considering all breeding programs evaluated together. [c]Number of cultivars tested. [d]Sum of sucrose, glucose, fructose, and sorbitol for each cultivar. [e]Sum of malic, citric, quinic, and shikimic acids for each cultivar.

Table 5. Mean Values of Quality, Antioxidant Capacity, and Anthocyanin and Nutrient Content Traits Associated with Qualitative Pomological Traits from 106 Commercial Peach Cultivars over the 2010 and 2011 Seasons[a]

	fruit type							flesh Color				fruit shape		group and TA range	
quality trait	YPE (18)[b]	WPE (10)	YNE (38)	WNE (13)	NMP (9)	YFP (3)	WFP (15)	Y (54)	YR (14)	W (21)	WR (17)	R (88)	F (18)	SW (70)	NSW (36)
SSC (°Brix)	12.06 b	12.14 b	13.28 a	13.68 a	12.71 ab	13.16 ab	13.42 a	13.05 ab	12.25 c	13.59 a	12.58 bc	12.88 b	13.37 a	13.07	12.77
TA (g of malic acid L $^{-1}$)	4.95 a	5.11 a	5.73 a	5.32 a	5.51 a	2.94 b	3.58 b	5.22 a	5.94 a	3.83 b	5.43 a	5.46 a	3.47 b	3.70 b	7.88 a
RI	3.03 bc	3.41 b	2.86 bc	2.85 bc	2.51 c	4.96 a	4.69 a	3.01 b	2.66 b	4.05 a	3.17 b	4.47 a	2.90 b	3.88 a	1.78 b
sweetness	6.94 bc	6.53 c	7.10 bc	7.17 abc	6.55 c	7.89 a	7.68 a	6.98 b	7.15 ab	7.67 a	6.64 b	6.95 b	7.71 a	7.50 a	6.26 b
sourness	6.42 a	6.41 a	6.55 a	6.78 a	6.94 a	4.67 b	4.60 b	6.51 a	6.38 a	5.15 b	6.55 a	6.60 a	4.62 b	5.19 b	8.34 a
flavor	5.93 ab	5.07 c	5.91 ab	5.98 ab	5.50 bc	6.26 a	6.27 a	5.88 b	5.85 b	6.34 a	5.27 c	5.75 b	6.27 a	6.05 a	5.43 b
overall score	5.33 ab	5.43 a	5.00 b	4.39 c	4.87 bc	5.02 ab	4.87 bc	5.00 b	4.99 b	5.44 a	4.49 c	4.92 b	5.41 a	5.24 a	4.55 b
sucrose content (%)	66.81 bc	68.77 abc	66.42 c	67.98 abc	68.40 ab	67.72 abc	68.61 a	67.10 bc	65.91 c	68.91 a	67.52 ab	67.12 b	68.46 a	68.41 a	64.67 b
glucose content (%)	10.40	10.50	10.21	10.15	10.57	9.84	9.96	10.15 b	10.87 a	9.92 b	10.46 ab	10.32	9.99	9.80	11.4
fructose content (%)	11.56 a	10.55 ab	10.67 ab	10.34 b	11.18 ab	10.52 ab	10.47 b	10.80 b	11.69 a	10.37 b	10.55 b	10.84	10.48	10.31 b	11.95 a
sorbitol content (%)	4.69 b	3.75 b	6.47 a	5.34 ab	3.58 b	5.32 ab	4.50 b	6.66 a	5.06 ab	4.38 b	4.80 ab	5.36	4.63	4.92 b	6.03 a
sucrose/glucose ratio	6.60	6.86	6.90	7.04	6.59	7.40	7.10	6.94 a	6.22 b	7.24 a	6.73 ab	6.80 b	7.15 a	7.27 a	5.81 b
glucose/fructose ratio	0.91	1.00	0.97	0.98	0.95	0.93	0.95	0.95 b	0.93 b	0.96 ab	1.00 a	0.96	0.95	0.96	0.97
total sugar content[c] (g L^{-1})	117.91 bc	114.91 c	131.37 a	133.04 a	123.57 abc	129.89 ab	128.93 ab	129.90 a	113.40 b	131.89 a	119.86 b	126.22	129.09	129.78 a	118.99 b
sweetener potency	97.66 a	96.77 ab	96.66 ab	96.88 ab	98.05 a	96.72 ab	97.11 ab	97.01	97.57	97.13	96.72	97.06	97.04	125.51 a	116.38 b
malic acid content (%)	59.32 ab	58.8 ab	59.4 ab	56.57 bc	62.68 a	55.12 bc	53.15 c	60.72 a	55.13 b	55.25 b	56.35 b	58.74 a	53.48 b	57.24 b	59.38 a
citric acid content (%)	13.37 bc	14.37 abc	15.25 ab	17.50 a	10.37 c	10.69 c	12.11 bc	12.70 b	18.53 a	12.51 b	16.82 a	14.37 a	11.87 b	12.17 b	18.41 a
quinic acid content (%)	26.76 b	26.21 b	24.87 b	25.32 b	26.63 b	33.50 a	33.86 a	26.07 b	25.84 b	31.47 a	26.17 b	25.68 b	33.80 a	28.88 a	22.52 b
shikimic acid content (%)	0.54 b	0.59 b	0.52 b	0.59 b	0.30 c	0.67 ab	0.87 a	0.50 b	0.48 b	0.76 a	0.64 ab	0.51 b	0.83 a	0.65 a	0.36 b
total acid content[d] (g L^{-1})	8.99 bc	9.13 ab	9.95 a	9.92 a	9.93 a	7.53 c	8.29 c	9.59 a	9.52 ab	8.49 b	9.72 a	10.04 a	8.07 b	8.66 b	12.36 a
RAC (μg of Trolox g $^{-1}$ of FW)	354.45 ab	289.25 c	326.42 b	332.10 b	418.65 a	330.75 b	350.25 ab	349.41 a	336.75 ab	355.03 a	294.97 b	349.75	349.18	337.38	340.12
anthocyanin content (mg of C3G kg $^{-1}$ of FW)	3.48 a	4.35 a	3.88 a	3.53 a	1.49 b	2.70 ab	3.13 ab	2.90 b	5.33 a	2.93 b	4.40 a	3.68	3.17	3.75 a	3.01 b

