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Carotenoids from New Apricot (*Prunus armeniaca* L.) Varieties and Their Relationship with Flesh and Skin Color

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Thirty-seven apricot varieties, including four new releases (Rojo Pasión, Murciana, Selene, and Dorada) obtained from different crosses between apricot varieties and three traditional Spanish cultivars (Currot, Mauricio, and Búlida), were separated according to flesh color into four groups. The *L**, *a**, *b**, hue angle, and chroma color measurements on the skin and flesh as well as other quality indices including flesh firmness, soluble solids, titratable acidity, and pH were plotted against the total carotenoid content measured by HPLC. Among the 37 apricot varieties, the total carotenoid content ranged from 1512 to 16500 μg 100 g^{-1} of edible portion, with β-carotene as the main pigment followed by β-cryptoxanthin and γ-carotene. The wide range of variability in the provitamin A content in the apricot varieties encouraged these studies in order to select the breeding types with enhanced carotenoid levels as the varieties with a higher potential health benefit. The carotenoid content was correlated with the color measurements, and the hue angle in both flesh and peel was the parameter with the best correlation ($R = 0.92$ and 0.84, respectively). An estimation of the carotenoid content in apricots could be achieved by using a portable colorimeter, as a simple and easy method for field usage applications.

KEYWORDS: **β-Carotene; color; colorimeter; correlation; HPLC; provitamin A**

INTRODUCTION

Scientific interest in the carotenoid content and the distribution patterns in fruits and vegetables has revived since it was discovered that carotenoids are important not only because of the color they impart but also because they show protective activity against a variety of degenerative diseases (*1*, *2*). In 1933, Brockmann (*3*) conducted one of the first studies on the carotenoid characterization of apricot (*Prunus armeniaca* L.), and β-carotene was found to be the principal pigment (*4*). Numerous other carotenoids are present in apricots but in small amounts (<2%) such as phytoene, phytofluene, γ-carotene, lycopene, β-cryptoxanthin, and lutein (*4*). Apricots have been described as one of the most important dietary sources of provitamin A carotenoids because 250 g of fresh or 30 g of dried apricots provide 100% of the recommended daily allowance (*5*). The carotenoids of ripe apricots have been poorly studied (*4*); changes in the individual pigments and their transformation during the developing, ripening, and senescent stages (*6*) have also received little attention. The subspecies and varieties of the fruit species analyzed are rarely monitored, and together with location and year, genotype is known to influence not only the total carotenoid content but also the proportions of each carotene species (i.e., α- and β- carotene) as is the case with peaches and plums (*7*).

Several studies have correlated the color with the pigment content of different fruits and vegetables (*8*). The color intensity of β-carotene in a food has been considered to be a reliable indication of vitamin A value, and thus color measurements have been considered to be appropriate for the rapid estimation of carotenoid content (*9*).

This study was carried out to characterize the carotenoid content of the new apricot varieties. In addition, the high number of evaluated varieties coming from different genetic origins and with a large phenotypic variability could provide valuable information about carotenoid content in the apricot species. The relationship between the color of the peel and flesh and total carotenoids was established due to the convenience and ease of using color measurements instead of long, tedious, and costly chemical methods.

MATERIALS AND METHODS

Plant Material. The plant material assayed included 30 apricot varieties and 4 new releases (Rojo Pasión, Murciana, Selene, and Dorada) obtained from different crosses between apricot cultivars from the apricot breeding program carried out at the research institute CEBAS-CSIC (Murcia, Spain). In addition, three traditional Spanish

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cultivars (Currot, Mauricio, and Búlida) were included as reference. All of the varieties were cultivated in the same experimental orchard (southeastern Spain, 37° N latitude, 1° W longitude, and 450 m altitude) according to habitual apricot orchard management. All varieties used were harvested between May 9 and June 27 (2003) at the commercial maturity stage on the basis of their skin color (fully colored). Immediately after harvest, fruits were transported in an air-conditioned car to the laboratory (55 km), where they were carefully selected to ensure that fruits were free of defects. For each variety, the ripening stage was based on assessing fruit firmness and surface color in all fruits. Three replicates of 10 fruits for each variety were selected. Fruits were peeled and two 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.

Quality Indices. A trained panel of four experts classified the apricots visually into four groups according to the perception of the flesh color as white, yellow, light orange, and orange flesh varieties. Skin and flesh color, firmness, titratable acidity (TA), pH, and soluble solids content (SSC) were evaluated as quality indices. Color values on the surface (ground skin color) and after peeling in the flesh were measured with a Minolta chroma meter (CR-300, Minolta, Ramsey, NJ) tristimulus color analyzer calibrated to a white porcelain reference plate. The color space coordinates L^*, a^*, b^*, hue angle [$H° =$ arctangent (b^*/a^*)], and chroma $(a^{*2} + b^{*2})^{1/2}$ were determined around the equatorial region in three different positions (with an average of nine times for each apricot). Fruit firmness was evaluated by a compression test using a Lloyd instrument (model LR10K, Fareham Hants, U.K.) equipped with two (12 × 18 cm) flat plates. The maximum force required to deform the fruit 5 mm at a speed of 25 mm/min, with the slice lying on the bottom plate, was recorded. TA was determined by titrating 5 mL of juice with 0.1 mol L^{-1} NaOH to pH 8.1 by an automatic titration system (*10*). The pH values were measured using a pH-meter, and SSC was determined with an Atago N1 handheld refractometer (Tokyo, Japan). The ripening stage values for each variety are shown in **Tables 1** and **2** (color values).

