Changes in external and internal color during postharvest ripening of ‘Manila’ and ‘Ataulfo’ mango fruit and relationship with carotenoid content determined by liquid chromatography–APCI*-time-of-flight mass spectrometry

José de Jesús Ornelas-Paz a,b,1, Elhadi M. Yahia a,* , Alfonso A. Gardea b

a Facultad de Ciencias Naturales, Universidad Autónoma de Querétaro, Avenida de las Ciencias s/n, 76230 Juriquilla, Querétaro, Mexico
b Centro de Investigación en Alimentación y Desarrollo, A.C. Carretera a la Victoria Km. 0.6, 83000 Hermosillo, Sonora, Mexico

A R T I C L E  I N F O

Article history:
Received 27 June 2007
Accepted 1 May 2008

Keywords:
Mangifera indica L.
Xanthophylls esters
Vitamin A
Carotenoid stereoisomers
CIELAB color system

A B S T R A C T

High-performance liquid chromatography–atmospheric pressure chemical ionization (APCI*)-time-of-flight mass spectrometry studies revealed that all-trans-β-carotene and the dibutyrates of all-trans-violaxanthin and 9-cis-violaxanthin were the main carotenoids in ‘Ataulfo’ and ‘Manila’ mango fruit mesocarp. The concentration of these carotenoids in the mesocarp was measured during fruit ripening and correlated with colorimetric changes of mesocarp and epidermis. The lowest and highest concentrations of all-trans-β-carotene, all-trans-violaxanthin and 9-cis-violaxanthin (as dibutyrates) during the ripening of ‘Manila’ mango were 0.25 × 10⁻³ to 35.57 × 10⁻³, 0.40 × 10⁻³ to 31.97 × 10⁻³ and 0 to 16.81 × 10⁻³ g·kg⁻¹ of fresh mesocarp, respectively. For ‘Ataulfo’ they were 2.55 × 10⁻³ to 39.72 × 10⁻³, 0.16 × 10⁻³ to 15.00 × 10⁻³ and 0.21 × 10⁻³ to 7.48 × 10⁻³ g·kg⁻¹ of fresh mesocarp, respectively. The concentration of these carotenoids increased in an exponential manner during fruit ripening in ‘Ataulfo’ and in an exponential or second-order polynomial manner in ‘Manila’. The highest correlation coefficients were obtained for the relationships between the mesocarp and epidermis a* and h* color values and the concentration of the evaluated carotenoids in both mango cultivars (R² = 0.81–0.94). Equations to predict the concentration of the most important carotenoids in ‘Manila’ and ‘Ataulfo’ mango fruit on the basis of their mesocarp and epidermis color values were obtained.

© 2008 Elsevier B.V. All rights reserved.

1. Introduction

Mango (Mangifera indica L.) is a very popular fruit in many countries. Mexico is the fourth biggest producer and first exporter, with very high fruit consumption (Yahia et al., 2006a). Mexico produces more than 50 mango cultivars but the most important are ‘Manila’ and ‘Ataulfo’, which are also becoming important in some export markets (Yahia et al., 2006a). ‘Manila’ and ‘Ataulfo’ mango fruits are medium size (200–300 g), rich in sugars at ripe stage, and their color changes from green to yellow-orange during ripening. The epidermal color of these fruits is homogeneous and does not develop a red blush (Ornelas-Paz et al., 2007).

Mango is a climacteric fruit (Sane et al., 2005; Yahia et al., 2006a), and its ripening process occurs rapidly after harvest, depending on cultivar, stage of maturity at harvest, and postharvest conditions (Vázquez-Caicedo et al., 2004). Several biochemical changes occur during mango ripening, among which carotenoid biosynthesis is one of the most important (Vázquez-Caicedo et al., 2004, 2005). Carotenoids are lipid soluble compounds associated with protective health effects such as against some types of cancer (Bertram and Vine, 2005), age-related macular degeneration (Bruno and Medeiros, 2000), and heart disease (Palace et al., 1999). In addition, some carotenoids, such as all-trans-β-carotene, are precursors of vitamin A. Several carotenoids have been identified in fruit of different mango cultivars (Cano and de Ancos, 1994; Ben-Amotz and Fishler, 1998; Chen et al., 2004), but only a few of them occur in significant concentrations (Ornelas-Paz et al., 2007). Mercadante et al. (1997) quantified several carotenoids in saponified extracts of ‘Keitt’ mangoes and concluded that the predominant ones were all-trans-β-carotene, all-trans-violaxanthin and 9-cis-violaxanthin accounting for 27, 38 and 18% of total carotenoid content, respectively. Similar findings have been reported for crude extracts from other mango cultivars (Mercadante and Rodríguez-Amaya, 1998; Pott et al., 2003a,b). Carotenoids are also the pigments responsible for the yellow-orange color of mango mesocarp (Vázquez-Caicedo et al., 2005).

