JOURNAL OF AGRICULTURAL AND FOOD CHEMISTRY

Antioxidant Capacities, Phenolic Compounds, Carotenoids, and Vitamin C Contents of Nectarine, Peach, and Plum Cultivars from California

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Genotypic variation in composition and antioxidant activity was evaluated using 25 cultivars, 5 each of white-flesh nectarines, yellow-flesh nectarines, white-flesh peaches, yellow-flesh peaches, and plums, at the ripe (ready-to-eat) stage. The ranges of total ascorbic acid (vitamin C) (in mg/100 g of fresh weight) were 5−14 (white-flesh nectarines), 6−8 (yellow-flesh nectarines), 6−9 (white-flesh peaches), 4−13 (yellow-flesh peaches), and 3−10 (plums). Total carotenoids concentrations (in μg/100 g of fresh weight) were 7−14 (white-flesh nectarines), 80−186 (yellow-flesh nectarines), 7−20 (white-flesh peaches), 71−210 (yellow-flesh peaches), and 70−260 (plums). Total phenolics (in mg/100 g of fresh weight) were 14−102 (white-flesh nectarines), 18−54 (yellow-flesh nectarines), 28−111 (white-flesh peaches), 21−61 (yellow-flesh peaches), and 42−109 (plums). The contributions of phenolic compounds to antioxidant activity were much greater than those of vitamin C and carotenoids. There was a strong correlation (0.93−0.96) between total phenolics and antioxidant activity of nectarines, peaches, and plums.

KEYWORDS: Stone fruit; *Prunus persica*; *Prunus salicina*; Rosaceae; phenolics; ascorbic acid; β-carotene; free radical scavenging activity

INTRODUCTION

Epidemiological studies have shown that consumption of fruit, vegetables, and derived food products have health benefits against chronic diseases including cardiovascular disease and certain types of cancer (*1*−*4*). The health-promoting properties of fruits and vegetables are due to the presence of some vitamins (A, C, E, and folates), dietary fiber, and nonessential phytochemicals in these food products. Among phytochemicals, polyphenols deserve a special mention due to their free radical scavenging activities and in vivo biological activities that are being investigated by many researchers (*4*−*8*).

In the past few years there has been a renewed interest in studying and quantifying the phenolic metabolites of fruits and vegetables due to their health-promoting properties. Fruit polyphenols include a wide range of compounds with antioxidant activity, that is, hydroxycinnamates, flavan-3-ols (condensed tannins), gallic acid derivatives (hydrolyzable tannins), flavonols, and anthocyanins. The phenolic composition of fruits varies greatly among cultivars. In a previous paper (*9*) we identified and quantified individual phenolic constituents of 25 California-grown cultivars of peaches, nectarines, and plums using a high-performance liquid chromatograph with a photodiode detector (HPLC-DAD) and high-performance liquid chromatography−electronspray ioniziation−mass spectrometry (HPLC-ESI-MS) methods. Peel tissues contain larger amounts of phenolics, anthocyanins, and flavonols than flesh tissues. Similar phenolic profiles were detected for both nectarines and peaches, and no differences were found between white-flesh and yellow-flesh cultivars.

The evaluation of fruit antioxidant capacity is not an easy task, as many methods can be used to determine this activity, and substrates, conditions, analytical methods, and concentrations can affect the estimated activity (*10*). We used two simple methods to evaluate the free radical scavenging capacity (DPPH method) (*11*) and the iron-reducing capacity (FRAP method) (*12*) of the fruit extracts, although we understand that these simple methods have some limitations (*10*). The aim of the present work was to determine the phenolic, carotenoid, and vitamin C contents plus the antioxidant capacity of ripe fruits of stone fruit cultivars. Both peel (skin) and flesh tissues were studied to estimate the relative contribution of these tissues to the nutritional value of nectarines peaches, and plums.

MATERIALS AND METHODS

Fruits. All fruits used were harvested at the "California mature" stage based on skin color and obtained from packinghouses in the Fresno area of California between June 2 and September 7, 1999, and

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10.1021/jf020136b CCC: $22.00
Published on Web 07/17/2002

Table 1. Quality Indices of White- and Yellow-Flesh Nectarines[a]

cultivar	skin color (*a** value)	flesh firmness (N)	soluble solids (%)	titratable acidity (%)	pH
white flesh					
Arctic Star	13.9 (9.0)	15.0 (4.3)	11.3 (1.4)	0.46 (0.01)	3.98 (0.03)
Arctic Queen	18.7 (9.9)	13.8 (3.4)	13.7 (0.1)	0.38 (0.03)	4.21 (0.09)
Arctic Snow	15.6 (13.6)	21.4 (5.3)	12.9 (0.9)	0.36 (0.05)	4.28 (0.12)
Fire Pearl	23.1 (11.2)	14.1 (3.6)	12.1 (0.7)	0.43 (0.06)	4.32 (0.10)
Brite Pearl	16.2 (10.9)	28.0 (6.0)	13.6 (1.2)	0.28 (0.04)	4.51 (0.09)
yellow flesh					
Red Jim	29.5 (6.3)	27.5 (7.3)	13.4 (1.0)	0.83 (0.12)	3.67 (0.07)
August Red	5.0 (3.7)	26.5 (7.6)	13.4 (0.4)	0.98 (0.07)	3.56 (0.01)
Spring Bright	28.0 (7.3)	15.9 (4.8)	15.3 (0.8)	0.91 (0.06)	3.64 (0.05)
May Glo	11.5 (8.0)	7.2 (1.2)	11.3 (1.0)	1.01 (0.03)	3.63 (0.04)
September Red	23.8 (9.2)	9.7 (1.8)	11.2 (0.2)	0.51 (0.07)	3.88 (0.11)

[a] Standard deviations ($n = 3$) in parentheses.

