POSTHARVEST RIPENING AND MATURITY INDICES FOR MARADOL PAPAYA

Felipe Santamaría Basulto, Enrique Sauri Duch, Francisco Espadas y Gil, Raúl Díaz Plaza, Alfonso Larqué Saavedra and Jorge M. Santamaría

SUMMARY

Fruit ripening in papaya Carica papaya *cultivars varies widely in terms of skin color changes, pulp firmness and shelf life. Most papaya ripening studies have been done using 'Solo' varieties. No objective maturity indices have been developed for Maradol papaya, and studies describing color changes during fruit ripening only cover the initial and final maturity stages. Changes in the main quality attributes of Maradol papaya were documented during the ripening process to identify maturity stages and define objective maturity indices to be applied as harvest indices and quality standards. Six maturity stages were identified and quality attribute value ranges proposed as quality standards. Skin color can be considered an appropriate maturity index,* b* *values are good indicators for early maturity stages, while* a* *value are better for late stages.*

Introduction

Fruit ripening in papaya *Carica papaya* cultivars varies widely in terms of softening, skin color changes and shelf life (Zhang and Paull, 1990; Thumdee *et al*., 2007). Yellow color in the fruit skin has been used as a harvest index criterion to assure adequate ripening and maximum shelf life. For instance, in Solo type papayas yellow color must cover 6% of the fruit skin surface to attain maximum total soluble solids (Akamine and Goo, 1971). Papaya fruits begin ripening with the appearance of light longitudinal stripes that turn progressively yellow, although the yellow coloration pattern is not necessarily restricted to longitudinal stripes, and yellow colored sites can appear almost anywhere on the fruit skin (Peleg and Gómez-Brito, 1975).

Most research on ripening in papaya fruit has been done using Solo varieties, a group including the Kapoho, Rainbow, Sunup, Sunrise and Sunset cultivars. The fruit of these cultivars is commonly pear-shaped, cylindrical or grooved; its weight ranges from 300-700g; pulp is greenish-white in the immature fruit, and pale orange-yellow, salmon pink or red when ripe, depending on the cultivar (Zhou *et al*., 2004; Chen *et al*., 2007). Fruit quality data have been generated for some newer cultivars such as Golden (De Oliveira *et al*., 2002; Bron and Jacomino, 2006), Tainung (Rocha *et al*., 2005), Caliman (De Morais *et al*., 2007), Baixinho de Santa Amalia and BH-65(Rancel *et al*., 2007).

The Maradol variety differs from other reported varieties in that its fruit has a red-orange skin, salmon red pulp and weighs 1.5-2.6kg. Originally from Cuba, this variety was quickly introduced to other countries and has become a commercially prominent cultivar. Mexico is the second largest papaya producer worldwide and main exporter to the USA, 95% of its total papaya production being of the Maradol variety (FAOSTAT, 2007; SIAP, 2007). Despite its commercial importance, no objective maturity indices have been developed for the Maradol variety, and the studies that describe color changes during fruit ripening only address the initial and final maturity stages (Pérez-Carrillo and Yahia, 2004; Hernández *et al*., 2007) or the fruit quality in anthracnose-affected fruit (Acosta *et al*., 2001). The purpose of the present study was to evaluate changes in the main quality attributes of Maradol papaya during different maturity stages so as to develop objective maturity indices that can function as harvest indices and quality standards for this cultivar.

Materials and Methods

Plant material (fruit)

Maradol papaya fruit were harvested from two commercial plantations in Yucatan State, Mexico, and transported for 2h at 25°C to the laboratory. The fruit were immersed in a $1ml\cdot l^{-1}$ azoxystrobin solution (Bankit, Syngenta) for 2min to prevent anthracnose damage. Plantation 1 is the Casa Blanca plantation located in Ucú, the production of which is intended for sale on the local market. Plantation 2 is Rancho San Pedro of Grupo Agrícola Sucilá S.P.R., that produces for export. In both cases, fruit were collected from plants grown from the certified papaya variety Maradol Roja seed (Carisem, Cuba) and selected on the basis of the criteria used by Grupo Agrícola Sucilá for export quality fruit: elongated in shape, weight of 1.5-2.0kg, no malformations or physical damage, and no apparent sign of disease.

Color values at initial and final stages of fruit ripening

In October 2005, preliminary skin color data were collected from fruit exhibiting the potential to ripen and attain an appearance typical of the Maradol variety. Fruit were harvested from plantation 1 and placed in three groups according to the maturity stage: green fruit (immature fruit), green skin with no yellow coloration; stage 1, green

KEYWORDS / Maradol Papaya / Maturity Indices / Quality Standards /

Received: 06/03/2008. Modified: 08/11/2009. Accepted: 08/12/2009.

Felipe Santamaría Basulto. Ph.D. in Plant Science and Biotecnnology, Centro de Investigación Científica de Yucatán (CICY), Mexico. Researcher, Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias (INIFAP), Mexico. Address: Campo Experimental Mocochá. Km. 25 carretera Mérida-Motul, C.P. 97454, Mocochá Yucatán, México.e-mail: santamaria.felipe@inifap.gob.mx

Enrique Sauri Duch. Ph.D. in Chemical Sciences, Universidad de Valencia, Spain. Researcher, Instituto Tecnológico de Mérida, Mexico. e-mail: esauri@itmerida.mx

Francisco Espadas y Gil. M.Sc., in Plant Biotecnnology, CICY, Mexico. e-mail: eafco@cicy.mx

Raúl Díaz Plaza. Ph.D. in Plant Science and Biotecnnology, CINVESTAV-Irapuato, Mexico. Researcher, INIFAP, Mexico. e-mail: diaz.raul@inifap.gob.mx