Extraction of Carotenoids. The procedures used were as described by Wright and Kader (*11*) based on the method of Hart and Scott (*12*) for the determination of carotenoids by HPLC. The sample of frozen fruit material (5 g) was homogenized with an Ultra Turrax (Ika, Staufen, Germany) for 2 min on ice, with 10 mL of extraction solution (methanol/hexane 1:1), and then the homogenates were centrifuged (10500*g*) for 15 min at 2−5 °C. The supernatant was recovered carefully to prevent contamination with the pellet. The extraction process was repeated three or four times with 5 mL of hexane until no color appeared in the hexane layer. The resulting solution was filtered through a bed of anhydrous Na_2SO_4 to remove the water and evaporated to dryness in the rotary evaporator at 35 °C. The pigments were collected with acetone to a volume of 2 mL, filtered through a 0.45-μm Osmonics/MSI cameo nylon filter (Fisher Scientific, Los Angeles, CA), and kept refrigerated until the analysis by HPLC, for a period not exceeding 12 h.

HPLC-DAD Analyses of Carotenoids. At the beginning of the extraction process, β-apo-8′-carotenal was added (0.6 mg/5 g of fruit material) to all samples as internal standard (IS) because this pigment is absent in apricots and separates well from the other carotenoids. It allows the quantification of carotenoid loss during the extraction process. The loss in the quantity of the IS was 12% on average during the extraction process and was uniform across the different apricot types. Samples of 20 μL of extracts were analyzed using an HPLC system equipped with a model L-6200 pump and an AS-2000A autosampler (Merck-Hitachi, Tokyo, Japan) and an SPD-M6A photodiode array UV−vis detector (Shimadzu, Tokyo, Japan). Separations were achieved on a 250 × 4 mm i.d., 5 μm LiChrocart C18 column (Merck, Darmstadt, Germany) protected with a precolumn containing the same stationary phase. Elution was performed at a solvent flow rate of 1.5 mL/min and detection at 450 nm. The mobile phases consisted of acetone and water, both of HPLC grade. First, there was a 10-min conditioning stage (EQ or equilibrium) before each injection with 85% acetone and 15% water. The gradient program started with 85% acetone and 15% water to reach 100% acetone at 15 min, 85% acetone at 16 min, and from 16 to 22 min to reach the initial conditions. After separation, the column was washed and returned to the initial conditions. The UV spectra of the different compounds were recorded with a diode array detector. The carotenoid compounds were identified on the basis of UV−vis spectra (β-carotene, β-cryptoxanthin, and γ-carotene).

Table 1. Quality Index Values in White, Yellow, Light Orange, and Orange Flesh Apricot Varieties[a]

variety	harvest date	fruit firmness (N)	soluble solids (%)	titratable acidity[b]	pH
		White Flesh			
Z 115/26	June 5	45.4 (5.8)	14.6 (0.5)	1.10 (0.03)	3.87 (0.02)
Z 109/58	May 27	45.1 (9.0)	16.1 (0.3)	1.92 (0.13)	3.49 (0.04)
Z 108/38	June 05	29.7 (5.0)	15.5 (0.1)	1.43 (0.07)	3.73 (0.06)
Currot	May 12	45.8 (10.9)	11.0 (0.8)	1.52 (0.05)	3.71 (0.02)
Z 604/12	May 31	58.9 (12.4)	12.9 (0.5)	2.25 (0.14)	3.24 (0.06)
Z 501/28	June 24	24.5 (3.8)	15.2 (0.1)	1.29 (0.06)	3.65 (0.02)
		Yellow Flesh			
Z 405/17	May 9	60.1 (18.7)	11.0 (0.5)	2.13 (0.11)	3.39 (0.03)
S 407/8	May 17	44.5 (15.4)	13.1 (0.5)	1.48 (0.04)	3.27 (0.03)
S 406/22	May 18	49.5 (15.5)	14.3 (0.5)	2.04 (0.10)	3.17 (0.02)
Z 209/1	June 20	32.3 (5.4)	14.8 (0.4)	1.34 (0.03)	3.51 (0.04)
Mauricio	May 26	43.7 (8.0)	11.2 (0.1)	1.86 (0.05)	3.58 (0.02)
Z 102/19	June 27	29.4 (4.5)	17.0 (0.3)	1.20 (0.05)	3.68 (0.02)
		Light Orange Flesh			
Z 506/7	May 15	23.8 (5.4)	11.7 (0.3)	1.56 (0.02)	3.36 (0.01)
Rojo Pasión	May 17	41.8 (7.8)	11.3 (0.1)	1.41 (0.03)	3.36 (0.03)
Z 111/61	June 17	43.8 (9.0)	16.6 (0.5)	1.09 (0.04)	3.75 (0.06)
Dorada	June 24	29.0 (5.2)	13.8 (0.1)	1.15 (0.02)	3.69 (0.04)
Z 502/6	May 29	43.6 (13.9)	14.6 (0.5)	1.50 (0.08)	3.71 (0.02)
Búlida	May 29	49.3 (6.8)	10.7 (0.1)	1.31 (0.06)	3.55 (0.04)
Murciana	June 05	26.8 (4.7)	12.6 (0.2)	0.90 (0.06)	3.78 (0.04)
Z 115/13	June 12	37.3 (8.2)	14.1 (0.7)	1.17 (0.07)	3.81 (0.02)
		Orange Flesh			
Z 308/6	June 7	30.9 (7.6)	13.1 (0.3)	1.78 (0.09)	3.33 (0.02)
Z 201/13	May 28	46.2 (5.2)	12.5 (0.2)	2.10 (0.06)	3.27 (0.05)
Z 211/18	June 2	52.9 (6.4)	13.2 (0.3)	2.43 (0.04)	3.23 (0.04)
Z 308/9	June 12	34.2 (8.7)	11.3 (0.1)	1.51 (0.08)	3.40 (0.03)
S 401/33	May 18	47.8 (13.3)	11.4 (0.1)	1.96 (0.07)	3.22 (0.02)
Z 203/8	June 15	24.9 (3.9)	16.7 (0.5)	2.09 (0.04)	3.23 (0.02)
S 404/42	May 21	57.7 (12.4)	10.4 (0.1)	2.20 (0.13)	3.24 (0.01)
Z 505/2	June 3	40.3 (10.3)	12.8 (0.2)	1.18 (0.08)	3.58 (0.08)
Z 212/6	June 5	65.5 (20.5)	14.3 (0.5)	2.44 (0.04)	3.26 (0.01)
Z 403/2	June 11	37.3 (15.6)	13.2 (0.3)	1.55 (0.12)	3.47 (0.04)
Selene	June 7	36.7 (7.3)	12.8 (0.4)	2.37 (0.05)	3.21 (0.02)
S 102/43	May 31	46.4 (16.9)	13.6 (0.4)	2.38 (0.10)	3.29 (0.01)
Z 207/4	June 3	35.7 (9.7)	14.1 (0.3)	2.18 (0.05)	3.27 (0.01)
Z 203/15	June 7	39.8 (3.7)	13.1 (0.3)	2.19 (0.12)	3.22 (0.06)
Z 402/16	June 2	47.5 (10.7)	13.5 (1.1)	2.28 (0.02)	3.25 (0.01)
Z 209/17	June 9	24.2 (4.1)	14.7 (0.5)	2.03 (0.11)	3.33 (0.04)
Z 308/12	June 11	25.9 (6.6)	10.4 (0.5)	1.75 (0.05)	3.30 (0.01)