Table 2. Quality Indices of White- and Yellow-Flesh Peaches[a]

cultivar	skin color (*a** value)	flesh firmness (N)	soluble solids (%)	titratable acidity (%)	pH
white flesh					
Summer Sweet	22.0 (7.6)	5.3 (0.8)	11.9 (0.7)	0.20 (0.02)	4.75 (0.07)
Snow King	27.0 (6.9)	11.3 (3.3)	11.6 (1.1)	0.24 (0.02)	4.41 (0.11)
Snow Giant	14.6 (7.0)	7.9 (2.3)	11.0 (0.6)	0.20 (0.01)	4.51 (0.02)
Champagne	8.9 (9.9)	7.9 (2.6)	12.3 (1.5)	0.31 (0.04)	4.34 (0.08)
September Snow	5.9 (4.0)	9.7 (2.4)	9.3 (0.4)	0.13 (0.02)	4.98 (0.06)
yellow flesh					
Flavorcrest	19.3 (9.7)	19.1 (5.2)	12.9 (0.6)	0.73 (0.04)	3.67 (0.02)
Spring Lady	5.3 (4.8)	10.8 (2.9)	12.6 (0.5)	0.87 (0.08)	3.63 (0.04)
Rich Lady	23.8 (7.0)	14.1 (5.2)	11.9 (0.6)	0.84 (0.12)	3.50 (0.05)
O'Henry	26.6 (6.4)	8.3 (1.2)	11.2 (0.6)	0.45 (0.04)	3.72 (0.04)
September Sun	25.0 (7.3)	15.7 (5.9)	10.9 (0.5)	0.57 (0.02)	3.67 (0.02)

[a] Standard deviations ($n = 3$) in parentheses.

Table 3. Quality Indices of Plums[a]

cultivar	skin color (*a** value)	flesh firmness (N)	soluble solids (%)	titratable acidity (%)	pH
Wickson	10.2 (1.9)	12.1 (2.4)	10.3 (0.2)	0.41 (0.05)	4.04 (0.08)
Black Beaut	14.8 (4.9)	18.5 (6.8)	12.1 (0.3)	0.45 (0.08)	3.84 (0.11)
Red Beaut	21.8 (1.7)	7.6 (1.9)	9.9 (0.6)	0.48 (0.08)	3.86 (0.12)
Santa Rosa	24.0 (6.2)	16.9 (4.1)	13.8 (0.7)	0.55 (0.09)	3.87 (0.09)
Angeleno	6.4 (2.9)	19.5 (5.2)	13.5 (0.4)	0.31 (0.06)	4.35 (0.11)

[a] Standard deviations ($n = 3$) in parentheses.

transported in an air-conditioned car (for ~3−4 h) to the Postharvest Laboratory at the University of California, Davis. The characteristics of the different fruit cultivars (color by a Minolta colorimeter, firmness by a fruit penetrometer with an 8-mm tip, acidity by an automatic titration system, and soluble solids by a refractometer) were evaluated after ripening at 20 °C for 5 days (**Tables 1−3**). Fruits were peeled and four wedges cut vertically from each side of the fruit. The flesh and peel were frozen separately in liquid nitrogen and kept at −80 °C until analyzed. The frozen fruit was ground to a fine powder in liquid nitrogen before sampling to ensure uniformity, and three replicates of 10 fruits each were analyzed.

Extraction and Analysis of Vitamin C. Procedures used were as described by Wright and Kader (*13*) based on the method of Zapata and Dufour (*14*) for the determination of ascorbic acid and dehydroascorbic acid by HPLC.

Extraction and Analysis of Carotenoids. Procedures used were as described by Wright and Kader (*15*) based on the method of Hart and Scott (*16*) for the determination of carotenoids by HPLC.

Extraction of Phenolic Compounds. The extraction procedure was carried out as described in our previous paper (*9*). Five grams of frozen fruit with 10 mL of water/methanol (2:8) containing 2 mM NaF was homoginized, and the extracts were centrifuged (11500 rpm, 15 min, 2−5 °C) and filtered through a 0.45 μm filter to analyze by HPLC.

Phenolic Compound Identification and Quantification. Samples (20 μL of extract) were analyzed using an HPLC system (Hewlett-Packard 1050 pump) coupled with a photodiode array detector (DAD) (series 1040M, series II) and an autosampler (series 1050), operated by HP ChemStation software. A reversed phase C_{18} Nucleosil column (150 × 4.6 mm; particle size = 5 μm) with a guard column containing the same stationary phase (Safeguard holder 5001-CS) was used. The mobile phases and elution gradient were those previously described (*9*). The phenolic compounds in the stone fruit were identified by their UV spectra, recorded with a diode array detector, and HPLC-MS (electrospray), and, whenever possible, by chromatographic comparisons with authentic markers. Repeatability of the analyses was ±5%. Total phenolics were determined by summation of concentrations of the individual phenolic compounds, which were reported in our previous paper (*9*).