Alfonso Larqué Saavedra. M.Sc., Colegio de Postgraduados, Mexico. Ph.D., University of London, UK. Researcher, CICY, Mexico. e-mail: larque@cicy.mx

Jorge M. Santamaría. M.Sc., University of Queensland, Australia. Ph.D. in Plant Physiology, University of Lancaster, UK. Researcher, CICY, Mexico. e-mail: jorgesm@cicy.mx

MADURACIÓN POSTCOSECHA E ÍNDICES DE MADUREZ DE PAPAYA MARADOL

Felipe Santamaría Basulto, Enrique Sauri Duch, Francisco Espadas y Gil, Raúl Díaz Plaza, Alfonso Larqué Saavedra y Jorge M. Santamaría

RESUMEN

Las variedades de papaya muestran una amplia variación en la maduración del fruto en términos de ablandamiento, cambios del color de la cáscara y vida de anaquel. La mayoría de los estudios sobre maduración de papaya se han reportado en variedades 'Solo'. No se han desarrollado índices de maduración objetivos para la variedad Maradol, los estudios que describen el cambio de color en la maduración del fruto cubren sólo a los estados de maduración inicial y final. Se evaluaron los cambios en los principales atributos de calidad de papaya Maradol durante la maduración para identificar estados de maduración y definir índices de maduración objetivos que puedan ser sugeridos como índices de cosecha y estándares de calidad. El color de la cáscara puede ser considerado como un índice de madurez apropiado, los valores de b* *son buenos indicadores para los estados tempranos de madurez, mientras que los valores de* a* *son mejores para los últimos estados.*

AMADURECIMENTO POS COLHEITA E ÍNDICES DE MATURAÇÃO DE PAPAYA MARADOL

Felipe Santamaría Basulto, Enrique Sauri Duch, Francisco Espadas e Gil, Raúl Díaz Plaza, Alfonso Larqué Saavedra e Jorge M. Santamaría

RESUMO

As variedades de papaya mostram uma ampla variação no amadurecimento do fruto em termos de amolecimento, mudança da cor da casca e vida nas gôndolas. A maioria dos estudos sobre amadurecimento de papaya tem sido relatado na variedade 'Solo'. Não tem se desenvolvido índices de amadurecimento objetivos para a variedade Maradol, os estudos que descrevem a mudança de cor no amadurecimento do fruto abrangem somente aos estados de amadurecimento inicial e final. Avaliaram-se as mudanças nos principais atributos de qualidade de papaya Maradol durante o amadurecimento para identificar estados de amadurecimento e definir índices de amadurecimento objetivos que possam ser sugeridos como índices de colheita e estándares de qualidade. A cor da casca pode ser considerada como um índice de maturação apropriado, os valores de b* *são bons indicadores para os estágios recentes de maturação, enquanto que os valores de* a* *são melhores para os últimos estágios.*

skin with a faint yellow stripe; and stage 2, those with green skin and a well-defined yellow stripe, similar to the maturity stage used for export. Five fruit were used for each stage and their color was measured daily until they reached a maturity level appropriate for consumption. Overall average color values ± standard deviation were *a**= -16.9 ±0.89 and *b**= +25.8 ±1.9 for green fruit; *a**= -15.1 ±0.17 and *b**= +30.1 ±0.72 for stage 1; and *a**= -14.9 ±0.99 and *b**= +33.0 ±2.19 for stage 2.

Respiration rate and ethylene production

An additional 25 fruit in stage 1 (green skin, faint yellow stripe) were also harvested in October 2005 from plantation 1, transported and treated as described above. Three days after harvest, six fruit exhibiting homogeneous maturity (average *b**= +32) were separated and stored at 23ºC. Gas production was measured by gas chromatography, following the static method (Salveit and Sharaf, 1992). Each fruit was placed daily in a 9.5 litres, airtight acrylic container for 2h, and 3ml gas samples were drawn from the container headspace. From this gas sample, 2ml were injected into a gas chromatograph (Varian Star 3400 CX) fitted with a Porapak Q column, and both conductivity detector (TDC) and flame ionization detector (FID). Temperature settings were 120/80/210ºC for injector/column/FID, respectively, and the carrier gas was He_2 at $0.50 ml \cdot s^{-1}$. Each sample was run in triplicate. The C_2H_4 and CO_2 concentrations were calculated from the concentration of a standard gas mixture (50ppm ethylene, 5005ppm CO_2) according to chromatogram peaks areas.

Determination of maturity stages

Maturity stages were measured in fruit harvested from both plantations in March, 2006. Four fruit from each plantation were selected for each of the seven maturity stages: green fruit, which failed to ripen in previous experiments; stages 1 and 2, which ripened and had visual characteristics typical of the Maradol variety; stage 3, an intermediate stage; Stage 4, which coincided with maximum respiration rate and ethylene production; and stages 5 and 6, corresponding to fruit ready for consumption. Green fruit (G) and stages 1 and 2 were defined based on visual skin color and position on plant, while stages 3, 4, 5 and 6 were defined based on skin color changes in a pool of 50 fruit harvested at stage 2 and stored at 23ºC and 70% RH.

Analytical methods

Color. Color was measured using a Minolta CR-200 Colorimeter and data reported as *L**, *a** and *b** values of Cielab scale (McGuire, 1992). Skin color was measured with six readings near the peduncle, the center and the apex on opposite sides of the fruit. Each fruit was then cut in half and color parameters taken for the pulp halfway between the skin and the central seed cavity. The *a** and *b** values were used to calculate hue angle [H=arctan (*b**/*a**)] and chroma values ($C= (a^{*2} + b^{*2})^{0.5}$).