Color is an important food quality parameter. It affects consumer acceptance (Crisosto et al., 2002), the perception of sweetness and flavor (Bayarri et al., 2001), and can even evoke emotional feelings.
in humans (Ou et al., 2004). In the case of mango, color of the epidermis plays an important role in the perception of overall quality (González-Aguilar et al., 2001), and can be an important tool for determining the appropriate maturity for harvest (Cocozza et al., 2004; Jha et al., 2007), processing (Mahayothee et al., 2004) and consumption (Cocozza et al., 2004; Jha et al., 2007). In addition, mango color can be used to estimate the content of all-trans-β-carotene (Vázquez-Caicedo et al., 2005), the most important provitamin A carotenoid (Wolf, 1984).

Color measurements have been used for carotenoid estimation in sweet potatoes (Lauber et al., 1967; Takahata et al., 1993; Ameny ter et al., 2004; Ameny ter et al., 2004) on the basis of the CIELAB color system (2.3. Color measurements)

2.2. Fruit selection and sampling

Fresh mango fruit (Mangifera indica L. cvs. Manila and Ataulfo) were bought in the local market of Querétaro, Mexico. Fruit of both cultivars were selected for uniform size and freedom from blemishes and defects, but with different ripening stages, as judged subjectively based on epidermal color. Fruit were then stored for up to 16 days at 28 ± 0.5 °C and 60% relative humidity and eight samplings were performed during the storage period. During each sampling period, four fruit of each cultivar were taken randomly and each fruit was individually evaluated for color and carotenoid concentration. The experiment was repeated twice.

2.3. Color measurements

Color was measured with a Minolta colorimeter (Minolta Co. Ltd., Osaka, Japan) on the basis of the CIELAB color system (L*, a*, b*, C, and h*). In this system L* describes the length of the color vector in the plane formed by the values of a* and b*, while h* determines the position of such vector. The colorimeter was calibrated with the white pattern during each sampling time. Epidermis color was longitudinally determined on three points of each flat side of the fruit (six points for each fruit). For mesocarp color, a big slice from a flat side of each fruit was obtained and color was determined longitudinally at three equidistant points.

2.4. Extraction of carotenoids

The extraction procedure of carotenoids was carried out as described by Pott et al. (2003a), with some modifications (Yahia et al., 2006b; Yahia et al., 2007). Fresh mango mesocarp from each fruit (6 g) was ground in a homogenizer (Ika Works Inc., Wilmington, NC) in the presence of calcium carbonate (0.2 g) and methanol (15 mL). The homogenate was filtered through a filter paper by adding methanol until retained solids became colorless. The methanolic extract was mixed with 50 mL of a mixture of hexane-acetone (1:1, v/v) containing 0.1% of BHT. After vigorous stirring, 40 mL of 10% sodium sulfate were added for phase separation. The upper layer was separated, washed several times with water, and evaporated in a Rotovapor® (Büchi Labortechnik AG, Flawil, Switzerland) at 35 °C. For saponification, the residue was dissolved in diethyl ether (30 mL) and 0.2 mL of 40% KOH in methanol were added. The mixture was left for 16 h in the dark at room temperature. After completion of saponification the extract was washed with water and evaporated as described above. Saponified and unsaponified residues were dissolved in 2-propanol (2 mL), filtered through a polyethylene membrane of 0.45 μm of pore size (Millipore Corp., Bedford, MA), and injected into the HPLC system (25 μL).

2.5. I2-catalized photoisomerization of carotenoids

The 9-cis isomer of violaxanthin was generated for identification purposes according to Molnár et al. (2004). A quantity of 0.11 mg of all-trans-violaxanthin was dissolved in 1 mL of benzene containing 0.002 mg of I2. The solution was exposed to daylight until equilibrium was reached, which occurred within 40 min. The reaction mixture was then washed with 5% Na2SO3 (50 mL), evaporated at reduced pressure (12 kPa) at 35°C and re-dissolved in 2-propanol (2 mL) prior to HPLC analysis.