[a] Standard deviation ($n = 3$) in parentheses. [b] Grams of malic acid per 100 mL of juice.

Different concentrations of β-carotene with the same amount of IS (β-apo-8′-carotenal) were added in each case to verify the calibration process and to make possible the calculation of carotenoid losses during the extraction process. *trans*-β-Carotene and β-apo-8′-carotenal were purchased from Sigma Chemical Co. (St. Louis, MO), and β-cryptoxanthin was from Indofine Chemical Co. Inc. (Hillsborough, NJ). γ-Carotene was quantified as β-carotene due to the similar spectral absorption maxima. The carotenoid concentrations of apricot varieties were calculated in peel and flesh by comparisons of their "peak area" values at 450 nm with stock standard solutions and expressed as micrograms per 100 g of fresh weight.

Statistical Analysis. All data are means of three replicates composed of 10 fruits with standard deviations. Correlation coefficients were determined by the coefficient of Pearson. Statistical analyses were performed using SPSS 11.5 for Windows (Chicago, IL).

Table 2. Color Values (Reflectance Measurements *L**, *a**, *b**, *H*°, and *C**) at Commercial Maturity in White, Yellow, Light Orange, and Orange Flesh Apricot Varieties[a]

cultivar	part	skin color	*L**	*a**	*b**	*H*° [b]	*C** [c]
			White Flesh				
Z 115/26	flesh		70.40 (1.91)	−1.86 (1.33)	30.81 (3.68)	93.45 (1.01)	30.87 (0.40)
	skin	white (dark rose)[d]	71.16 (1.50)	−4.12 (1.71)	36.21 (2.15)	96.48 (1.67)	36.46 (0.93)
Z 109/58	flesh		68.57 (3.50)	0.03 (1.22)	37.69 (3.47)	89.96 (0.70)	37.70 (0.40)
	skin	white (light red)	68.89 (1.86)	0.40 (2.25)	38.30 (2.38)	89.41 (1.12)	38.31 (0.54)
Z 108/38	flesh		69.60 (1.74)	0.22 (1.09)	33.98 (2.20)	89.63 (0.28)	33.98 (0.78)
	skin	white	72.09 (1.27)	−2.30 (1.25)	37.08 (1.19)	93.55 (0.41)	37.15 (0.50)
Z 501/28	flesh		67.94 (2.77)	2.55 (2.69)	41.17 (2.62)	86.47 (0.63)	41.25 (1.18)
	skin	yellow (red)	68.41 (1.82)	−0.69 (2.51)	42.66 (1.80)	90.93 (1.15)	42.67 (0.24)
Currot	flesh		66.02 (3.28)	3.35 (1.46)	39.56 (2.08)	85.16 (0.67)	39.70 (0.29)
	skin	yellow (light red)	68.07 (2.58)	3.60 (3.95)	39.33 (2.40)	84.76 (0.72)	39.49 (0.56)
Z 604/12	flesh		67.36 (1.98)	4.92 (1.68)	48.28 (1.59)	84.19 (0.65)	48.54 (1.04)
	skin	yellow	69.85 (1.16)	−1.01 (2.10)	45.50 (1.19)	91.27 (0.64)	45.51 (0.07)
			Yellow Flesh				
Z 405/17	flesh		72.14 (2.52)	−0.64 (2.15)	39.97 (4.02)	90.93 (0.87)	39.98 (1.25)
	skin	yellow (red)	73.68 (1.67)	−0.83 (3.19)	44.36 (2.50)	91.10 (1.68)	44.38 (1.12)
S 407/8	flesh		65.86 (4.34)	2.67 (1.50)	38.28 (2.37)	86.00 (0.73)	38.37 (0.85)
	skin	yellow (red)	67.91 (1.83)	1.38 (2.04)	47.11 (1.71)	88.32 (0.30)	47.13 (0.30)
Mauricio	flesh		66.19 (2.46)	4.05 (1.99)	41.24 (2.58)	84.40 (1.29)	41.44 (0.62)
	skin	yellow	68.89 (1.45)	0.38 (1.99)	43.77 (1.93)	89.50 (0.67)	43.78 (0.68)
Z 102/19	flesh		68.26 (2.38)	4.38 (1.98)	44.09 (1.49)	84.33 (0.15)	44.30 (0.25)
	skin	yellow	69.88 (1.45)	1.92 (1.56)	45.35 (1.33)	87.56 (0.70)	45.39 (0.87)
Z 209/1	flesh		69.77 (1.59)	5.71 (1.53)	44.78 (1.24)	82.73 (0.21)	45.14 (0.19)
	skin	yellow	69.02 (1.54)	4.39 (2.33)	47.16 (1.49)	84.68 (0.56)	47.37 (0.57)
S 406/22	flesh		68.06 (2.43)	6.73 (1.48)	44.86 (2.12)	81.48 (0.52)	45.37 (1.16)
	skin	yellow (red)	69.85 (1.59)	4.59 (2.15)	46.41 (1.69)	84.37 (1.24)	46.64 (0.66)
			Light Orange Flesh				
Dorada	flesh		70.30 (1.88)	9.00 (2.82)	49.92 (2.04)	79.79 (0.99)	50.73 (0.61)
	skin	light orange	69.29 (1.31)	9.62 (1.65)	48.55 (0.99)	78.79 (0.69)	49.50 (0.40)
Rojo Pasión	flesh		66.85 (2.72)	8.62 (2.61)	47.59 (1.70)	79.73 (0.40)	48.36 (1.32)