Pulp firmness. Six rectangular pulp samples were taken at the same sites where color readings were taken, skin and seeds eliminated from the sample, and the sides cut to form a square sample approximately 4.5cm to a side. Firmness was evaluated using an Instron 4442 penetrometer fitted with an 8mm wide, flat-end stainless steel probe inserted 15mm into the pulp at $25 mm \cdot s^{-1}$.

Total soluble solids (TSS). TSS were determined with an Atago Palette PR-101α digital refractometer and results expressed in ºBrix (AOAC, 1990).

Statistical analysis

Five fruits per maturity stage were used to calculate the mean color values (±SD) for initial and final stages of fruit ripening and these plotted against sampling time. Six fruits were used to calculate mean values (±SD) of respiration and ethylene production and these plotted against sampling time.

Data for color, firmness and TSS by maturity stage were used from a total of 28 fruits per plantation. Means were analyzed with ANOVA and the means for maturity stages and plantations compared with a Duncan test (5% confidence level; P<0.05). All analyses were done with the

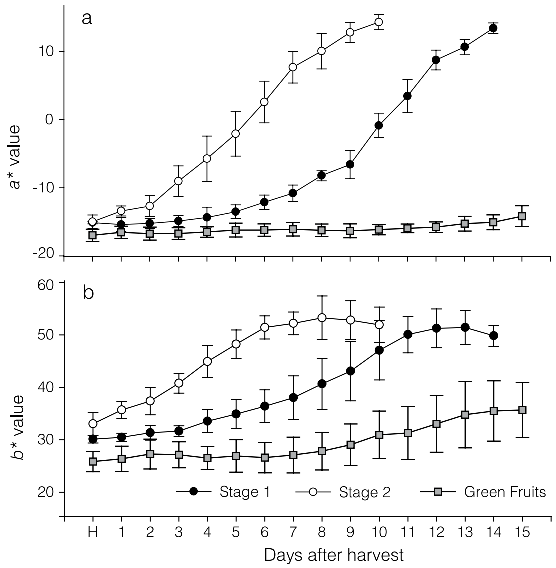

Figure 1. Skin color components *a** (a) and *b** (b) in Maradol papaya fruit harvested at three maturity stages. Green fruit: green skin, no yellow stripe; stage 1: green skin with light yellow stripe; stage 2: green skin with well-defined yellow stripe. Each point is the mean ±SD of five replicates (fruits). Fruit were stored at 23°C and 70%RH.

Statgraphics plus 4.1 statistical package (Statistical Graphics Corp.).

Results

Color values at initial and final fruit ripening stages

Fruit that were green when harvested (*a**= -16.9; *b**= +25.8) were unable to ripen correctly. The *a** value remained negative and almost without change throughout the 15 days of evaluation, and the *b** value increased only slightly to +35.6 (Figure 1). Fruit harvested in stage 1 (*a**= -15.1; *b**= +30.1) ripened correctly. Their *a** value increased steadily, reaching zero at ten days and by 14 days color values were *a**= +13.4 and *b**= +49.8. Fruit harvested in stage 2 (*a**= -14.9; *b**= +33.0) ripened in less time, with an *a** value near zero at five days and color values of *a**= +14.2 and *b**= +51.9 at ten days.

Respiration rate and ethylene production

Respiration rate increased gradually to 36.5ml·kg^{-1}·h^{-1} at eight days post-harvest, twice the rate measured at four days (Figure 2a). Ethylene production was detected at six days, reached its highest level (3.3µl·kg^{-1}·h^{-1}) at eight days and gradually decreased to half this level at 13 days (Figure 2b). Maximum respiration rate and ethylene production occurred at eight days, and these levels were higher ($P<0.05$) than on all other days. Maximum gas production coincided with the point at which the average skin color *a** value nearly reached zero (i.e. no green remains and red begins to appear). After this point, the *a** value became positive, reaching a high of +13.4 (Figure 2c), and the b* value changed little, from +48.8 at day 8 to approximately +50 at 13 days (Figure 2d).

Fruit visual characteristics at different maturity stages

External and internal characteristics of the sampled fruit at each maturity stage are shown in Figure 3 and described in Table I.