2.6. HPLC–MS analytical conditions

Samples containing carotenoids were automatically injected into an HP 1100 series HPLC system (Hewlett-Packard, Germany) equipped with a diode array detector. Absorption spectra for the main peaks were recorded between 200 and 500 nm (each 2 nm). Individual signals for 9-cis-violaxanthin, all-trans-violaxanthin and all-trans-β-carotene were monitored at 436, 439 and 452 nm, respectively. The HPLC system was equipped with a C18 reversed-phase column (4.6 mm × 150 mm) with a spherical particle size of 3 μm (YMC Inc., Wilmington, NC), which was kept at 15°C. The mobile phase was composed of water (A), methanol (B) and MTBE (C) with the following gradient program: 4% A, 95.2% B and 0.8% C at 0 min, decreasing to 4% A, 55.3% B and 40.7% C within 78 min at a flow rate of 1.25 × 10−2 mL s−1.

Mass spectra of the main carotenoids were obtained using the chromatographic system described above but with the addition of a 6210 model time-of-flight mass spectrometer (Agilent Technologies Inc., Palo Alto, CA) equipped with an atmospheric pressure chemical ionization (APCI+) interface and MassHunter software (Version A.02.01). The APCI+–MS system was operated in positive ion mode. High purity nitrogen (99.999%) was used as nebulizing (130 kPa) and drying gas (83.33 mL s−1). Other APCI+–MS parameters were as follows: gas and vaporizer temperatures were
Carotenoids were identified by comparing their retention time and UV–vis data with those obtained with reference standards as well as co-chromatography with added standards and using their mass spectra (m/z 100–1200). Quantitative data for all-trans-carotenoids were obtained by calibration curves constructed with pure compounds. Quantification of cis isomers of carotenoids was based on calibration curves of their parent all-trans-carotenoids.

2.7. Statistical analysis

Data were subjected to correlation studies and then to regression analyses. Tukey–Kramer Honestly Significant Difference test was used as a comparison of statistical significance for the carotenoid content in both mango cultivars. Data analysis was performed using JMP statistical software (SAS Institute Inc., Cary, NC) or Microsoft Excel 2002.

3. Results and discussion

3.1. Identification of the main carotenoids in ‘Manila’ and ‘Ataulfo’ mango fruit

Both mango cultivars presented the same chromatographic carotenoid profiles in which three peaks were dominant (peaks 1, 2 and 3 in Fig. 1). The absorption spectra for peaks 1 (λ_{max} at 416, 439, 469 nm), 2 (λ_{max} at 413, 436, 465 nm) and 3 (λ_{max} at 427, 452, 478 nm) were similar to those previously reported for all-trans-violaxanthin (λ_{max} at 416, 440, 469 nm), 9-cis-violaxanthin (λ_{max} at 414, 436, 466 nm), and all-trans-β-carotene (λ_{max} at 426, 452, 478 nm) (Davies, 1976; Pott et al., 2003a,b), suggesting the presence of such carotenoids in mango mesocarp. When crude extracts were saponified, peaks 1 and 2 disappeared but two intense new peaks were observed in the most polar region of the chromatogram (peaks 4 and 5 in Fig. 2), suggesting that peaks 1 and 2 were carotenoid esters, since the saponification step allows hydrolysis of xanthophylls esters (Kimura et al., 1990). Peak 3 was not affected by the saponification step. The absorption spectra of peaks 1 and 2 were exactly the same as those observed for peaks 4 and 5, respectively, demonstrating that peaks 4 and 5 were the un-esterified version of peaks 1 and 2. In order to further investigate the identity of the important carotenoids, reference compounds were employed. The retention time and absorption spectra of peaks 4, 5 (Fig. 2) and 3 (Figs. 1 and 2) were exactly the same as those obtained with standard compounds of all-trans-violaxanthin, 9-cis-violaxanthin and all-trans-β-carotene, thus peaks 1, 2 and 3 were identified as all-trans-violaxanthin ester, 9-cis-violaxanthin ester and all-trans-β-carotene, respectively.