Antioxidant Activity Evaluation. Two methods were used to test the antioxidant activity of stone fruit. One was based on the evaluation of the free radical scavenging capacity of the extracts, and the other measured their iron-reducing capacity. The antioxidant activity of the different samples was compared to that of a commercial Cabernet Sauvignon red wine (1997) from California. Diluted samples in water of 1:20 (v/v) for red wine and from 1:2 to 1:12 for stone fruit were used. The free radical scavenging assay used a commercially available free radical (2,2 diphenyl-1-picrylhydrazyl, $DPPH^{\bullet+}$), which is soluble in methanol (*11*), and the antioxidant activity measured the decrease in absorbance at 515 nm. The FRAP method was developed to measure the ferric reducing ability of plasma at low pH (*12*). An intense blue

Table 4. Total Phenolics, Total Ascorbic Acid, β-Carotene, β-Cryptoxanthin, and Free Radical Scavenging Activity by DPPH Method (Ascorbic Acid Equivalent Antioxidant Capacity, AEAC) in the Peel and Flesh Tissues of White-Flesh Nectarines[a]

cultivar	fruit tissue	total phenolics (mg/kg)	total ascorbic acid (mg/kg)	β-carotene (μg/kg)	β-cryptoxanthin (μg/kg)	DPPH (AEAC) (mg/kg)
Arctic Star	peel	875 (54)	93 (6)	570 (150)	nd	393 (17)
	flesh	154 (11)	42 (3)	40 (10)	nd	84 (10)
Arctic Queen	peel	904 (81)	160 (7)	170 (60)	30 (10)	553 (25)
	flesh	303 (59)	78 (13)	100 (30)	nd	145 (29)
Arctic Snow	peel	929 (263)	200 (3)	310 (50)	50 (20)	984 (162)
	flesh	454 (113)	122 (3)	40 (10)	nd	402 (65)
Fire Pearl	peel	418 (29)	134 (6)	50 (20)	80 (30)	230 (28)
	flesh	91 (14)	69 (6)	20 (0)	50 (10)	46 (7)
Brite Pearl	peel	2020 (201)	191 (8)	280 (20)	80 (20)	1447 (160)
	flesh	901 (84)	95 (12)	80 (1)	nd	837 (37)

[a] Standard deviations ($n = 3$) in parentheses. nd, not detected.

Table 5. Total Phenolics, Total Ascorbic Acid, β-Carotene, β-Cryptoxanthin, and Free Radical Scavenging Activity by DPPH Method (Ascorbic Acid Equivalent Antioxidant Capacity, AEAC) in the Peel and Flesh Tissues of Yellow-Flesh Nectarines[a]

cultivar	fruit tissue	total phenolics (mg/kg)	total ascorbic acid (mg/kg)	β-carotene (μg/kg)	β-cryptoxanthin (μg/kg)	DPPH (AEAC) (mg/kg)
Red Jim	peel	1403 (285)	130 (5)	1870 (240)	240 (50)	981 (107)
	flesh	415 (75)	55 (11)	730 (160)	140 (50)	317 (45)
August Red	peel	755 (61)	118 (26)	2730 (280)	270 (20)	459 (25)
	flesh	287 (78)	58 (3)	1280 (50)	140 (30)	159 (22)
Spring Bright	peel	829 (134)	114 (12)	3070 (330)	310 (10)	471 (61)
	flesh	247 (31)	35 (5)	850 (60)	210 (20)	126 (21)
May Glo	peel	629 (73)	119 (15)	1920 (100)	250 (10)	277 (31)
	flesh	155 (17)	61 (9)	580 (50)	80 (0)	62 (3)
September Red	peel	427 (29)	78 (4)	1990 (480)	280 (90)	283 (32)
	flesh	138 (31)	53 (1)	1310 (230)	150 (60)	120 (19)

[a] Standard deviations ($n = 3$) in parentheses.

Table 6. Total Phenolics, Total Ascorbic Acid, β-Carotene, β-Cryptoxanthin, and Free Radical Scavenging Activity by DPPH Method (Ascorbic Acid Equivalent Antioxidant Capacity, AEAC) in the Peel and Flesh Tissues of White-Flesh Peaches[a]

cultivar	fruit tissue	total phenolics (mg/kg)	total ascorbic acid (mg/kg)	β-carotene (μg/kg)	β -cryptoxanthin (μg/kg)	DPPH (AEAC) (mg/kg)
Summer Sweet	peel	670 (88)	134 (41)	110 (10)	140 (40)	530 (18)
	flesh	228 (20)	57 (24)	40 (10)	120 (0)	146 (21)
Snow King	peel	1836 (333)	202 (40)	430 (80)	70 (20)	1789 (194)
	flesh	1042 (83)	65 (4)	80 (20)	nd	1006 (115)
Snow Giant	peel	1522 (105)	142 (22)	290 (30)	60 (0)	1314 (65)
	flesh	670 (113)	51 (8)	60 (10)	nd	657 (83)
Champagne	peel	1224 (87)	136 (12)	310 (30)	70 (10)	1275 (55)
	flesh	429 (110)	61 (9)	70 (10)	nd	479 (78)
September Snow	peel	832 (187)	112 (5)	300 (50)	60 (0)	624 (58)
	flesh	303 (92)	48 (2)	40 (10)	nd	403 (109)