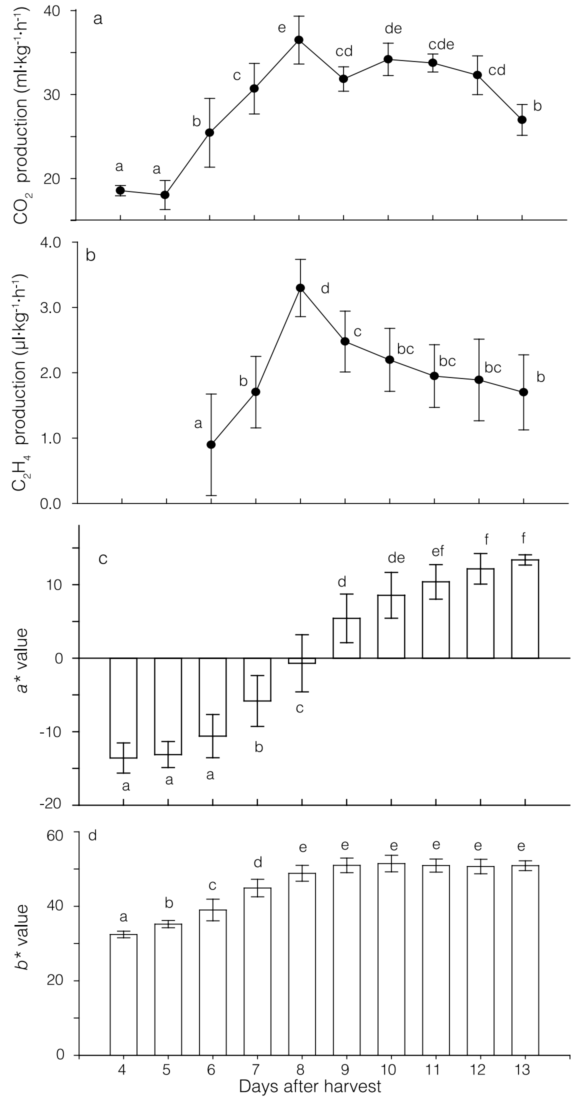

Figure 2. Respiration rate (a), ethylene production (b), and changes in skin *a** (c) and *b** values (d) in Maradol papaya fruit. Fruit were harvested in stage 1 (green skin with light yellow stripe) and gases measured after four days, once fruit had entered stage 2 (green skin with well-defined yellow stripe). Fruit were stored at 23°C and 70%RH. Each point is the mean ±SD of six fruits. Values with the same letter suffix are not different according to the Duncan test (P≤0.05).

Color

During ripening, skin luminosity (*L**) increased from ~41 in green fruit to 58.3 in stage 4, and then decreased slightly in stages 5 and 6 (Figure 4a). Pulp *L** values decreased from an average of 70 in green fruit to 48.5 in stage 6 fruit (Figure 4b).

Skin *a** values exhibited distinct changes linked to maturity stage. Values were negative (green color) in green fruit and stages 1 to 4, and then positive (red color) in stages 5 and 6 (Figure 4c). This makes the skin *a** value a useful indicator in the later ripening stages, although it is not very useful in defining the early maturity stages, since there is little distinction in *a** values between green fruit and stage 2 fruit. Pulp *a** values were red beginning in stage 1, indicating the initiation of ripening, and then increased steadily to +20 in stages 5 and 6 (Figure 4d).

Skin *b** values varied from an average of +25.7 in green fruit to +30.9 at stage 1, and +35.7 at stage 2 (Figure 4e). This makes the *b** value useful in differentiating the early maturity stages from immature fruit, but not very applicable in the later maturity stages. Pulp *b** values increased from +22.1 in green fruit to +31.9 in stage 1, increased very slightly up to stage 3 and then remained unchanged (Figure 4f).

Fruit skin color changed from green to orange during ripening, as shown in a change in the hue angle from 125° to 74°. Yellow developed in the skin at stage 4, when hue angle was ~90°, then orange predominated in stages 5 and 6 (Figure 4g). Pulp was yellow at stage 1 and became orange by stages 4, 5 and 6, with values of ~63° (Figure 4h).

Color intensity increased as the fruit ripened. Skin color intensity changed only 4.3 points from 31.4 in green fruits to 35.7 in stage 1 (Figure 4i), while pulp color intensity changed almost 9 points from 24 in green fruit to 32.7 in stage 1 (Figure 4j).

Pulp firmness

In green fruit, pulp firmness was 140N in fruit from both plantations, and decreased slightly but significantly between green fruit and stage 1. Firmness then decreased almost 8 fold between stages 3 and 4

(16N at stage 4), which is consistent with the higher ethylene production and respiration rate in these stages. Further, but less drastic decreases (8-5N) occurred in the later maturity stages (Figure 5a).

Total soluble solids

TTS in fruit from plantation 1 increased rapidly between green fruit and stage 1, and then increased more gradually to stages 5 and 6, reaching values of up to 11°Brix. In fruit from plantation 2, TSS also increased from green fruit to stage 1, but then continued to increase steadily through stages 3 and 4, eventually reaching values of about 12°Brix (Figure 5b). TTS were higher (P>0.05) in fruit from plantation 2 than in those from plantation 1, with a 1.5°Brix difference between them in the final maturity stages.

Discussion

Color change is widely used as a visual maturity index in many fruits (Reid, 2002). Color intensity and uniformity affect fruit quality (López Camelo, 2003), since in many fruits these involve loss of chlorophyll, synthesis of new pigments such as carotenoids and unmasking of other pigments previously formed during fruit development (Aked, 2000; Ferrer *et al*., 2005).

The initial changes in Maradol papaya fruit appearance observed in the present study were caused by increases in the *L** (luminosity) and *b** (yellow) values, and not by loss of green color, since the negative skin *a** (green) values remained relatively unchanged in green fruit and stage 1 and 2 fruit (Figure 4c). Although Maradol is an orange-red skin variety, the *b** value was a better indicator of early stage maturity because it allows distinction between immature fruits and those beginning the ripening process (Figure 4e).

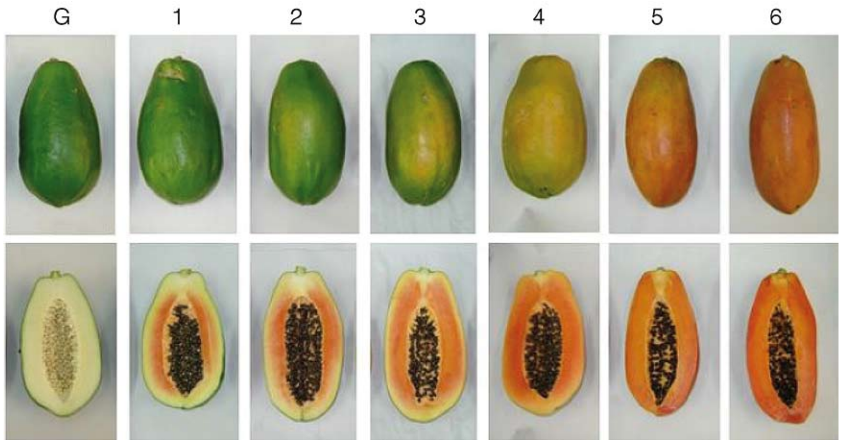

Figure 3. Visual aspect of representative Maradol papaya fruit at each maturity stage. G: green skin without yellow stripe; 1: green skin with light yellow stripe; 2: green skin with well-defined yellow stripe; 3: one or more orange-colored stripes in skin; 4: clearly orange-colored skin with some light green areas; 5: characteristic orange-colored skin of Maradol papaya; 6: fruit color similar to stage 5, but more intense.