	skin	yellow (red)	67.22 (2.75)	4.01 (3.39)	44.70 (1.55)	84.87 (0.85)	44.89 (0.21)
Z 111/61	flesh		68.40 (1.54)	8.51 (1.66)	44.02 (1.11)	79.07 (0.61)	44.84 (0.30)
	skin	yellow (light red)	67.66 (1.42)	9.45 (1.53)	46.21 (1.37)	78.43 (0.64)	47.17 (0.50)
Z 506/7	flesh		61.90 (2.39)	8.72 (1.65)	43.73 (1.94)	78.72 (0.41)	44.59 (0.18)
	skin	light orange (red)	64.25 (1.68)	2.56 (2.24)	44.29 (1.45)	86.69 (1.25)	44.37 (0.06)
Z 502/6	flesh		66.67 (3.44)	10.02 (1.88)	46.22 (2.09)	77.76 (0.95)	47.29 (0.95)
	skin	light orange (dark rose)	73.16 (1.15)	3.18 (1.59)	45.45 (2.25)	85.99 (1.82)	45.57 (0.42)
Búlida	flesh		64.17 (1.76)	12.75 (1.83)	48.87 (1.26)	75.38 (1.51)	50.52 (0.83)
	skin	light orange	66.53 (1.79)	11.09 (3.03)	45.40 (1.74)	76.27 (1.05)	46.74 (0.51)
Murciana	flesh		66.88 (1.68)	12.66 (1.83)	47.40 (2.07)	75.04 (0.66)	49.06 (0.90)
	skin	light orange (red)	68.83 (1.86)	7.94 (1.97)	48.11 (1.55)	80.62 (0.50)	48.76 (0.73)
Z 115/13	flesh		67.76 (1.58)	11.46 (1.93)	42.69 (1.78)	74.97 (0.35)	44.20 (1.02)
	skin	white (light red)	70.43 (1.65)	4.86 (2.56)	43.84 (1.95)	83.69 (2.14)	44.13 (0.35)
			Orange Flesh				
Z 308/6	flesh		75.55 (1.97)	9.85 (1.77)	53.04 (0.97)	79.49 (0.99)	53.95 (0.52)
	skin	light orange (red)	75.63 (1.21)	5.66 (2.27)	51.41 (1.24)	83.72 (0.85)	51.72 (0.14)
Z 308/9	flesh		62.82 (1.70)	9.76 (2.31)	49.94 (2.07)	78.94 (0.27)	50.89 (0.89)
	skin	light orange (red)	62.13 (1.30)	4.20 (3.27)	43.85 (1.78)	84.53 (1.00)	44.06 (0.22)
Z 201/13	flesh		66.16 (1.81)	12.48 (2.38)	50.00 (1.28)	75.98 (0.58)	51.53 (0.44)
	skin	light orange (red)	67.90 (1.55)	3.81 (2.74)	46.64 (1.28)	85.33 (1.00)	46.80 (0.51)
Z 505/2	flesh		68.64 (1.87)	13.95 (1.87)	51.61 (1.51)	74.87 (0.21)	53.47 (0.38)
	skin	light orange (red)	67.49 (1.40)	9.35 (2.01)	49.69 (1.77)	79.34 (1.05)	50.57 (0.71)
S 401/33	flesh		68.63 (1.56)	14.28 (1.25)	51.52 (1.22)	74.51 (0.32)	53.46 (0.20)
	skin	orange	69.07 (1.40)	5.08 (2.63)	46.24 (1.49)	83.73 (0.84)	46.52 (0.47)
Z 203/8	flesh		65.98 (1.56)	14.04 (1.38)	47.87 (1.42)	73.65 (0.48)	49.89 (0.33)
	skin	light orange	65.37 (2.04)	11.41 (2.07)	45.52 (1.83)	75.97 (1.73)	46.94 (1.86)
Z 402/16	flesh		61.25 (2.34)	15.31 (2.13)	50.50 (1.66)	73.13 (1.13)	52.78 (0.60)
	skin	orange (red)	64.07 (1.46)	6.64 (2.19)	41.41 (2.18)	80.88 (1.33)	41.95 (0.12)
Z 211/18	flesh		61.33 (1.90)	15.87 (0.92)	48.53 (1.60)	71.89 (0.52)	51.06 (0.24)
	skin	orange	63.21 (1.56)	12.31 (2.07)	43.10 (1.40)	74.06 (0.88)	44.83 (0.31)
S 404/42	flesh		65.66 (1.00)	17.08 (1.06)	51.14 (1.25)	71.53 (0.15)	53.91 (0.60)
	skin	orange	23.63 (1.60)	29.57 (2.22)	41.12 (1.12)	77.32 (0.72)	45.68 (0.25)
Selene	flesh		69.34 (1.92)	17.93 (1.37)	53.32 (1.69)	71.41 (0.36)	56.26 (0.71)
	skin	orange	70.28 (1.63)	15.90 (1.87)	46.50 (1.44)	71.13 (0.68)	49.15 (0.33)
Z 203/15	flesh		71.52 (1.83)	18.29 (1.84)	53.70 (0.95)	71.19 (0.63)	56.73 (0.52)
	skin	orange (light red)	69.68 (1.05)	14.15 (2.21)	49.35 (1.30)	74.00 (0.54)	51.34 (0.53)
Z 403/2	flesh		66.87 (1.53)	14.87 (1.91)	43.42 (1.42)	71.10 (1.06)	45.90 (0.57)
	skin	light orange (red)	67.32 (1.05)	10.67 (2.57)	45.23 (1.47)	76.73 (0.47)	46.47 (0.67)
Z 212/6	flesh		64.51 (1.73)	18.90 (1.93)	53.54 (1.49)	70.55 (0.70)	56.78 (0.32)
	skin	orange	62.76 (1.48)	16.86 (2.61)	45.36 (2.40)	69.60 (0.88)	48.40 (0.79)
S 102/43	flesh		64.65 (1.11)	19.57 (0.98)	51.33 (1.26)	69.13 (0.75)	54.93 (0.73)
	skin	orange	63.46 (1.35)	14.23 (1.55)	45.01 (1.83)	72.45 (1.11)	47.21 (1.13)
Z 209/17	flesh		62.18 (1.72)	18.76 (0.91)	47.48 (1.32)	68.45 (0.26)	51.05 (0.74)