Mass spectra of peaks 1 (Fig. 3) and 2 exhibited the same quasimolecular ion ([M+H]^+) and fragmentation patterns, which showed the successive loss of water (m/z 723, [M+H–H_2O]^+), probably from the epoxy groups, one neutral molecule of butyric acid (BA, 88 kDa) (m/z 635, [M+H–H_2O–BA]_1^+), and the loss of another molecule of BA (m/z 547, [M+H–H_2O–BA–BA]_1^+) in addition, the mass spectra of both peaks revealed the subsequent loss of the two molecules of BA from the quasimolecular ion (m/z 653, [M+H–BA]_1^+; m/z 565, [M+H–BA–BA]_2^+) without loss of water. This fragmentation pattern for diesters of violaxanthin has been previously reported in potatoes and mango (Breithaupt et al., 2002; Pott et al., 2003b). Thus peaks 1 and 2 were identified as dibutyrates of all-trans-violaxanthin and 9-cis-violaxanthin, respectively. Our findings are in agreement with those generated by Pott et al. (2003b), who concluded that the dibutyrates of all-trans-violaxanthin and 9-cis-violaxanthin were the main carotenoid esters in crude extracts of ‘Kent’ mangoes. The quasimolecular ion for peak 3 (m/z 537, [M+H]^+) has led to the identification of all-trans-β-carotene. The presence of cis and all-trans isomers of violaxanthin and β-carotene has been reported for some mango cultivars (Mercadante et al., 1997; Chen et al., 2004; Vázquez-Caicedo et al., 2005).

Fig. 1. Typical carotenoid profile at 452 nm of crude extracts of ripe ‘Manila’ and ‘Ataulfo’ mangoes. Peaks 1 and 2 were identified as dibutyrates of all-trans-violaxanthin and 9-cis-violaxanthin, and peak 3 was identified as all-trans-β-carotene. See text for UV–vis data of numbered peaks. Non-numbered peaks were not studied.

Fig. 2. Typical carotenoid profile at 452 nm of saponified extracts of ripe ‘Manila’ mango fruit. Peaks 4 and 5 correspond to all-trans-violaxanthin and 9-cis-violaxanthin, and peak 3 was identified as all-trans-β-carotene. See text for UV–vis data of numbered peaks. Non-numbered peaks were not studied.

Fig. 3. Mass spectra (APCL mode) of all-trans-violaxanthin dibutyrate (corresponding to peak 1 in Fig. 1) as an example of fragmentation pattern of xanthophylls esters in ‘Ataulfo’ mango fruit. Fragments belonging to the main fragmentation pathways are labeled. [M+H]^+ represents the quasimolecular ion and BA represents a molecule of butyric acid.
Fig. 4. Relationships between the content of all-trans-β-carotene (▲), all-trans-violaxanthin (as dibutyrate, ●), 9-cis-violaxanthin (as dibutyrate, ○) in mesocarp and the $a^*$, $b^*$ and $L^*$ values, measured in mesocarp or epidermis of 'Ataulfo' mango fruit during the ripening process. Each point represents the mean of two independent measurements ± the standard error (vertical bars). The continuous line represents an exponential regression.

3.2. Carotenoid concentrations in ‘Manila’ and ‘Ataulfo’ mango fruit

The concentrations of all-trans-β-carotene, all-trans-violaxanthin and 9-cis-violaxanthin (as dibutyrates) increased during the ripening period and the values ranged between $0.25 \times 10^{-3}$ to $35.57 \times 10^{-3}$, $0.40 \times 10^{-5}$ to $31.97 \times 10^{-3}$ and $0$ to $16.81 \times 10^{-3}$ g kg$^{-1}$ of fresh mesocarp in 'Manila' mango fruit, whereas the concentrations in 'Ataulfo' mango were $2.55 \times 10^{-3}$ to $39.72 \times 10^{-3}$, $0.16 \times 10^{-3}$ to $15.00 \times 10^{-3}$ and $0.21 \times 10^{-3}$ to $7.48 \times 10^{-3}$ g kg$^{-1}$ of fresh mesocarp, respectively (Figs. 4–7). The concentrations of all-trans-violaxanthin and 9-cis-violaxanthin (as dibutyrates) were higher in 'Manila' than in 'Ataulfo' mango fruit ($P<0.05$). The maximum concentration of xanthophylls in 'Ataulfo' and 'Manila' mangoes was smaller and greater, respectively, than those reported for Brazilian mango cultivars (Mercadante et al., 1997; Mercadante and Rodríguez-Amaya, 1998). The concentration of 9-cis-violaxanthin was slightly lower than that of all-trans-violaxanthin in both cultivars, although no statistical differences were found. Similar results were found in 'Keitt' and 'Tommy Atkins' mango fruit (Mercadante et al., 1997; Mercadante and Rodríguez-Amaya, 1998).

