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POSTHARVEST RIPENING AND MATURITY INDICES FOR MARADOL PAPAYA

Interciencia, vol. 34, núm. 8, agosto, 2009, pp. 583-588

Asociación Interciencia
Caracas, Venezuela

Disponible en: http://www.redalyc.org/articulo.oa?id=33913144010
Introduction

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.

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.

KEYWORDS / Maradol Papaya / Maturity Indices / Quality Standards /
Skin with a faint yellow stripe; and stage 2, those with green skin and a well-defined yellow stripe. 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 estudios 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 y Gil, Raúl Díaz Plaza, Alfonso Larqué Saavedra y 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. Avaliam-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.**
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 36.5 ml·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 (3.3 μl·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.
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 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.

4.5.3. Observation of Maradol papaya fruit color during marketing. Green skin and when averaged among the fruit of Maradol papaya was observed to be similar to those recorded in Sunrise variety. 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 $+17$ (Jio-Fen and Paull, 1990) while in the present study the values for Maradol were $+20$, indicating that Sun-
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).

TSS 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.

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 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 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.

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.

The Mexican regulation of Maradol papaya fruit quality standards (Secretaría de Economía, 2007) is based on °Brix 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 Mar-
TABLE II

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

<table>
<thead>
<tr>
<th>Maturity stage</th>
<th>Skin color</th>
<th>Pulp color</th>
<th>Firmness</th>
<th>TSS</th>
<th>Brix</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(L^*)</td>
<td>(a^*)</td>
<td>(b^*)</td>
<td>(N)</td>
<td></td>
</tr>
<tr>
<td>G</td>
<td>40 to 42</td>
<td>-17 to -18</td>
<td>+25 to +26.5</td>
<td>69 to 71</td>
<td>-8.5 to -9.5</td>
</tr>
<tr>
<td>1</td>
<td>43 to 46</td>
<td>-18 to -19</td>
<td>+30 to +32</td>
<td>58 to 64</td>
<td>-2 to +5.5</td>
</tr>
<tr>
<td>2</td>
<td>46 to 48</td>
<td>-16 to -19</td>
<td>+33.5 to +37.5</td>
<td>55 to 56</td>
<td>+10 to +12</td>
</tr>
<tr>
<td>3</td>
<td>52 to 53</td>
<td>-12 to -14</td>
<td>+40 to +42</td>
<td>51 to 56</td>
<td>+14 to +17</td>
</tr>
<tr>
<td>4</td>
<td>56 to 58</td>
<td>-1 to -4</td>
<td>+50 to +51.5</td>
<td>51 to 54</td>
<td>+17 to +20</td>
</tr>
<tr>
<td>5</td>
<td>56 to 58</td>
<td>+6 to +9</td>
<td>+50 to +52</td>
<td>49 to 53</td>
<td>+19 to +20</td>
</tr>
<tr>
<td>6</td>
<td>55 to 56</td>
<td>+13 to +15</td>
<td>+49 to +50</td>
<td>48 to 50</td>
<td>+21 to +22</td>
</tr>
</tbody>
</table>

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