TABLE I
VISUAL CHARACTERISTICS OF MARADOL PAPAYA FRUIT MATURITY STAGES

Maturity stage	Description
Green fruit	Green skin without yellow stripe; pulp very hard and white in color; seeds well-formed but white or slightly dark in color.
1	Green skin with a light yellow stripe; pulp exhibits some areas with orange color, is very hard and contains large amounts of latex.
2	Green skin with well-defined yellow stripe; pulp is orange in color near seed cavity and light green near skin, although still hard and with large amounts of latex.
3	One or more orange-colored stripes in skin; pulp almost completely orange in color, except near skin, still hard but contains less latex.
4	Skin clearly orange in color with some light green areas; pulp completely orange, except near peduncle, softer than in stage 3, but still too hard for consumption, low latex content.
5	Skin displays orange color characteristic of Maradol variety; pulp firmness appropriate for consumption, latex no longer present.
6	Conditions similar to stage 5, but with more intense orange color in skin and softer pulp still adequate for consumption.

The *L** and *a** data observed in the present study are consistent with reported skin (Pérez-Carrillo and Yahia, 2004) and pulp (Hernández *et al*., 2007) in ripe Maradol fruit, while the hue angle values are slightly lower than values reported by Acosta (2001).

Maturity stage at harvest greatly influences postharvest fruit behavior during marketing. Green fruit with average *b** values of +25.8 did not ripen (Figure 1b); when averaged among the fruit collected at both plantations green fruit *b** values were +25.7 (Figure 4e), indicating that Maradol papaya fruit with *b** values <+26 do not ripen properly.

In contrast, fruit harvested with *b** values between +30 to +32 (stage 1) ripened adequately, suggesting that this stage can be considered the physiological maturity stage. This coincides with the +30.3 *b** value reported by Vázquez and Ariza (2006) for Maradol papaya physiological maturity stage. In pulp, the *L**, *a**, *b**, hue angle and chroma values all clearly mark initial ripening and the presence of stage 1 (Figures 4b, d, f, h and j). However, determining pulp color values requires destructive sampling and consequent loss of product.

The relationships between color parameters and maturity stages did not differ (P>0.05) between plantations. Skin hue angle was most closely correlated to firmness (R^2= 0.92 and 0.91) and also had a good correlation with TSS (R^2= 0.82 and 0.75; Figure 6). Color values can therefore be considered as good maturity stage indicators and reliable quality standards in Maradol papaya. Based on color values and ripening behavior, stages 1 and 2 are the proper times to harvest for long distance shipment (export), while fruit can be harvested in stage 3 for local markets.

Measuring ethylene and CO_2 is neither practical nor simple as a maturity index. Given that skin *a** values near zero coincided with maximum production of both gases, this color variable can be used as a rough proxy for ethylene and CO_2 production in Maradol papaya fruit (Figures 2a, b, c).

Maradol papaya exhibits a color pattern development during ripening which differs from Cielab data for other varieties. Pulp values of *L**= 52 to 55, hue= 50-53, and chroma= 41-47 have been reported in Sunrise papaya (Miller and McDonald, 1999; Ergun *et al*., 2006), showing it to be similar to Maradol in terms of luminosity and color intensity (saturation), although Maradol has an orange-yellow pulp and Sunrise has orange pulp. No skin color value data have been reported for the Sunrise variety.

Reported *L**, hue and chroma values for Sunset variety skin and pulp in early maturity stages (Rancel *et al*., 2007) show them to be similar to those recorded in the present study for Maradol.

When fully ripe, however, skin color values in Sunset have higher luminosity and color saturation, and an 80° hue angle, the result of Sunset's yellow skin. In the pulp, Sunset fruit have *a** values of +12 to +17 (Jo-Fen and Paull, 1990) while in the present study the values for Maradol were ~+20, indicating that Sun-