The concentration of all-trans-β-carotene was similar in both mango cultivars ($P>0.05$). The maximum concentration of all-trans-β-carotene observed during the ripening of 'Manila' and 'Ataulfo' mangoes was similar to that of 'Gedong' mangoes but higher than concentrations previously reported in 'Manalagi', 'Indramayn', 'Harum Manis', 'Golek', 'Haden', 'Tommy Atkins', 'Mangga' and 'Keitt' mangoes (Godoy and Rodríguez-Amaya, 1989; Hulshof et al., 1997; Mercadante et al., 1997; Mercadante and Rodríguez-Amaya, 1998).

Fig. 5. Relationships between the concentrations of all-trans-β-carotene (▲), all-trans-violaxanthin (as dibutyrate, ●), 9-cis-violaxanthin (as dibutyrate, ○) in mesocarp and the $C^*$ and $h^*$ values, measured in mesocarp or epidermis of 'Ataulfo' mango fruit during the ripening process. Each point represents the mean of two independent measurements ± the standard error (vertical bars). The continuous line represents an exponential regression.
3.3. Relationship between the concentration of the main carotenoids and the color of 'Manila' and 'Ataulfo' mango fruit

The green color of the epidermis of both mango cultivars changed gradually to a yellow pigmentation during ripening. Singh (1973) demonstrated that the change of epidermis color, from green to yellow, correlates well with the physiological stage of some mango cultivars. As the storage time elapsed, the yellow-orange color of the mesocarp was also more intense and its carotenoid content increased. The increase of the intensity of the yellow-orange color of the epidermis and mesocarp was accompanied by an increase in the values of $a^*$, $b^*$ and $L^*$, and a reduction in the values of $L^*$ and $h^\circ$ (Figs. 4–7). Similar behaviors for $a^*$, $b^*$ and $L^*$ have been reported during the ripening of ‘Dashehari’, ‘Nam Dokmai’, ‘Kaew’ and ‘Mahahanaka’ mangoes (Mahayothee et al., 2004; Saranwong et al., 2004; Jha et al., 2006).

The data analysis showed high correlation coefficients ($R$) between the concentrations of the main carotenoids in mesocarp and the values of $a^*$ and $h^\circ$ evaluated on epidermis or mesocarp of the fruit of both cultivars (Table 1). The best correlations between the carotenoid content and $a^*$ and $h^\circ$ values were associated with the concentration of all-trans-β-carotene in ‘Ataulfo’ mango. In ‘Manila’ mango the best results were associated with the concentrations of all-trans-violaxanthin and 9-cis-violaxanthin (as dibutyrates) (Table 1). This high level of correlation between mesocarp $a^*$ and $h^\circ$ values and the concentration of all-trans-β-carotene in mesocarp has been described for nine Thai mango cultivars (Vázquez-Caicedo et al., 2004, 2005); however, up to now, the relationships between mesocarp and epidermis color values and the concentrations of other important carotenoids in mesocarp have not been assessed. The $R$ values observed for the relationships between the concentrations of the main carotenoids and $b^*$...
The correlation analysis was performed using ‘Ataulfo’ Color value All- and ‘Manila’ mango fruit main carotenoids in mesocarp and the mesocarp/epidermis color values in ‘Ataulfo’ and ‘Manila’ mango (Table 1). This effect could be explained in terms value were very low in ‘Ataulfo’, and were substantially larger in ‘Manila’ mango was higher than the individual content of the evaluated xanthophylls (P < 0.05) and the concentrations of the three evaluated carotenoids were not statistically different in ‘Manila’ (P > 0.05), we infer that b* value (intensity of yellow color) is closely related to the content of xanthophylls. On the other hand, since the R values for the relationships between the concentrations of all-trans-β-carotene and the a* and h* values were smaller in ‘Manila’ (rich in xanthophylls) than in ‘Ataulfo’ (poor in xanthophylls) mango, we also tentatively infer that the concentrations of xanthophylls affects negatively such correlation.