[a]Abbreviations: SSC, soluble solids content; TA, titratable acidity; RI, ripening index; RAC, relative antioxidant capacity; C3G, cyanidin-3-glucoside; YPE, yellow melting peach; WPE, white melting peach; YNE, yellow nectarine; WNE, white nectarine; NMP, nonmelting peach; YFP, yellow flat peach; WFP, white flat peach; Y, yellow; YR, yellow-red; W, white; WR, white-red; R, round; F, flat; SW, sweet; NSW, nonsweet. Mean separation within rows by Tukey's test ($p \leq 0.05$). In each row values with the same letter are not significantly different. [b]Number of cultivars tested. [c]Sum of sucrose, glucose, fructose, and sorbitol for each cultivar. [d]Sum of malic, citric, quinic, and shikimic acids for each cultivar.

Table 6. Sweetness, Sourness, SSC, TA, Individual Sugar and Individual Organic Acid Contents of Three Sweet Cultivars and Three Nonsweet Cultivars over the 2010 and 2011 Seasons[a]

cultivar	group and TA range	sweetness	sourness	SSC (°Brix)	TA (g of malic acid L^{-1})	sucrose content (%)	glucose content (%)	fructose content (%)	malic acid content (%)	citric acid content (%)	quinic acid content (%)
Amiga	nonsweet	4.43 c	7.80 b	10.82	7.40 b	60.03 b	15.41 a	16.82 a	48.09 c	30.84 a	20.58 b
Diamond Ray	nonsweet	6.50 b	9.55 a	13.22	10.21 a	64.63 ab	11.54 b	12.16 b	60.05 ab	22.75 b	16.90 b
Rose Diamond	nonsweet	5.73 b	7.01 bc	10.65	6.02 c	65.36 ab	10.56 bc	9.89 b	65.31 ab	16.69 bc	19.27 b
Big Top	sweet	8.46 a	5.52 cd	11.45	4.59 d	65.87 ab	10.09 bc	11.09 b	45.87 c	22.66 b	31.01 a
Gardeta	sweet	8.31 a	5.14 d	13.20	4.11 de	71.53 a	8.51 c	9.47 b	52.78 bc	17.86 bc	28.85 a
Luciana	sweet	6.92 ab	5.85 cd	11.77	3.21 e	70.30 a	9.07 bc	9.89 b	65.29 a	11.94 c	22.08 b