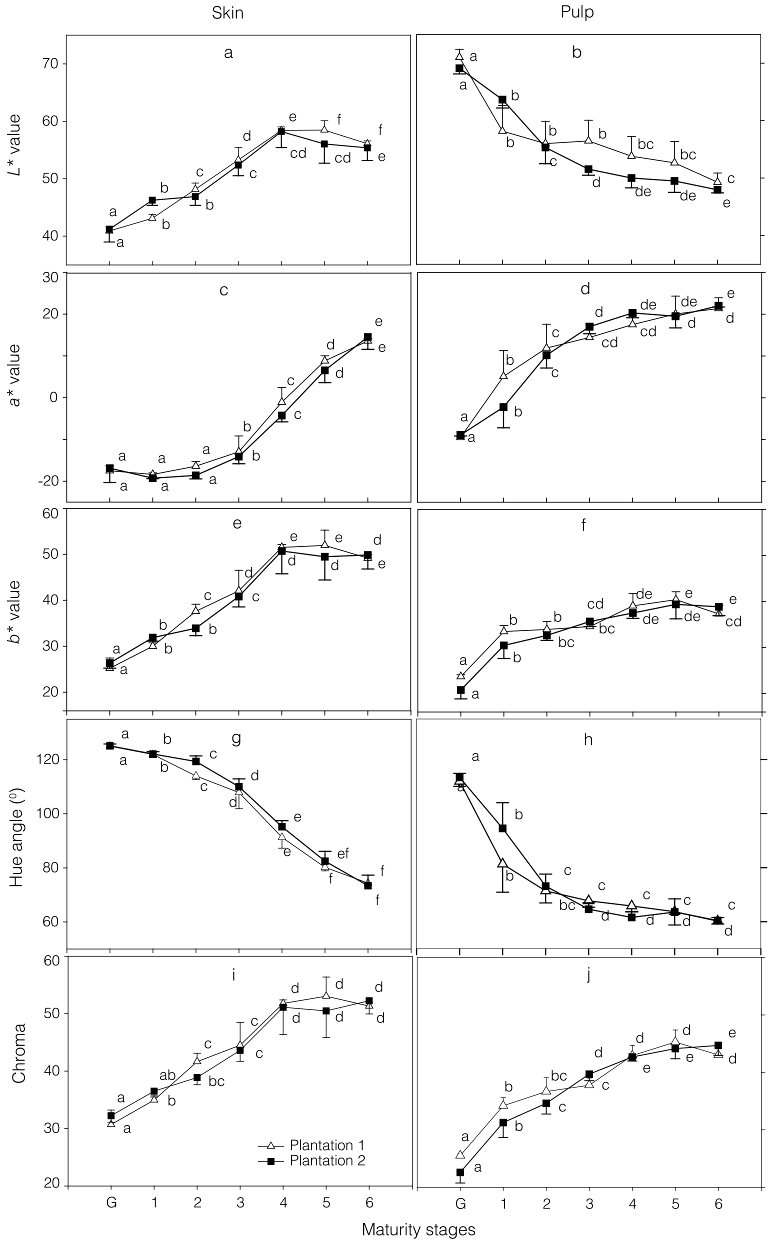

Figure 4. Luminosity (*L**), red-green (*a**), yellow (*b**), hue angle and chroma for skin (a, c, e, g, i) and pulp (b, d, f, h, j) of Maradol papaya fruit from two plantations in each of seven maturity stages. Each point is the mean ±SD of four fruits. Values for each plantation with the same letter suffix are not different according to Duncan test (P≤0.05). G: green skin without yellow stripe; 1: green skin with light yellow stripe; 2: green skin with well-defined yellow stripe; 3: one or more orange-colored stripes in skin; 4: clearly orange-colored skin with some light green areas; 5: characteristic orange-colored skin of Maradol papaya; 6: fruit color similar to stage 5, but more intense.

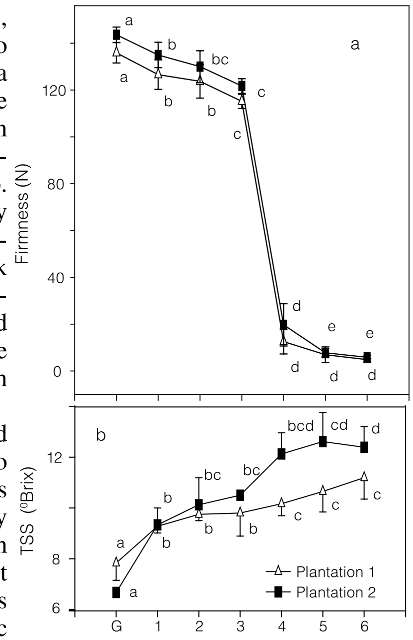

Figure 5. Pulp firmness (a) and total soluble solids (b) in Maradol papaya fruit from two plantations in each of seven maturity stages. Each point is the mean ±SD of four fruits. Values for each plantation with the same letter suffix are not different according to the Duncan test (P≤0.05). G: green skin without yellow stripe; 1: green skin with light yellow stripe; 2: green skin with well-defined yellow stripe; 3: one or more orange-colored stripes in skin; 4: clearly orange-colored skin with some light green areas; 5: characteristic orange-colored skin of Maradol papaya; 6: fruit color similar to stage 5, but more intense.

set pulp is less red than Maradol pulp. In the Golden variety, skin hue angle in ripe fruits is ~80-86º (Bron *et al*., 2004; Bron and Jacomino, 2006), more yellow than ripe Sunset and Maradol fruit. The pulp of ripe Golden papaya has reported color values of a^*= +7.7 and b^*= +2.6 (Fabi *et al*., 2007), lower than those observed for Maradol, meaning that the pulp of Golden fruit is less red and less yellow.

The fruit from both plantations exhibited no differences (P>0.05) in pulp firmness by maturity stage, meaning that this variable is a reliable quality standard for Maradol papaya. Clear changes are apparent in pulp firmness between green fruit and stage 1, and between stages 3 and 4, when the process involved in fruit softening occurred. This variable also indicates when fruit is in the edible maturity stages.

In the present results, firmness continued to decrease, albeit at a lower rate, after the ethylene peak, when orange-yellow skin color begins to develop. In Golden papaya, by contrast, ethylene production does not peak until fruit reaches edible pulp firmness and quality changes have already occurred (Bron and Jacomino, 2006).

TTS content differed in fruit from the two sampled plantations during the maturity stages (Figure 5b), with higher values in fruit from plantation 2. This suggests that climatic factors, soil conditions and agricultural management practices can affect fruit sugar content, but apparently have no significant effect on fruit color.