[a] Standard deviations ($n = 3$) in parentheses; nd, not detected.

color is formed when the ferric−tripyridyltriazine (Fe^{3+}−TPTZ) complex is reduced to the ferrous (Fe^{2+}) form at 593 nm. Standard solutions of 5.7 mM L-ascorbic acid (Aldrich) in deionized water were prepared. Diluted standards or diluted extract samples were used on the day of preparation except the ascorbic acid solutions, which were used within 1 h of preparation. Antioxidant activity assays were preformed as previously described (*17*). The results were expressed as ascorbic acid equivalent antioxidant capacity (AEAC) (*18*).

Statistical Analysis. All data presented are means of three replicates along with standard deviations. Correlation coefficients were determined between antioxidant capacity and phenolic constituents.

RESULTS AND DISCUSSION

Fruit Ripeness Stage. Flesh firmness and other quality indices (**Tables 1**−**3**) identified all fruits used in this study as ripe and ready-to-eat. In the case of nectarines (**Table 1**) and peaches (**Table 2**), the most significant difference between yellow-flesh and white-flesh cultivars was noted in the pH and titratable acidity. Titratable acidity was higher and pH was lower in the yellow-flesh than in the white-flesh cultivars.

Phenolics, Carotenoids, Vitamin C Content, and Antioxidant Capacity of Fruit Tissues. *Nectarines.* The peel of both white- and yellow-flesh nectarines always contained higher concentrations of phenolics, carotenoids, and total ascorbic acid than the flesh (**Tables 4** and **5**). The total ascorbic acid (vitamin C) content ranged from 48 to 132 mg/kg in white-flesh cultivars and from 56 to 68 mg/kg in yellow-flesh cultivars. β-Carotene and β-cryptoxanthin were the main carotenoids present; α-carotene was detected (60 ± 3 μg/kg) in the peel of cv. May Glo nectarines.

Among the five white-flesh nectarine cultivars, Brite Pearl and Arctic Snow showed the higher antioxidant activity, whereas Fire Pearl had the lowest activity. In general, the fruits showing

Table 7. Total Phenolics, Total Ascorbic Acid, β-Carotene, β-Cryptoxanthin, and Free Radical Scavenging Activity by DPPH Method (Ascorbic Acid Equivalent Antioxidant Capacity, AEAC) in the Peel and Flesh Tissues of Yellow-Flesh Peaches[a]

cultivar	fruit tissue	total phenolics (mg/kg)	total ascorbic acid (mg/kg)	β-carotene (μg/kg)	β-cryptoxanthin (μg/kg)	DPPH (AEAC) (mg/kg)
Flavorcrest	peel	485 (60)	115 (17)	3240 (90)	200 (70)	313 (77)
	flesh	172 (16)	60 (5)	530 (200)	60 (30)	104 (17)
Spring Lady	peel	1163 (186)	181 (25)	2700 (500)	250 (30)	1066 (125)
	flesh	547 (79)	86 (7)	700 (110)	100 (20)	432 (71)
Rich Lady	peel	1044 (61)	92 (23)	3790 (190)	360 (30)	604 (44)
	flesh	262 (40)	47 (3)	810 (70)	160 (0)	93 (22)
O'Henry	peel	1202 (142)	72 (16)	2650 (170)	80 (10)	1107 (99)
	flesh	353 (93)	31 (6)	810 (70)	80 (20)	398 (59)
September Sun	peel	1123 (156)	127 (12)	3350 (160)	nd	790 (95)
	flesh	437 (48)	126 (4)	1680 (130)	nd	314 (47)

[a] Standard deviations ($n = 3$) in parentheses; nd, not detected.

Table 8. Total Phenolics, Total Ascorbic Acid, β-Carotene, β-Cryptoxanthin, and Free Radical Scavenging Activity by DPPH Method (Ascorbic Acid Equivalent Antioxidant Capacity, AEAC) in the Peel and Flesh Tissues of Plums[a]

cultivar	fruit tissue	total phenolics (mg/kg)	total ascorbic acid (mg/kg)	β-carotene (μg/kg)	β-cryptoxanthin (μg/kg)	DPPH (AEAC) (mg/kg)
Wickson	peel	1631 (197)	130 (2)	3380 (230)	110 (30)	815 (68)
	flesh	220 (96)	82 (3)	400 (40)	50 (10)	205 (23)
Black Beaut	peel	3180 (169)	67 (13)	4100 (900)	290 (50)	1135 (60)
	flesh	769 (12)	22 (3)	1880 (170)	130 (10)	512 (33)
Red Beaut	peel	1656 (25)	169 (12)	2170 (430)	60 (10)	1091 (71)
	flesh	408 (48)	90 (9)	640 (120)	30 (10)	349 (50)
Santa Rosa	peel	1633 (192)	51 (7)	2280 (170)	390 (60)	701 (52)
	flesh	379 (34)	20 (2)	490 (120)	70 (30)	212 (48)
Angeleno	peel	3323 (617)	62 (10)	4080 (490)	29 (2)	1314 (166)
	flesh	407 (59)	39 (4)	570 (90)	30 (0)	518 (91)

[a] Standard deviations ($n = 3$) in parentheses.