[a]Abbreviations: SSC, soluble solids content; TA, titratable acidity. Mean separation within columns by Tukey's test ($p \leq 0.05$). In each column values with the same letter are not significantly different.

around 7.3% greater SSC than round peach cultivars.[37,62] This agrees with the results obtained, although the flat peach SSC was 5% higher than the round peach SSC (Table 5).

By group and TA range (Table 5), sweet cultivars showed higher sweetness, flavor, overall score, RI, sucrose and total sugar content, sweetener potency, and quinic acid, shikimic acid, and anthocyanin content than nonsweet cultivars. Sourness, TA, and fructose, sorbitol, malic acid, citric acid, and total acid contents were significantly higher in nonsweet cultivars than sweet cultivars. However, Picha et al.[63] reported that low-acid (or sweet) cultivars contain less malic acid than normal cultivars at any stage during development. On the other hand, no differences were observed in SSC between sweet and nonsweet cultivars. One example of this result is shown in Table 6, where sweet cultivars ('Big Top', 'Gardeta', and 'Luciana') were compared to nonsweet cultivars ('Amiga', 'Diamond Ray', and 'Rose Diamond'). They differed mainly in TA value and the perception of sourness. Liverani et al.,[64] when comparing sweet to nonsweet cultivars, have reported that TA is from 3 to 5 times higher and RI at commercial harvest is 3−4 fold higher. In the present study we also found these differences in TA and RI between the two groups of cultivars, though the magnitude of difference was only a factor of 2−3, in agreement with those reported by Iglesias and Echeverría.[24]

The influence of qualitative pomological characteristics on these quality traits indicates that they also play an important role in determining fruit quality.

Correlations among Fruit Quality Traits. Pearson's correlation coefficients between pairs of traits are shown in Table 7. Among individual sugars, the highest correlations were positively found between glucose and fructose ($r = 0.72$, $p \leq 0.01$), as reported by other authors.[36,52,65] Sweetener potency was highly correlated with glucose ($r = 0.70$, $p \leq 0.01$) and fructose ($r = 0.82$, $p \leq 0.01$).

Malic acid was significantly negatively correlated with quinic acid ($r = -0.61$, $p \leq 0.01$). However, several studies[16,51,65] have found a positive correlation between malic and quinic acids.

In this study, a poor correlation was found between RAC and anthocyanin content. This result suggests that the anthocyanin content has little effect on the antioxidant capacity in peaches and nectarines due to their lower anthocyanin content compared to strawberries, raspberries, or plums. Nevertheless, this study suggests that the anthocyanin trait should be taken into consideration and included in breeding programs for the selection of higher fruit quality cultivars, mainly because many breeding programs improve new cultivars with red or orange flesh, mainly to attract consumers due to health benefits from anthocyanins.[66,67] Sweetness is mostly attributable to mono- and disaccharides rather than to other compounds.[23,35] However, we found that sweetness had a high significant correlation with flavor ($r = 0.72$, $p \leq 0.01$), as reported by López et al.[68] and Crisosto et al.,[21] and overall score ($r = 0.64$, $p \leq 0.01$) (Table 6).

Flavor had a high significant correlation with overall score ($r = 0.76$, $p \leq 0.01$). Kader[69] and Byrne[70] suggested that to provide better tasting fruits and vegetables to consumers, one of the main objectives to achieve this was to replace poor-flavor cultivars with good-flavor cultivars from among those that already exist and/or by selecting new cultivars with desirable flavor and textural quality.