According to the color, firmness and TSS values observed in the present study, certain value ranges indicate the most appropriate harvest times of Maradol papaya for different markets and can aid in quality control. To establish quality standards, the recorded values were rounded to the highest and lowest average for each variable (Table II). This is an important step towards standardizing quality control for this commercially significant papaya variety, a step which has not been taken for some other varieties. For instance, maturity stage data have been published for Golden papaya using subjective skin yellow color percentages, although Cielab scale values are available for L^*, a^*, b^* (De Oliveira *et al*., 2002) and hue angle (Bron and Jacomino, 2006). In cultivars such as Tainung (Rocha *et al*., 2005) and Caliman (De Morais *et al*., 2007), maturity stages are still based on subjective scales employing skin yellow percentage.

The Mexican regulation of Maradol papaya fruit quality standards (Secretaría de Economía, 2007) is based on ºBrix and subjective visual description of skin color (yellow and orange stripes), but includes no corresponding Cielab color values. Inclusion of the color data provided here for the seven different Maradol papaya maturity stages in the law regulating this product would be a step towards making it more explicit and less subjective, improving the standards used to control this product in national markets and providing a model for international standards.

Conclusions

Maradol papaya fruit exhibits a ripening pattern that differs from those reported for other varieties, and specific maturity indices need to be developed as quality standards. Six maturity stages are proposed for the Maradol variety and, of these, stage 1 can be used as an indicator of physiological maturity, stages 1 and 2 can be used as a harvest index for export markets requiring distant shipment, and stage 3 can be used as a harvest index for nearby local markets. Fruit color is a good maturity index, and Cielab color, TSS and firmness values can be used as quality standards. Skin color is an appropriate maturity index, while *b** values are good indicators for early maturity stages, and the *a** value for late stages.

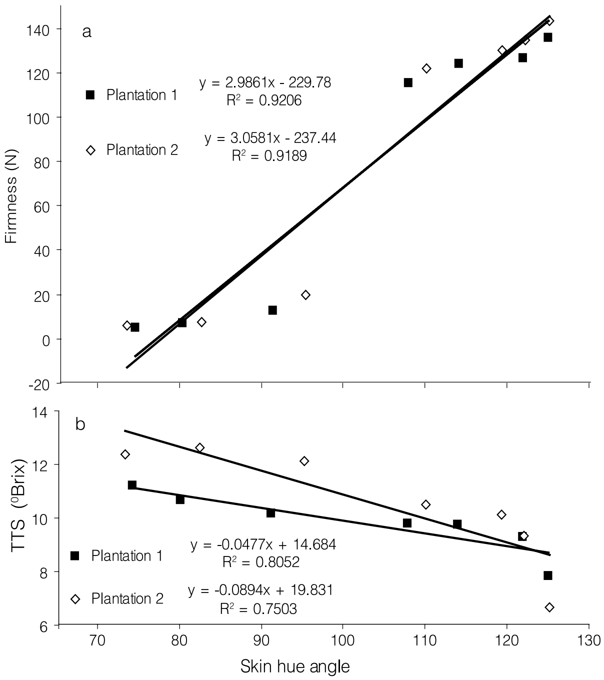

Figure 6. Changes in Maradol papaya fruit pulp firmness (a) and total soluble solids (b) as correlated to changes in skin hue angle.

REFERENCES

Acosta RM, Nieto-Ángel D, Domínguez-Álvarez JL, Delgadillo-Sánchez F (2001) Calidad y tolerancia en frutos de papaya (*Carica papaya* L.) a la inoculación del hongo Colletotrichum gloeosporioides Penz. en postcosecha. *Rev. Chapingo Ser. Hort. 7*: 119-130

Akamine EK, Goo T (1971) Relationship between surface color development and total soluble solids in papaya. *HortScience 6*: 567-568.

Aked J (2000) Fruits and vegetables. In Kilcast D, Subramaniam P (Eds.) *The Stability and Shelf-life of Food*. Woodhead. Cambridge, UK. pp. 249-278.

AOAC (1990) *Oficial Methods for Analysis*. 15th ed. Association of Official Analytical Chemist. Washington, DC, USA. 1141 pp.

Bron IU, Jacomino AP (2006) Ripening and quality of 'Golden' papaya fruit harvested at different maturity stages. *Braz. J. Plant Physiol. 18*: 389-396.

Bron IU, Vasconcelos RR, Azzolini M, Jacomino AP, Caruso ME (2004) Chlorophyll fluorescence as a tool to evaluate the ripening of "Golden" papaya fruit. *Postharv. Biol. Technol. 33*: 163-173.

Chen NJ, Manenoi A, Paull RE (2007) Papaya Postharvest Physiology and Handling - Problems and Solutions. *Acta Hort. 740*: 285-294.

De Morais PLD, Da Silva GG, Menezes JB, Nogueira Maia FE, Dantas DJ, Sales R (2007) Pós-colheita de mamão híbrido UENF/CALIMAN 01 cultivado no Rio Grande do Norte. *Rev. Bras. Frutic. 29*: 666-670.

De Oliveira MAB, Vianni R, De Souza G, Araújo TMR (2002) Caracterização do estádio de maturação do papaia 'golden' em função da cor. *Rev. Bras. Frutic. 24*: 559-561.

Ergun M, Huber DJ, Jeong J, Bartz JA (2006) Extended shelf life and quality of fresh-cut papaya derived from ripe fruit treated with the ethylene antagonist 1-methylcyclopropene. *J. Amer. Soc. Hort. Sci. 131*: 97-103.

Fabi JP, Cordenunsi BR, Mattos BG, Mercadante AZ, Lajolo FM, Oliviera NJB (2007) Papaya fruit ripening: responses to ethylene and 1-methylcyclopropene (1-MCP) *J. Agric. Food Chem. 55*: 6118-6123.