Table 2. (Continued)

cultivar	part	skin color	L^*	a^*	b^*	H° [b]	C^* [c]
			Orange Flesh (Continued)				
	skin	orange (orange-red)[d]	63.63 (1.27)	11.72 (2.55)	44.12 (1.19)	75.12 (0.77)	45.65 (0.62)
Z 308/12	flesh		63.45 (1.23)	20.72 (0.95)	51.39 (1.11)	68.04 (0.37)	55.41 (0.46)
	skin	orange (red)	63.97 (1.30)	17.78 (2.25)	47.71 (1.49)	69.56 (1.14)	50.92 (0.71)
Z 207/4	flesh		62.46 (1.38)	20.44 (0.67)	49.96 (1.30)	67.75 (0.23)	53.98 (0.87)
	skin	orange (orange-red)	63.55 (0.77)	13.02 (2.38)	43.96 (1.10)	73.50 (0.50)	45.85 (0.40)

[a] Standard deviation (n = 3) in parentheses. [b] H° = hue value = arc tg (b^*/a^*). [c] C^* = color intensity (chroma) = $(a^{*2} + b^{*2})^{1/2}$. [d] Blush color of skin given in parentheses.

RESULTS AND DISCUSSION

Quality Indices and Color Evaluation. The trained panel classified the apricot varieties into four groups according to the perception of the flesh color as white, yellow, light orange, and orange. This color perception was independent of the harvest date because some of the white or orange flesh varieties were harvested early in mid-May and some others with the same flesh colors were harvested later in mid-June (**Table 1**). The quality indices of the apricot varieties including fruit firmness, soluble solids content (SSC), titratable acidity (TA), and pH identified the fruits used in this study as ripe and ready-to-eat apricots (**Table 1**). Fruit firmness ranged from soft fruits (24.6 N) to very firm (60.1 N), and the large variation was one of the intrinsic characteristics of the specific variety (independent of the harvest date or other quality attributes). SSC ranged from 10.4 to 16.7% and was also inherent to the apricot variety and independent of the harvest date. The most significant difference among the color groups was noted in the pH and TA of the white and orange flesh apricot varieties. TA was higher and pH was lower in the orange flesh than in the white or yellow flesh varieties (**Table 1**). These results agree with those previously reported for peaches and nectarines (*7*). A wide variability in the quality indices among the studied varieties was observed and could be due to the different genetic origins. Exceptional apricots have been described as having a balance of sugar and acidity as well as aroma (*13*). Most of the new varieties obtained achieved the most important quality criteria for consumer demand.

The analysis of the color values showed that the lightness factor, L^*, in general, decreased from the white flesh to the orange flesh varieties (**Table 2**). The decrease of L^* reflected the darkening of the apricot varieties by carotenoid accumulation. The L^* value in the skin was, in general, slightly higher than in the flesh for the same variety. The a^* value increased as an indicator of the increase in the red color from negative values in those white and yellow flesh varieties to positive a^* values in the light orange and orange flesh varieties (**Table 2**). In general, the a^* value was higher in the flesh than in the skin for the same variety. The b^* value ($-b^*$, blue; and $+b^*$ yellow) and chroma (C^*) increased in the orange flesh variety compared to the white flesh ones. The hue angle has been described as a suitable and intuitively understandable color index (for example, red, yellow, blue, etc.) (*8*). It decreased from 96.48° in the white flesh variety to 69.56° in the orange flesh ones. This decrease in hue angle was from the yellow to the orange stage due to carotenoid accumulation.

Carotenoid Content of Apricot Varieties. β-Carotene was found to be the main pigment in the 37 studied varieties followed by β-cryptoxanthin and γ-carotene. A characteristic HPLC chromatogram is presented in **Figure 1**. A trace of another carotenoid with a higher t_R (retention time) was observed at the end of the chromatogram, but identification was not possible

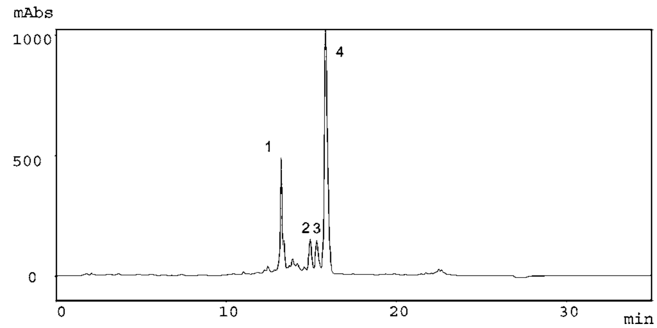

Figure 1. HPLC chromatogram of apricot extracts at 450 nm. Peaks: (1) β-apo-8′-carotenal (IS); (2) β-cryptoxanthin; (3) γ–carotene; (4) β-carotene.