Table 9. Total Phenolics, Vitamin C, Total Carotenoids, and Antioxidant Activity Evaluated by DPPH and FRAP Methods (Ascorbic Acid Equivalent Antioxidant Capacity, AEAC) per Serving of White- and Yellow-Flesh Nectarines[a]

cultivar	total phenolics (mg/serving)	vitamin C (mg/serving)	total carotenoids (μg/serving)	DPPH (AEAC) (mg/serving)	FRAP (AEAC) (mg/serving)
white flesh					
Arctic Star	25.4 (1.7)	4.8 (0.3)	10 (2)	12.6 (1.0)	17.2 (0.8)
Arctic Queen	37.8 (5.9)	8.8 (1.1)	11 (3)	19.9 (2.7)	27.3 (3.9)
Arctic Snow	50.3 (13.0)	13.2 (0.5)	8 (0)	46.9 (7.6)	44.3 (6.9)
Fire Pearl	13.6 (1.6)	7.7 (0.2)	8 (1)	7.1 (1.0)	14.4 (1.0)
Brite Pearl	102.4 (9.7)	10.7 (1.2)	11 (0)	88.7 (5.4)	104.5 (10.4)
yellow flesh					
Red Jim	54.3 (10.3)	6.5 (1.1)	102 (19)	40.0 (5.2)	49.5 (8.6)
August Red	34.3 (7.1)	6.6 (0.5)	162 (5)	19.6 (2.1)	25.1 (4.2)
Spring Bright	32.2 (4.5)	5.1 (0.2)	135 (5)	17.2 (2.6)	26.9 (3.9)
May Glo	21.8 (2.5)	6.8 (0.8)	86 (5)	9.1 (0.7)	15.9 (1.1)
September Red	17.5 (2.9)	5.6 (0.3)	157 (27)	13.9 (2.0)	17.1 (3.3)

[a] Serving = 100 g of fruit (80% flesh + 15% peel). Standard deviations ($n = 3$) in parentheses.

higher antioxidant capacity contained the higher amounts of phenolics.

Intercultivar variation among yellow-flesh nectarines was noted in antioxidant capacity and phenolic content (**Table 5**). Cv. Red Jim had the higher antioxidant capacity and phenolic content. However, this activity was lower than that found in the white-flesh cultivar Brite Pearl (**Table 4**). In addition, cv. May Glo and September Red showed less antioxidant capacity and phenolic content, although they had carotenoid and vitamin C levels similar to those found in Red Jim.

There was no clear trend in terms of antioxidant capacity and phenolic content between white- and yellow-flesh nectarine cultivars as a group. It is the individual cultivar that matters. For example, Brite Pearl (white flesh) and Red Jim (yellow flesh) have similar antioxidant capacities and phenolic contents, which are quite high, whereas Fire Pearl (white flesh) and May Glo (yellow flesh) have very low antioxidant capacities and phenolic contents. The only consistent difference is that yellow-flesh cultivars have a higher carotenoid content.

Peaches. A wide variation in the total antioxidant capacity and phenolics content of white peaches was observed (**Table 6**). The cultivar showing the highest antioxidant capacity was Snow King followed by Snow Giant. In contrast, Summer Sweet showed only a low antioxidant activity, and it had the smallest phenolic content. Carotenoids and ascorbic acid were mainly present in the peel.

The yellow-flesh peach cultivars showed in general lower antioxidant capacity than the white flesh ones (**Table 7**). The differences were especially evident in the flesh. Cv. Spring Lady peaches showed the highest antioxidant activity in this group,

Table 10. Total Phenolics, Vitamin C, Total Carotenoids, and Antioxidant Activity by DPPH and FRAP Methods (Ascorbic Acid Equivalent Antioxidant Capacity, AEAC) per Serving of White- and Yellow-Flesh Peaches[a]

cultivar	total phenolics (mg/serving)	vitamin C (mg/serving)	total carotenoids (μg/serving)	DPPH (AEAC) (mg/serving)	FRAP (AEAC) (mg/serving)
white flesh					
Summer Sweet	28.3 (2.9)	6.7 (2.7)	17 (2)	19.6 (2.0)	27.9 (3.3)
Snow King	110.9 (11.6)	8.2 (0.8)	13 (2)	107.3 (12.1)	119.6 (9.8)
Snow Giant	76.4 (10.6)	6.2 (0.9)	9 (1)	72.2 (7.6)	74.0 (8.4)
Champagne	52.6 (10.1)	7.1 (0.9)	11 (1)	57.5 (7.8)	54.3 (8.3)
September Snow	36.7 (10.1)	5.6 (0.3)	8 (1)	41.6 (8.7)	50.3 (11.1)
yellow flesh					
Flavorcrest	21.0 (2.1)	6.7 (0.2)	95 (21)	13.0 (2.5)	19.0 (2.4)
Spring Lady	61.2 (9.1)	9.8 (0.5)	107 (12)	50.5 (7.5)	67.9 (9.8)
Rich Lady	36.6 (4.1)	5.2 (0.4)	147 (7)	16.5 (2.2)	37.7 (4.0)
O'Henry	46.2 (9.6)	3.6 (0.7)	112 (5)	48.5 (6.2)	49.3 (7.4)
September Sun	51.8 (6.2)	12.6 (0.5)	197 (13)	36.9 (5.2)	72.2 (8.4)