FAOSTAT (2007) PRODUCTION CROPS. http://faostat.fao.org/site/567/DesktopDefault.aspx?PageID=567#ancor

Ferrer A, Remón S, Negueruela A, Oria R (2005) Changes during ripening of the very late season Spanish pech cultivar Calanda Feasibility of using CIELAB coordinates as maturity indices. *Sci. Hort. 105*: 435-446.

Hernández Y, Lobo MG, González M (2007) Optimización del tipo de troceado de papaya mínimamente procesada y su efecto en la Translucidez. V *Cong. Iberoam. Tecnología Postcosecha y Agroexportaciones.* pp:751-759

Jo-Feng A, Paull RE (1990) Storage temperature and ethylene influence on ripening of papaya fruit. *J. Amer. Soc. Hort. Sci. 115*: 872-1058.

López Camelo A (2003) *Manual para la Preparación y Venta de Frutas y Hortalizas.* Boletín de Servicios Agrícolas Nº 151. FAO. Rome, Italy. 180 pp.

McGuire RG (1992) Reporting of objective color measurements. *Hortscience 27*: 254-255.

Miller WR, McDonald RE (1999) Irradiation, stage of maturity at harvest, and storage temperature during ripening affect papaya fruit quality. *HortScience 34*: 1112-1115.

Peleg M, Gómez-Brito L (1975) The red component of the external color as a maturity index of papaya fruits. *J. Food Sci. 40*: 1105-1106.

Pérez-Carrillo E, Yahia EM (2004) Effect of postharvest hot air and fungicide treatments on the quality of 'Maradol' papaya (Carica papaya L.) *J. Food Qual. 27*: 127-139.

Rancel DJ, Lobo RMG, Rodríguez PMC, González M (2007) Postharvest behavior of three papaya cultivars produced in mesh greenhouse in Tenerife (Canary Islands, Spain). *Acta Hort. 740*: 295-302.

Reid MS (2002) Maturation and maturity indices. In Kader AA (Ed.) *Postharvest Technology of Horticultural Crops*. University of California. Oakland, CA, USA. pp. 55-62.

Rocha RHC, De Carvalho Nascimento SR, Menezes JB, De Souza Nunes GH, De Oliveira SE (2005) Qualidade pós-colheita do mamão formosa armazenado sob refrigeração. *Rev. Bras. Frutic. 27*: 386-389.

Salveit ME, Sharaf AR (1992)Ethanol inhibits ripening of tomato fruit harvested at various degrees of ripeness without affecting subsequent quality. *J. Am. Soc. Hort. Sci 117*: 793-798.

Secretaría de Economía (2007) NMX-FF-041-SCFI-2007. Productos alimenticios no industrializados para consumo humano - fruta fresca - papaya (*Carica papaya* L.) - especificaciones (cancela a la NMX-FF-041-SCFI-2003). http://www.economia.gob.mx/work/normas/nmx/2007/nmx-ff-041-scfi-2007.pdf

SIAP (2007) Anuario Estadístico de la Producción Agrícola. Cíclicos y Perennes 2007. Servicio de Información Agroalimentaria y Pesquera. http://www.campomexicano.gob.mx/portal_sispro/index.php?portal=tf

Thumdee S, Manenoi A, Paull RE (2007) Activity of papaya fruit hydrolases during natural softening and modified softening. *Acta Hort. 740*: 317-322.

Vázquez GE, Ariza FR (2006) Características de calidad en postcosecha de papaya "Maradol" en la región de las Huastecas. In 1ª Reunión Nacional de Innovación Agrícola y Forestal. Merida, Mexico. p. 136.

Zhang LX, Paull RE (1990) Ripening behavior of papaya genotype. *HortScience 25*: 454-455.

Zhou L, Paull RE, Chen NJ (2004) Papaya. In Gross KC, Wang CY, Salveit M (Eds.) The Commercial Storage of Fruits, Vegetables, and Florist and Nursery Stocks. Agriculture Handbook Nº 66. USDA-ARS. USA. http://www.ba.ars.usda.gov/hb66/

TABLE II
PROPOSED PAPAYA CV. MARADOL FRUIT MATURITY INDICES VALUE RANGES FOR SEVEN MATURITY STAGES

Maturity stage	Skin color			Pulp color			Firmness	TSS
	*L**	*a**	*b**	*L**	*a**	*b**	(N)	ºBrix
G	40 to 42	-17 to -18	+25 to +26.5	69 to 71	-8.5 to -9.5	+20 to +24	136 to 146	6.0 to 8.0
1	43 to 46	-18 to -19	+30 to +32	58 to 64	-2 to +5.5	+30 to +33.5	126 to 135	9.0 to 9.5
2	46 to 48	-16 to -19	+33.5 to +37.5	55 to 56	+10 to +12	+33 to +34	123 to 130	9.6 to 10
3	52 to 53	-12 to -14	+40 to +42	51 to 56	+14 to +17	+34 to +36	115 to 121	9.8 to 10.2
4	56 to 58	-1 to -4	+50 to +51.5	51 to 54	+17 to +20	+37 to +39	12.7 to 16.6	10.2 to12.0
5	56 to 58	+6 to +9	+50 to +52	49 to 53	+19 to +20	+39 to +41	6.8 to 7.8	11.0 to 12.5
6	55 to 56	+13 to +15	+49 to +50	48 to 50	+21 to +22	+38 to +39	4.9 to 5.8	11.0 to 12.5

G: green fruit (immature), 1: physiological maturity, 5 and 6: edible maturity.