as it was present in a very small amount. The total carotenoid contents varied from 1359 μg 100 g^{-1} in the flesh of a white flesh variety to 38522 μg 100 g^{-1} in the peel of an orange flesh apricot variety (**Table 3**). The percentages of β-carotene, β-crytoxanthin, and γ-carotene contents in the four groups of apricots did not follow any particular pattern. The β-carotene ranged from 48% in a white flesh variety to 88% in an orange flesh apricot. In previous studies, β-carotene accounted for some 60% of the total carotenoid content (*6*). Therefore, in our case, there was a wide range of variability among the new apricot varieties. β-Crytoxanthin ranged from 5% in an orange flesh apricot to 28% in a yellow flesh apricot. γ-Carotene varied from 5% in an orange flesh variety to 26% in a white flesh one. Similars percentage of each individual carotenoid were detected in both flesh and peel. However, the total carotenoid content was, in general, 2−3 times higher in the peel than in the flesh. The carotenoids described in a previous study of two Japanese apricot varieties showed a similar patten, where β-carotene was about 70%, β-crytoxanthin, 7%, and γ-carotene, 7% (*14*). The variety with less β-carotene and β-crytoxanthin and more γ-carotene was described as slightly more reddish in color compared with the other variety (*14*). These previous findings were not able to be corroborated because in our case the changes in the content of both β-crytoxanthin and γ-carotene did not depend on the flesh color.

Some papers have recommended that research studies focus on those carotenoids which dominate, in terms of quantity, and on those showing a provitamin A activity (*15*). Consequently, the carotenoids phytoene, phytofluene, and ξ-carotene should be of no antioxidative significance (*15*). Because provitamin A carotenoids include β-carotene, β-cryptoxanthin, and α-carotene, in our case, only β-carotene and β-cryptoxanthin were considered, and the content of the different apricot varieties is shown in **Table 3**. The daily intake of provitamin A can only be achieved by consuming 100−200 g per day of fruits and vegetables with particularly high carotenoid contents (*16*). Some of the new apricot varieties showed a high provitamin A content, with content as high as 2 mg per 100 g. This is one of the richest

Table 3. Carotenoid Pigments Content at Commercial Maturity in White, Yellow, Light Orange, and Orange Flesh Apricot Varieties (*P. armeniaca* L.)[a]

variety	part	skin color	β-crypto-xanthin	γ-carotene	β-carotene	provitamin A[b]	total carotenoids[c]
			White Flesh				
Z 115/26	flesh		254 (91)	182 (75)	924 (353)	175 (66)	1512 (444)
	peel	white (dark rose)[d]	628 (47)	417 (73)	1969 (423)	381 (67)	
Z 109/58	flesh		267 (148)	188 (102)	1078 (475)	202 (91)	1877 (658)
	peel	white (light red)	640	559	4059	730	
Z 108/38	flesh		325 (85)	230 (35)	1189 (582)	225 (103)	1880 (673)
	peel	white	671 (115)	423 (62)	2139 (462)	412 (86)	
Currot	flesh		672 (291)	690 (310)	1264 (476)	267 (104)	2833 (1038)
	peel	yellow (light red)	1159 (232)	1097 (220)	2638 (257)	536 (45)	
Z 604/12	flesh		734 (93)	472 (36)	1724 (471)	348 (86)	3224 (597)
	peel	yellow	1060 (194)	687 (110)	4378 (890)	818 (132)	
Z 501/28	flesh		681 (30)	557 (63)	1948 (774)	381 (128)	3376 (766)
	peel	yellow (red)	940 (72)	761 (56)	3566 (366)	673 (64)	
Yellow Flesh							
Z 405/17	flesh		211 (76)	231 (73)	2007 (561)	352 (98)	2694 (584)
	peel	yellow (red)	594 (24)	652 (42)	3867 (477)	694 (78)	
S 407/8	flesh		317 (84)	385 (85)	2199 (425)	393 (77)	3692 (524)
	peel	yellow (red)	716 (96)	1154 (351)	9567 (422)	1654 (65)	
S 406/22	flesh		667 (63)	417 (44)	2026 (264)	393 (47)	3770 (347)
	peel	yellow (red)	1267 (180)	1359 (108)	7609 (371)	1374 (75)	
Z 209/1	flesh		978 (59)	493 (52)	1971 (404)	410 (66)	3885 (54)
	peel	yellow	1451 (158)	787 (157)	6009 (401)	1122 (80)	
Mauricio	flesh		506 (114)	579 (123)	3089 (535)	557 (99)	4579 (637)
	peel	yellow	1076 (100)	1070 (224)	6420 (550)	1160 (95)	
Z 102/19	flesh		674 (123)	421 (52)	3374 (254)	619 (37)	4907 (191)
	peel	yellow	951 (75)	623 (37)	7647 (158)	1354 (23)	
			Light Orange Flesh				
Z 506/7	flesh		914 (94)	704 (77)	2648 (166)	518 (31)	4920 (201)
	peel	light orange (red)	1444 (51)	1855 (46)	8049 (727)	1462 (119)	
Rojo Pasión	flesh		678 (111)	613 (52)	3741 (216)	680 (38)	6028 (391)
	peel	yellow (red)	1079 (50)	1787 (196)	12934 (1423)	2246 (239)	
Z 111/61	flesh		944 (136)	544 (108)	4992 (697)	911 (127)	6979 (859)
	peel	yellow (light red)	1090 (71)	818 (77)	10014 (380)	1760 (62)	
Dorada	flesh		1361 (380)	1019 (200)	4325 (718)	834 (151)	7405 (1154)
	peel	light orange	2157 (206)	1485 (134)	10659 (321)	1956 (55)	
Z 502/6	flesh		1143 (257)	1146 (443)	4642 (726)	869 (128)	7471 (1124)
	peel	light orange (dark rose)	1562 (79)	1618 (105)	9634 (717)	1736 (118)	
Búlida	flesh		1627 (274)	1852 (375)	3668 (365)	746 (84)	7637 (936)
	peel	light orange	2338 (194)	2615 (152)	7545 (224)	1452 (22)	
Murciana	flesh		1052 (193)	901 (36)	5768 (432)	1049 (56)	9088 (153)
	peel	light orange (red)	1828 (140)	2262 (73)	18410 (780)	3221 (139)	
Z 115/13	flesh		1314 (157)	1055 (158)	6882 (429)	1257 (84)	9556 (651)
	peel	white (light red)	1579 (254)	968 (184)	10081 (845)	1812 (156)	
			Orange Flesh				
Z 308/6	flesh		1504 (206)	926 (116)	5307 (304)	1010 (64)	8062 (554)
	peel	light orange (red)	1857 (307)	990 (132)	8464 (350)	1566 (66)	
Z 201/13	flesh		1300 (85)	1050 (25)	4953 (80)	934 (18)	8260 (94)
	peel	light orange (red)	2264 (102)	1315 (105)	14086 (374)	2536 (64)	
Z 211/18	flesh		2147 (310)	1359 (123)	5505 (359)	1097 (63)	10472 (574)
	peel	orange	2261 (262)	2980 (216)	19580 (350)	3452 (79)	
Z 308/9	flesh		679 (98)	544 (141)	8944 (933)	1547 (157)	10649 (913)
	peel	light orange (red)	1479 (176)	919 (67)	13076 (1001)	2303 (156)	
S 401/33	flesh		2228 (264)	1627 (107)	5616 (86)	1122 (36)	10883 (462)
	peel	orange	3031 (502)	3728 (190)	17996 (320)	3252 (66)	
Z 203/8	flesh		1432 (240)	994 (148)	8050 (313)	1461 (72)	11118 (976)
	peel	light orange	1375 (191)	1183 (223)	14927 (1523)	2602 (270)	
S 404/42	flesh		1689 (40)	1815 (40)	7307 (562)	1359 (96)	11984 (747)
	peel	orange	2831 (405)	2664 (199)	18051 (2455)	3244 (442)	
Z 505/2	flesh		2118 (425)	1447 (233)	8214 (601)	1546 (127)	12932 (1010)
	peel	light orange (red)	2128 (278)	2955 (206)	19226 (419)	3382 (93)	
Z 212/6	flesh		3045 (704)	1894 (360)	6856 (754)	1396 (184)	13476 (421)
	peel	orange	2802 (78)	3588 (153)	23609 (292)	4168 (42)	
Z 403/2	flesh		2355 (702)	1435 (353)	9794 (38)	1829 (65)	13831 (975)
	peel	light orange (red)	2373 (451)	1265 (210)	12752 (505)	2323 (121)	
Selene	flesh		2393 (338)	1507 (113)	9265 (56)	1744 (37)	14007 (485)
	peel	orange	2955 (93)	2348 (108)	17063 (1351)	3090 (218)	
S 102/43	flesh		2211 (336)	1836 (240)	7911 (180)	1503 (58)	14417 (638)
	peel	orange	3412 (160)	4610 (66)	30500 (1245)	5368 (205)	
Z 207/4	flesh		729 (75)	766 (38)	11058 (537)	1904 (87)	14524 (498)
	peel	orange (orange-red)[d]	3789 (290)	4463 (340)	25636 (586)	4589 (100)	
Z 203/15	flesh		3137 (483)	2111 (165)	8267 (343)	1639 (48)	14604 (425)
	peel	orange (light red)	3254 (310)	3547 (136)	18572 (961)	3367 (136)	