Although in this study the b* values did not properly correlate with the concentrations of carotenoids in fruit mesocarp, they seem to play an important role in the determination of ripening stage based on color in some mango cultivars. For example, Jha et al. (2007) considered important to include the a* and b* values in several terms of a model that allows the prediction of maturity in ‘Dashehari’ mango because both values describe suitably the transition of mango color during the ripening process. Medicott et al. (1992) also found a significant correlation between the visual evaluation of mango color and the relation a*/b*, which was related to the ripening stage.

L* value showed some correlation with the content of carotenoids in the mesocarp of both cultivars, especially in ‘Manila’ mango. Since color and carotenoid concentration have been proposed as reliable maturity indices for some mango cultivars (Ueda et al., 2000; Kudachikar et al., 2001), our results contrast with those obtained by Jha et al. (2007), who found that L* has no value in predicting the ripening stage of ‘Dashehari’ mango.

With some exceptions, the accumulation of the main carotenoids in the mesocarp of both mango cultivars showed an exponential behavior when related to the values of mesocarp or epidermis color. The dispersion graphs for the relationships between the content of the main carotenoids and the color in both mango cultivars are shown in Figs. 4–7. In these figures it is possible to observe that all-trans-β-carotene could be detected throughout the overall ripening process of both mango cultivars. In contrast, the dibutyrates of all-trans-violaxanthin and 9-cis-violaxanthin, which were not detected in ‘Manila’ mango at early stages of ripening (Figs. 6 and 7). This could indicate that the carotenogenesis in ‘Manila’ and ‘Ataulfo’ mangoes lead initially to the biosynthesis of all-trans-β-carotene. These findings differ from those of Mercadante and Rodriguez-Amaya (1998), who found a higher amount of all-trans-violaxanthin and 9-cis-violaxanthin than of all-trans-β-carotene in ‘Keitt’ and ‘Tommy Atkins’ mangoes at early stages of ripening, although this could be due to differences associated with the type of cultivar and geographic origin.

Once the concentration of all-trans-β-carotene reached a value near 5.67 × 10⁻³ g kg⁻¹ in both cultivars (Figs. 4–7) the proportion of all-trans-β-carotene to all-trans-violaxanthin in mesocarp seemed to stabilize when related to mesocarp h* values (Fig. 8). The mean values and the standard deviation of this proportion, which we have called “carotenoid index” (I_{CAT}), in the stable region were 0.98 ± 0.36 and 4.15 ± 1.50, for ‘Manila’ and ‘Ataulfo’ mangoes, respectively. These values were statistically different (P < 0.05). In a separate experiment, four fruit of each cultivar were evaluated for carotenoid content and the I_{CAT} was calculated. The obtained I_{CAT} were 0.64 and 3.27 for ‘Manila’ and ‘Ataulfo’ mangoes, respectively, which were described for the values mentioned above. Although further studies with other mango cultivars are needed to establish the validity of the proposed I_{CAT}, it may serve as a useful index for the identification of mango cultivars (Kalra et al., 1995).

The equations obtained for the best relationships between the concentrations of the main carotenoids in fruit mesocarp and the color of the epidermis and mesocarp of ‘Manila’ and ‘Ataulfo’ mangos are shown in Table 2. Some of these equations could have several applications. For example, the equations associated with the concentration of all-trans-β-carotene could be important in many regions where ‘Ataulfo’ and ‘Manila’ (or similar colored cultivars) mangoes are popular, and therefore are important sources of provitamin A carotenoids. Therefore, with a fast color measurement the concentration of all-trans-β-carotene in mango could be estimated as it has been done in other types of foods (Lauber et al., 1992; McGuire, 1992; Takahata et al., 1993; Camire et al., 1994). Recently, similar equations to estimate the content of β-carotene in Thai mangoes based on color values were reported (Vázquez-Caicedo et al., 2005). The equations related to the epidermis color of mango (Table 2) also can be useful for the non-destructive determination of the maturity of ‘Manila’ and ‘Ataulfo’ mangoes, since that color and carotenoid concentrations have been proposed as maturity indices for some mango cultivars (Ueda et al., 2000; Kudachikar et al., 2001). Recently, Ornelas-Paz et al. (2007) demonstrated that some color values of epidermis and mesocarp were similar in ‘Manila’ and ‘Ataulfo’ mangoes (non-blushed), in contrast to blushed cultivars such as ‘Criollo’, ‘Paraíso’ and ‘Kent’. Thus, further studies are needed to test the applicability of this type of equation to estimate the carotenoid content in fruit of blushed mango cultivars, which