Many authors have reported a not very high correlation between SSC and total sugar content for citrus[71] and peach[35,36] cultivars, probably owing to the contribution of optically active soluble compounds (pectins, salts, and organic acids) other than sugars and the high correlation between SSC and organic acids.[51] However, high correlation between SSC and total sugar content ($r = 0.72$, $p \leq 0.01$) was found.

Principal Component Analysis and Grouping of Cultivars. PCA was applied to describe all the information contained in the data set to detect the most important variables for data structure determination. This can help to select a set of cultivars with better quality performance[72] and to determine the best cultivars for each fruit type.

The results for melting peach cultivars are presented in Figure 2A. The variances explained by the first two PCs were 34% and 22%, respectively. This biplot showed a clear separation among melting peach cultivars. Strong relationships were found among sourness, TA, and total acid content (TAC) and between overall score and sweetness. Positive values for PC1 suggested cultivars that have higher values of sweetness, overall score, RI, and quinic acid and shikimic acid contents and lower values of sourness, TA, citric acid content, and TAC. Cultivars such as 'Azurite', 'IFF 1230', 'Onyx', 'PG 3/719', 'Summersweet', and 'Sweetmoon' belong to this group. Flavor, SSC, glucose, fructose, sorbitol, and total sugar (TS) contents, and sweetener potency (SP) exhibited positive values for PC2, whereas sucrose and anthocyanin contents showed negative values. Cultivars such as 'Big Sun', 'Fullred', 'Grenat', 'IFF 1233', 'IFF 331', 'Sweetprim', 'Sweetstar', and 'Very Good' belong to this group.

As for nectarine cultivars, the first two PCs accounted for 61% of the total variance (Figure 2B). Sweetness, flavor, overall score, RI, and shikimic acid content exhibited positive values for PC1, while glucose and fructose contents and SP exhibited

Table 7. Pearson's Correlation Coefficients between Traits in 106 Commercial Peach Cultivars over the 2010 and 2011 Seasons[a]

quality trait	sweetness	sourness	flavor	overall score	SSC	RI	TA	sucrose content	glucose content	fructose content	sorbitol content	total sugar content[b]	sweetener potency	malic acid content	citric acid content	shikimic acid content	quinic acid content	total acid content[c]	RAC
sourness	−0.37**																		
flavor	0.72**	−0.14**																	
overall score	0.64**	−0.22**	0.76**																
SSC	0.30**	NS	0.21**	0.22**															
RI	0.38**	−0.63**	0.19**	0.29**	0.37**														
TA	−0.38**	0.72**	−0.21**	−0.31**	NS	−0.82**													
sucrose content	0.25**	−0.29**	0.16**	0.26**	−0.14**	0.30**	−0.44**												
glucose content	−0.29**	0.35**	−0.18**	−0.23**	−0.15**	−0.35**	0.37**	−0.56**											
fructose content	−0.29**	0.28**	−0.17**	−0.25**	−0.17**	−0.38**	0.35**	−0.68**	0.72**										
sorbitol content	NS	0.08*	NS	NS	0.57**	NS	0.18*	−0.62**	−0.10**	NS									
total sugar content[b]	0.37**	NS	0.28**	0.34**	0.72**	0.38**	−0.18**	0.14**	−0.28**	−0.37**	0.46**								
sweetener potency	−0.15**	0.24**	NS	−0.08*	−0.12**	−0.24**	0.18**	−0.26**	0.70**	0.82**	−0.36**	−0.11**							
malic acid content	NS	0.24**	0.10**	NS	0.31**	NS	0.13**	−0.07*	NS	−0.15**	0.31**	0.31**	0.29**						
citric acid content	−0.26**	0.25**	−0.15**	−0.17**	−0.39**	−0.50**	0.42**	−0.24**	0.36**	0.46**	−0.22**	−0.46**	−0.42**	−0.29**					
shikimic acid content	0.21**	−0.13**	0.10**	0.19**	NS	0.29**	−0.34**	0.37**	−0.14**	−0.33**	−0.11**	0.32**	0.32**	0.13**	−0.24**				
quinic acid content	0.19**	−0.44**	NS	NS	0.10*	0.49**	−0.48**	0.19**	−0.26**	−0.15**	NS	NS	−0.12*	−0.61**	−0.40**	NS			
total acid content[c]	−0.18**	0.48**	−0.11**	−0.13*	NS	−0.49**	0.59**	−0.10**	0.16**	0.08*	NS	NS	NS	−0.20**	0.10**	−0.09*	0.12**		
RAC	NS	−0.12**	NS	NS	0.23**	NS	NS	−0.21**	−010*	0.11**	0.21**	NS	NS	NS	NS	−0.36**	NS	−0.17**	
anthocyanins content	−0.11**	−0.08*	−0.09*	NS	NS	NS	NS	NS	NS	NS	NS	−0.10*	−0.10*	−0.21**	0.22**	−0.10**	NS	NS	0.08*