[a] Serving = 100 g of fruit (80% flesh + 15% peel). Standard deviations (n = 3) in parentheses.

Table 11. Total Phenolics, Vitamin C, Total Carotenoids, and Antioxidant Activity by DPPH and FRAP Methods (Ascorbic Acid Equivalent Antioxidant Capacity, AEAC) per Serving of Plums[a]

cultivar	total phenolics (mg/serving)	vitamin C (mg/serving)	total carotenoids (μg/serving)	DPPH (AEAC) (mg/serving)	FRAP (AEAC) (mg/serving)
Wickson	42.0 (3.7)	9.0 (0.3)	87 (5)	28.6 (2.8)	50.7 (13.4)
Black Beaut	109.2 (3.5)	2.9 (0.4)	231 (27)	58.0 (3.5)	127.2 (9.8)
Red Beaut	57.4 (13.6)	10.2 (1.5)	87 (15)	44.3 (5.0)	76.4 (5.2)
Santa Rosa	54.8 (5.6)	2.5 (0.3)	83 (11)	27.4 (4.6)	40.5 (5.4)
Angeleno	82.4 (14.0)	4.2 (0.4)	113 (7)	61.1 (9.8)	106.7 (13.1)

[a] Serving = 100 g of fruit (80% flesh + 15% peel). Standard deviations (n = 3) in parentheses.

whereas cv. Flavorcrest peaches had less antioxidant capacity and fewer phenolics. The total carotenoids content was much higher in yellow-flesh cultivars than in the white-flesh cultivars. β-Carotene was the main carotenoid followed by β-cryptoxanthin; α-carotene was found in small quantities and only in cultivars Champagne (10−30 μg/kg) and Rich Lady and September Sun (100−110 μg/kg).

As in the case of nectarines, it is not possible to generalize a ranking between white-flesh and yellow-flesh peach cultivars as a group in terms of antioxidant capacity, as this activity is more related to individual cultivar.

Plums. In this case one yellow cultivar (Wickson) and four red cultivars were studied (**Table 8**). Plums were rich in phenolic compounds, particularly cv. Black Beaut and Angeleno. Among the studied stone fruit, plums is the group showing a higher phenolic content with some individual exceptions including Snow King peaches and Brite Pearl nectarines. In addition, carotenoids were mainly present in the peel, and their content was similar to that of yellow-flesh peaches. Again, β-carotene was the main carotenoid with β-cryptoxanthin in smaller amounts, and α-carotene was detected only in the peel of Wickson and Angeleno plums (200−220 μg/kg) and in the flesh of Angeleno plums (40 μg/kg). In general, all of the studied plums had relatively high antioxidant capacities, especially the Black Beaut, Red Beaut, and Angeleno cultivars.

Phenolics, Carotenoids, Vitamin C, and Antioxidant Capacity per Fruit Serving. To evaluate the dietary impact of stone fruit consumption on the intake of these compounds and the ingested antioxidant equivalents, the antioxidants supplied by stone fruit serving were determined. These calculations were based on a fruit serving of 100 g (15 g of peel + 80 g of flesh + 5 g of stone).

In the case of nectarines (**Table 9**), the amount of phenolics per serving ranges from 13.6 to 102.4 mg, the vitamin C from 5.1 to 13.2 mg, and the carotenoids from 8 to 162 μg. As expected, the carotenoids content was 10 times higher in the yellow-flesh than in the white-flesh cultivars. The total anti-