<table>
<thead>
<tr>
<th>Color value</th>
<th>All-trans-violaxanthin</th>
<th>9-cis-Violaxanthin</th>
<th>All-trans-β-carotene</th>
</tr>
</thead>
<tbody>
<tr>
<td>‘Ataulfo’</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a*</td>
<td>0.84/0.90</td>
<td>0.83/0.87</td>
<td>0.90/0.90</td>
</tr>
<tr>
<td>b*</td>
<td>–0.05/0.41</td>
<td>0.00/0.41</td>
<td>–0.05/0.45</td>
</tr>
<tr>
<td>L*</td>
<td>–0.75/0.19</td>
<td>–0.75/0.21</td>
<td>–0.80/0.27</td>
</tr>
<tr>
<td>C*</td>
<td>0.31/0.71</td>
<td>0.34/0.70</td>
<td>0.33/0.72</td>
</tr>
<tr>
<td>h*</td>
<td>–0.88/–0.89</td>
<td>–0.86/–0.87</td>
<td>–0.94/–0.90</td>
</tr>
<tr>
<td>‘Manila’</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a*</td>
<td>0.92/0.87</td>
<td>0.93/0.89</td>
<td>0.86/0.81</td>
</tr>
<tr>
<td>b*</td>
<td>0.76/0.69</td>
<td>0.75/0.67</td>
<td>0.67/0.54</td>
</tr>
<tr>
<td>L*</td>
<td>–0.86/0.35</td>
<td>–0.86/0.32</td>
<td>–0.74/0.18</td>
</tr>
<tr>
<td>C*</td>
<td>0.81/0.74</td>
<td>0.81/0.73</td>
<td>0.73/0.61</td>
</tr>
<tr>
<td>h*</td>
<td>–0.90/–0.89</td>
<td>–0.92/–0.91</td>
<td>–0.82/–0.82</td>
</tr>
</tbody>
</table>

The correlation analysis was performed using α = 0.5.
Table 2

<table>
<thead>
<tr>
<th>Mango Cultivar</th>
<th>All-trans-β-carotene in mesocarp (g kg⁻¹)</th>
<th>All-trans-β-carotene in epidermis (g kg⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>'Manila'</td>
<td>0.02 × 10⁻² (a) 0.93</td>
<td>0.02 × 10⁻² (a) 0.93</td>
</tr>
<tr>
<td>'Ataulfo'</td>
<td>0.005 × 10⁻² (b) 0.85</td>
<td>0.005 × 10⁻² (b) 0.85</td>
</tr>
</tbody>
</table>

Exponential function of γ = |γ| = e⁻|γ| (a, b)

Equations for the relationships between the content of all-trans-β-carotene and the concentration of trans-violaxanthin in 'Manila' and 'Ataulfo' mangoes:

γ = 0.10 x 10⁻² + 0.96

The concentrations of the studied carotenoids in mesocarp were correlated with the changes in mesocarp or epidermis color, measured calorimetrically, during the ripening of both mango cultivars. The values of a* and h*, measured in mesocarp or epidermis of both mango cultivars, highly correlated with the concentrations of the evaluated carotenoids. The high R and Ro obtained for the relationships between carotenoid concentration and some epidermis color values demonstrate that the corresponding equations would allow estimating the content of the main carotenoids in both mango cultivars by fast, low cost and non-destructive color measurements.

4. Conclusions

The all-trans-β-carotene and the dibutyrate of all-trans-violaxanthin and 9-cis-violaxanthin were the most important carotenoids in mesocarp of 'Manila' and 'Ataulfo' mangoes. It must be emphasized that the concentration of all-trans-β-carotene in both cultivars during ripening was high compared with other cultivars of different geographical origins. Therefore, these mango cultivars can play an important role for human nutrition and health. The concentrations of the studied carotenoids in mesocarp were correlated with the changes in mesocarp or epidermis color, measured calorimetrically, during the ripening of both mango cultivars. The values of a* and h*, measured in mesocarp or epidermis of both mango cultivars, highly correlated with the concentrations of the evaluated carotenoids. The high R and Ro obtained for the relationships between carotenoid concentration and some epidermis color values demonstrate that the corresponding equations would allow estimating the content of the main carotenoids in both mango cultivars by fast, low cost and non-destructive color measurements.

References