[a]Abbreviations: SSC, soluble solids content; TA, titratable acidity; RI, ripening index; RAC, relative antioxidant capacity. One and two asterisks represent statistical significance at $p \leq 0.05$ and $p \leq 0.01$, respectively. NS = not significant. [b]Sum of sucrose, glucose, fructose, and sorbitol for each cultivar. [c]Sum of malic, citric, quinic, and shikimic acids for each cultivar.

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negative values. Strong relationships between overall score and flavor and among sweetness, RI, and shikimic acid content were found for PC1. 'Amiga', 'Fire Top', 'IFF 1182', 'Nectadiva', 'Nectalady', 'Nectapi', 'Nectapink', 'Nectatop', and 'Nectavanpi' were part of this group. Sucrose, citric acid, quinic acid, and anthocyanin contents showed positive values for PC2, while sourness, SSC, TA, sorbitol, TS, and malic acid contents, TAC, and RAC showed negative values. Strong relationships among SSC and sorbitol, TS, and malic acid content were found for PC2. 'August Red', 'Fairlane', 'IFF 813', and 'Noracila' were characterized by these relationships.

The variances explained by the first two PCs for nonmelting peaches were 52% and 15% (Figure 2C), respectively. Positive values for PC1 suggested cultivars with high sourness, TA, glucose and citric acid contents, and TAC and low sweetness, flavor, overall score, RI, and malic acid and quinic acid contents. 'African Bonnigold', 'Hesse', and 'PI 2/84' belong to this group. A strong relationship for SSC and sorbitol and TS contents was observed in PC2. Positive values for PC2 suggested cultivars with more sucrose and low SSC, RI, fructose, sorbitol, and TS contents, SP, and RAC, such as 'Catherina' and 'Romea'.

As expected, flat peach cultivars presented a different behavior compared to the other fruit types (Figure 2D). An examination of PC1 shows that the cultivar 'Donutnice' had high TA and TAC and low sucrose, quinic acid and shikimic acid contents, and examination of PC2 showed that 'ASF 06–90', 'Mesembrine', and 'Platifirst' had more sweetness, flavor, overall score, glucose and fructose contents, SP, and citric acid and anthocyanin contents and less sourness, SSC, sorbitol, TS, and malic acid contents, and RAC.

The most appropriate combination of these fruit quality, sensorial, nutritional, and antioxidant capacity traits should be considered by the breeder when planning future crosses to achieve higher quality value (good flavor, taste, health benefits, etc.)