Table 3. (Continued)

variety	part	skin color	β-crypto-xanthin	γ-carotene	β-carotene	provitamin A[b]	total carotenoids[c]
			Orange Flesh (Continued)				
Z 402/16	flesh		2529 (226)	2260 (189)	9421 (477)	1781 (61)	14986 (116)
	peel	orange (red)	1493 (63)	1225 (11)	19985 (1015)	3455 (164)	
Z 209/17	flesh		2399 (110)	2314 (98)	10272 (566)	1912 (95)	16054 (577)
	peel	orange (orange-red)	2145 (200)	2858 (182)	21645 (1680)	3786 (278)	
Z 308/12	flesh		3672 (1126)	2444 (535)	9248 (147)	1847 (98)	16500 (1591)
	peel	orange (red)	4835 (498)	3257 (161)	19657 (471)	3679 (89)	

[a] Means in μg 100 g^{-1} fresh weight. Standard deviations (n = 3) in parentheses. [b] IU of provitamin A/mg of fresh fruit = (166.7 × mg of β-carotene + 83.3 × mg of β-cryptoxanthin) 100 g^{-1} fresh fruit. [c] Total carotenoids = μg 100 g^{-1} of fresh weight from the edible portion (91% flesh + 9% peel). [d] Blush color of skin given in parentheses.

Table 4. Average of Flesh Color Value, Total Carotenoids, and Provitamin A in White, Yellow, Light Orange, and Orange Flesh Apricot Varieties (*P. armeniaca* L.)[a]

flesh color	H° flesh[b]	total carotenoids[c]	provitamin A[d]
white	88.14 a	2450 a	296 a
yellow	84.97 a	3921 a	524 a
light orange	77.55 b	7385 b	957 b
orange	72.45 c	12750 c	1669 c

[a] Values with different letters showed statistically significant differences at the 5% level, according to Duncan's multiple-range test. [b] $H°$ = hue value = arc tg (b^*/a^*). [c] Total carotenoids = μg 100 g^{-1} of fresh weight from the edible portion (91% flesh + 9% peel). [d] Provitamina A = IU of provitamin A/mg of fresh fruit from the edible portion (91% flesh + 9% peel).

Table 5. Correlation Coefficients between Total Carotenoids and Quality Indices[a]

	maturity date	flesh firm-ness	soluble solids	titrat-able acidity	pH	H° flesh
total carotenoids[b]	0.221	–0.089	–0.163	0.417*	–0.455**	–0.939**

[a] Pearson's correlation coefeciients. *, **, significant at $P \leq 0.05$ or 0.01, respectively. [b] Total carotenoids in the edible portion.