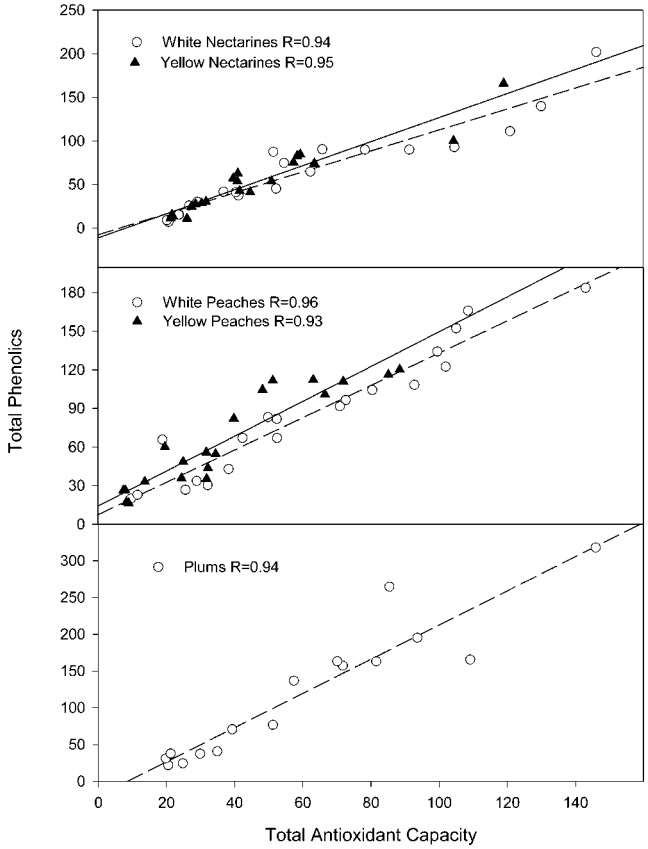

Figure 1. Correlation between total antioxidant capacity (by the DPPH method) and total phenolics (summation of concentrations of individual phenolics determined by HPLC) in milligrams per 100 g of nectarines, peaches, and plums.

Table 12. Correlation Coefficients between Antioxidant Activity Evaluated by DPPH and Total Phenolics, Hydroxycinnamic Derivatives (OH Cinnamics), Flavan-3-ols, Flavonols, and Anthocyanins in the Peel and Flesh of White and Yellow Nectarines, White and Yellow Peaches, and Plums[a]

stone fruit	fruit tissue	DPPH/total phenolics	DPPH/OH cinnamics	DPPH/flavan-3-ols	DPPH/flavonols	DPPH/anthocyanins
white-flesh nectarines	flesh	0.89***	0.97***	0.95***	ns	ns
	peel	0.90***	0.79**	0.95***	ns	ns
yellow-flesh nectarines	flesh	0.96***	0.82**	0.95***	ns	ns
	peel	0.92***	0.93***	0.96***	0.84**	0.66*
white-flesh peaches	flesh	0.89***	0.86**	0.85**	ns	ns
	peel	0.95***	0.83**	0.94***	ns	ns
yellow-flesh peaches	flesh	0.87***	0.94***	0.78**	ns	ns
	peel	0.89***	0.83**	0.90***	ns	ns
plums	flesh	0.91**	ns	0.87**	nd	nd
	peel	0.78*	ns	0.73*	ns	ns

[a] Values are means ($n = 10$); nd, not detected; ns, not significant; *, $P \leq 0.05$; **, $P \leq 0.01$; ***, $P \leq 0.001$.

Table 13. Correlation Coefficients between Antioxidant Activity Evaluated by FRAP and Total Phenolics, Hydroxycinnamic Derivatives (OH Cinnamics), Flavan-3-ols, Flavonols, and Anthocyanins in the Peel and Flesh of White and Yellow Nectarines, White and Yellow Peaches, and Plums[a]

stone fruit	fruit tissue	FRAP/total phenolics	FRAP/OH cinnamics	FRAP/flavan-3-ols	FRAP/flavonols	FRAP/anthocyanins
white flesh nectarines	flesh	0.98***	0.98***	0.95***	ns	ns
	peel	0.96***	0.89***	0.98***	ns	ns
yellow flesh nectarines	flesh	0.99***	0.86**	0.98***	ns	ns
	peel	0.92***	0.87**	0.89***	0.89***	0.75*
white flesh peaches	flesh	0.98***	0.91***	0.96***	ns	ns
	peel	0.98***	0.87***	0.93***	ns	ns
yellow flesh peaches	flesh	0.91***	0.83**	0.90***	ns	ns
	peel	0.94***	0.73*	0.96***	0.68*	ns
plums	flesh	0.86**	ns	0.82*	nd	nd
	peel	0.93***	ns	0.86**	ns	ns

[a] Values are means ($n = 10$); nd, not detected; ns, not significant; *, $P \leq 0.05$; **, $P \leq 0.01$; ***, $P \leq 0.001$.

oxidants (expressed as ascorbic acid equivalents) ranged from 7.1 to 88.7 mg per serving when determined by the DPPH method and from 14.4 to 104.5 mg when evaluated by the FRAP method. To match the antioxidant activity provided by a glass (100 mL) of red wine (177 mg/100 mL; by the DPPH method), 200 g of Brite Pearl nectarines or 2 kg of Fire Pearl nectarines would have to be consumed. This indicates that some nectarine cultivars (Brite Pearl, Arctic Snow, or Red Jim) can provide a significant amount of natural antioxidants in the diet, whereas the small content of other cultivars makes them a modest source of these compounds.

In white- and yellow-flesh peaches (**Table 10**), the amount of phenolics per serving ranges from 21.0 to 110.9 mg, the vitamin C from 3.6 to 12.6 mg, and the carotenoids from 8 to 197 μg. As in the case of nectarines, the carotenoids were 10 times greater in the yellow-flesh cultivars. The total antioxidants supplied by a serving ranged from 13.0 to 107.3 mg of ascorbic acid equivalents when evaluated by the DPPH method and from 19.0 to 119.6 mg of ascorbic acid equivalents when evaluated by the FRAP method. When these values were compared with the amount of ascorbic acid equivalents provided by a 100 mL of red wine, 100 g of Snow King will provide the same amount of antioxidants. In contrast, 900 g of Rich Lady would have to be ingested to provide the same amount of antioxidants.