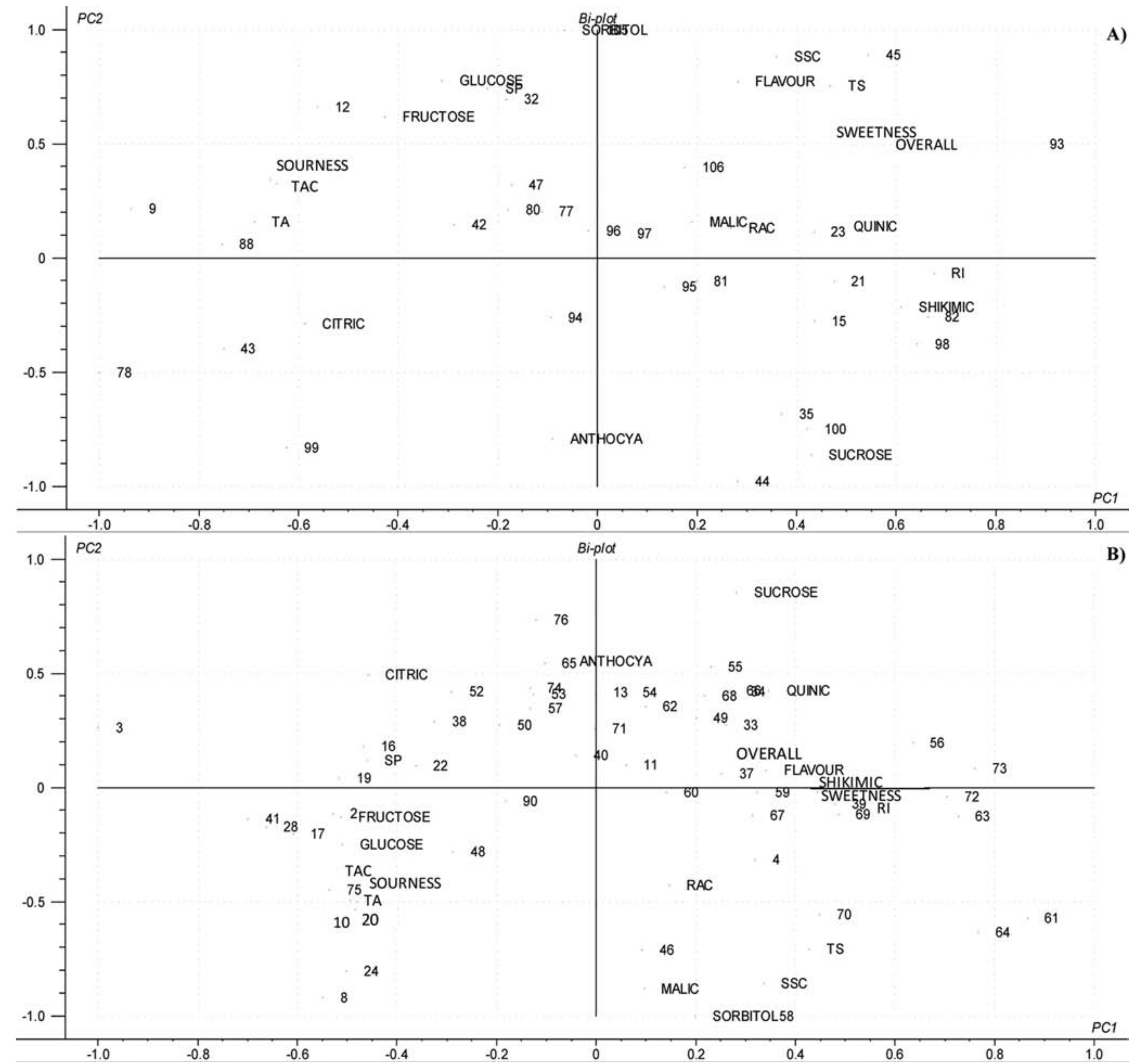

Figure 2. continued

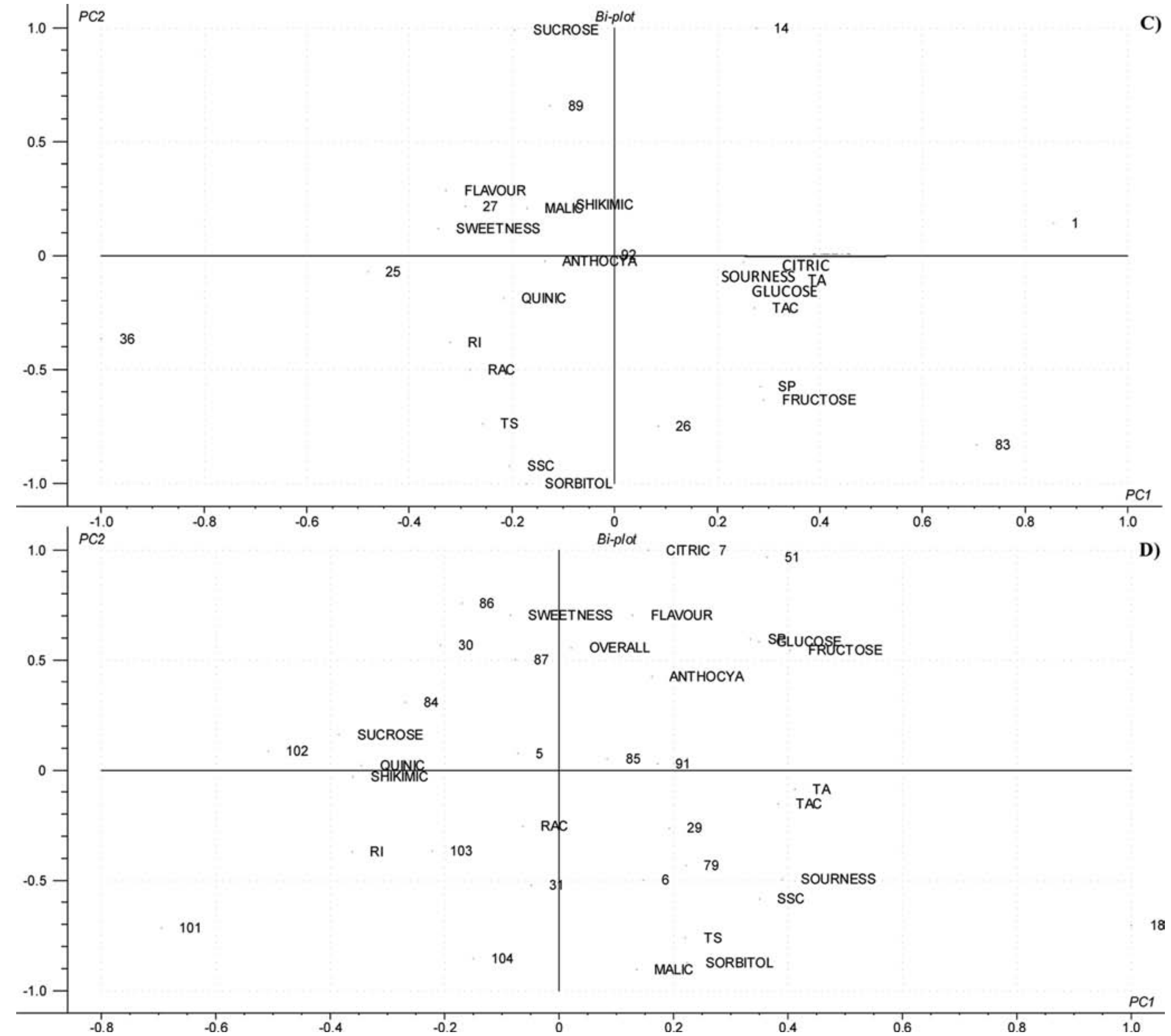

Figure 2. Segregation of the 106 peach cultivars, divided by fruit type [(A) melting peach, (B) nectarine, (C) nonmelting peach, and (D) flat peach], according to antioxidant capacity, quality, and anthocyanin and nutrient contents determined by PCA from the data of the 2010 and 2011 seasons. Abbreviations: SSC, soluble solids content; TA, titratable acidity; RI, ripening index; TS, total sugar content; SP, sweetener potency; TAC, total acid content; RAC, relative antioxidant capacity; Anthocya, anthocyanin content.

and by technicians and researchers to obtain more information about which peach cultivars will satisfy market and consumer demands. With these improved cultivars consumer expectations of fruits with high health benefits can be met.

■ AUTHOR INFORMATION

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