Table 6. Correlation Coefficients between Carotenoids and Color Indices[a]

	L*	a*	b*	H°	C*
		Apricot Flesh			
β-cryptoxanthin	–0.240	0.843**	0.714**	–0.814**	0.771**
γ-carotene	–0.379*	0.856**	0.696**	–0.835**	0.758**
β-carotene	–0.383*	0.885**	0.685**	–0.882**	0.756**
provitamin A	–0.377*	0.909**	0.711**	–0.903**	0.783**
total carotenoids	–0.380*	0.935**	0.741**	–0.924**	0.813**
		Apricot Peel			
β-cryptoxanthin	–0.321	0.778**	0.395*	–0.822**	0.596**
γ-carotene	–0.319	0.695**	0.306	–0.761**	0.487**
β-carotene	–0.370*	0.737**	0.335*	–0.817**	0.515**
provitamin A	–0.372*	0.750**	0.344*	–0.829**	0.527**
total carotenoids	–0.371*	0.762**	0.350*	–0.839**	0.538**

[a] Pearson's correlation coefficients. *, **, significant at $P \leq 0.05$ or 0.01, respectively.

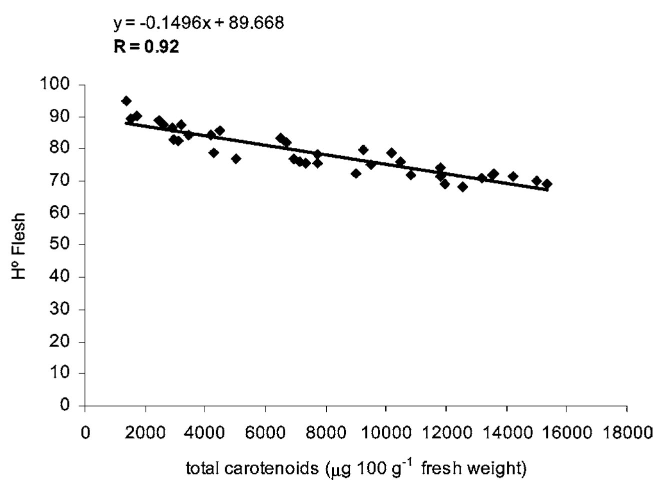

Figure 2. Correlation between total carotenoids in flesh (μg 100 g^{-1} of fresh weight) and flesh color value ($H°$).

carotenoid fruits along with other fruits such as grapefruit, papaya, nectarine, and some more recent pineapple cultivars.

The data on the carotenoid content of the edible portion were calculated by considering 9% peel and 91% flesh, which correspond with the whole fruit except the kernel (**Table 3**). This content ranged from 1512 to 16500 μg 100 g^{-1} of edible portion. In the case of apricots, it is very important to emphasize that the peel is consumed as an edible portion in contrast with other fruits such as peaches, because it is the richest portion of the apricot, with its carotenoid content 2–3 times higher than in flesh.

The new apricot varieties were separated according to flesh color into four groups: white, yellow, light orange, and orange. The average total carotenoid and provitamin A contents in each group are shown in **Table 4**, where significant differences were observed between the groups except for white-yellow flesh apricots. The same behavior was detected for the hue angle (**Table 4**).

Relationship between Color and Carotenoid Content. Regression analysis was performed on the quality indices including color values and total carotenoids. Correlation analysis was carried out to determine the strength of the linear relationship between total carotenoid content and quality indices. No correlation was observed between total carotenoid content and maturity stage, flesh firmness, and soluble solids, whereas a poor correlation coefficient was shown in the case of titratable acidity and pH (**Table 5**). The hue angle of the flesh had the highest correlation of −0.939 ($P \leq 0.01$), showing that the relationship between total carotenoids and color was linear (**Table 5**). The correlations between color parameters and the individual and total carotenoids found in the flesh and peel are shown in **Table 6**. The color parameters a^*, b^*, hue angle, and chroma showed good correlations with individual and total carotenoids in both flesh and peel. The best correlation was observed between total carotenoids and a^* value in the case of flesh (R = 0.93), whereas for the peel it was between total carotenoids and hue angle (R = 0.84). The decrease of hue angle was directly associated with the content of carotenoids, and

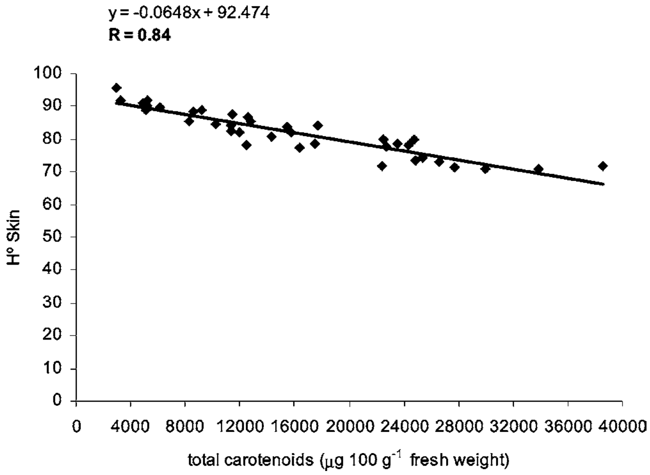

Figure 3. Correlation between total carotenoids in peel (μg 100 g^{-1} of fresh weight) and skin color value (H°).

therefore hue angle is the most appropriate color reading for estimating the carotenoid content in apricots (**Figures 2** and **3**). The light transmittance characteristics have been described to be useful in assessing the desired harvest maturity in peaches, nectarines, and apricots (*17*). In the case of tomato, the increase in the a* value was related to lycopene synthesis (*8*).

The correlation between the carotenoid content, measured by HPLC, and the hue angle of the apricot skin and flesh measured with a portable Minolta chroma meter has been established. The carotenoid content of apricots can be accurately predicted with the use of a portable chroma meter. It is an easy, convenient, and nondestructive method that provides a good estimation of the carotenoid content of apricots. Due to this result, most of the principal apricot breeding programs could use the hue angle as a quality criterion to select new varieties with higher carotenoid contents. Apricot color has a large influence not only on consumer perception of quality but also on nutritional recognition for their vitamin A content.

ABBREVIATIONS USED

IS, internal standard; t_R, retention time; SSC, soluble solids content; TA, titratable acidity; H°, hue angle.

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