Plums are a good source of phenolic compounds (**Table 11**) and provide 42.0−109.2 mg per serving. The amount of vitamin C provided is considerably smaller (2.5−10.2 mg), and even smaller are the carotenoids (83−231 μg). These values for vitamin C and carotenoids are similar to those supplied by nectarine and peach cultivars. The total antioxidants provided by a serving of plums ranges from 27.4 to 61.1 mg of ascorbic acid equivalents (estimated by the DPPH method) and from 40.5 to 127.2 mg of ascorbic acid equivalents (estimated by the FRAP method). Two servings of Black Beaut and Angeleno plums will provide the same amount of antioxidants as a 100 mL of red wine. These results agree with those previously reported for dried plums or prunes (*Prunus domestica*) in which a good antioxidant capacity was also related to their high phenolic content (*19*).

The ranges of total ascorbic acid (vitamin C) contents (mg/100 g of fresh weight) are 6−8 (yellow-flesh nectarines), 5−14 (white-flesh nectarines), 4−13 (yellow-flesh peaches), 6−9 (white-fresh peaches), and 3−10 (plums). These values are slightly higher than those reported in the USDA Food Composition Database (www.nal.usda.gov/fnic/foodcomp/), in which mean ascorbic acid contents are indicated as 5.4, 6.6, and 9.5 mg/100 g of fresh weight for yellow-flesh nectarines, yellow-flesh peaches, and plums, respectively. Our data are based on a broader range of cultivars and a larger number of samples than the USDA data. This is also true for the carotenoids data. We found the following ranges of total carotenoids concentrations (μg/100 g of fresh weight): 80−186 (yellow-flesh nectarines), 7−14 (white-flesh nectarines), 71−210 (yellow-flesh peaches), 7−20 (white-flesh peaches), and 70−260 (plums). These values are slightly higher than those reported in the USDA Food Compostion Database (Carotenoids Section), in which mean carotenoids concentrations are reported as 160, 179, and 114 μg/100 g of fresh weight for yellow-flesh nectarines, yellow-flesh peaches, and plums, respectively.

Correlation between Fruit Constituents and Antioxidant Capacity. Phenolic compounds are the only stone fruit constituents that correlated with the total antioxidant capacity. The

correlation coefficients were >0.9 in all cases for the whole fruit (**Figure 1**). No correlation was obtained with any of the other antioxidant constituents such as vitamin C and carotenoids (data not shown). The correlation coefficients between total phenolics content of peel and flesh tissues of the different cultivars and their antioxidant capacity evaluated by the DPPH and FRAP are shown in **Tables 12** and **13**, respectively. In general, there was a very good correlation (R values > 0.9) with both antioxidant activity assays. As these fruits contain different types of phenolics compounds, including hydroxycinnamic acids, flavan-3-ols, flavonols, and anthocyanins, we used our recently published results on phenolic analysis of these samples (*9*) to determine the correlation between the antioxidant capacity and each group of phenolic compounds to identify which compounds are mainly responsible for this activity. In nectarines and peaches, both hydroxycinnamic acid derivatives and flavan-3-ols are strongly correlated with antioxidant activity, whereas flavonols and anthocyanins, which are mainly located in the peel, are not (**Tables 12** and **13**). In the case of plums, the correlation was mainly with flavan-3-ols, whereas hydroxycinnamates were not correlated.

Although the antioxidant capacity evaluated by the FRAP method was always higher than that evaluated by the DPPH method, especially in the case of plums, correlations were equally good for both methods. These results are not surprising as previous reports on antioxidant capacity of fruits such as strawberry, raspberry, and other berries indicate that vitamin C is not the main antioxidant in these fruits and polyphenols are mainly responsible for the observed activity (*20*). Previous studies on the antioxidant activity of blueberries showed a close correlation between phenolics content and antioxidant capacity; a linear relationship was reported between oxygen radical absorbance capacity (ORAC) and total phenolic content (R = 0.92) of these fruits (*21*). Vinson et al. (*22*) reported that the antioxidant quality of extracts of 20 kinds of fruits, including nectarine, peach, and plum, was better than the vitamin antioxidants and most pure phenols, suggesting synergism among the antioxidants in the mixture.

Antioxidant activity of nectarines, peaches, and plums varied greatly among the 25 cultivars used in this study and was highly correlated with their contents of phenolic compounds. In general, plums have a higher antioxidant activity than nectarines and peaches. A serving (100 g) of plums has ~33−50% of the antioxidant activity of a 100 mL glass of red wine. Increasing the phenolic content of nectarines, peaches, and plums by genetic manipulation will increase their antioxidant capacity. However, there is a limit beyond which increased phenloic concentration may cause undesirable levels of astringency in these fruits. Meanwhile, nectarines, peaches, and plums should be included in the range of fruits selected by consumers to meet the recommended two to four servings of fruits per day.

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Received for review February 1, 2002. Revised manuscript received June 10, 2002. Accepted June 10, 2002. Partial funding for this research was provided by the California Tree Fruit Agreement.

JF020136B