Market Quality of Guavas after Hot-water Quarantine Treatment and Application of Carnauba Wax Coating

Raymond G. McGuire
U.S. Department of Agriculture, Agricultural Research Service, Subtropical Horticulture Research Station, 13601 Old Cutler Road, Miami, FL 33158

Abstract. Immersion of guavas (Psidium guajava L.) for 35 min in water at 46.1 ± 0.2 °C slowed softening, sweetening, and color development of fruit and delayed ripening by 2 days. Heat treatment also increased susceptibility to chilling injury, decay, and weight loss in storage, but overall loss of quality was minimal. Waxing fruit within 90 min of heat treatment exacerbated chilling injury, further delayed ripening with a concomitant increase in the percentage of fruit not ripening, and caused fruit to remain greener. Waxing fruit had a lower acidity and soluble solids concentration and did not appear to ripen normally. Although heating did not appreciably affect the percentage of fruit that failed to ripen, the combination of heating and nearly immediate waxing increased the proportion not ripening to 45%. Heat and wax treatments, alone or in combination, caused CO₂ levels to increase significantly before the initiation of ripening, but waxing also reduced the O₂ content of fruit at this time. Before ripening, O₂ levels were inversely correlated (r = -0.980) with injury, firmness, date and percentage of fruit ripening, and pH and directly correlated (r = 0.980) with peel color and the concentration of acids and sugars in the pulp. Delaying the waxing of heat-treated guavas or reconditioning them for 24 h at 20 °C before cold storage promoted normal ripening and helped to maintain the quality of heat-treated fruit.

Guava fruit are preferred by female Caribbean fruit flies (Anastrepha suspensa (Loew.)) for oviposition, and virtually all guavas from South Florida contain larvae of these insects (Murray and Campbell, 1989). With no fly-free zones in the commercial growing areas, all fruit to be exported to states and countries with an environment conducive to fly development must be treated to eradicate this pest. A quarantine protocol has been proposed by Gould and Sharp (1992) that employs a 35-min immersion in water at 46.1 ± 0.5 °C.

Guavas are climacteric with high rates of respiration and usually ripen within 7 days at 20 °C (Campbell, 1994). Waxing has generally not been included in the postharvest processing of this commodity. Markets that have gradually expanded outside Florida, however, require increased transit times in many cases, and waxing fruits is a common method to decrease moisture loss in storage and transit (Kester and Fennema, 1986). Depending on their composition and thickness, all fruit coatings resist the exchange of gases and affect the rate of fruit ripening (Smith et al., 1987). The application of a cellulose-based film to papa

Received for publication 22 Apr. 1996. Accepted for publication 22 Oct. 1996. I thank Everett Bather for his technical assistance and Maria Trunk of Brooks Tropicals, Inc., which provided the fruit used in these experiments. Mention of a trade name does not constitute a recommendation by the U.S. Dept. of Agriculture. The cost of publishing this paper was defrayed in part by the payment of page charges. Under postal regulations, this paper therefore must be hereby marked advertisement solely to indicate this fact.

Material and Methods

Treatment and quality evaluation. "Ruby" guavas (65 to 235 g, median weight = 115 g) were picked from trees in a commercial orchard in Dade County, Fla. Two tests were run concurrently; the first, with four treatments, compared the effects of heating (immersion for 35 min in water at 46.1 ± 0.2 °C) and waxing guavas in a split-plot design. A commercial carnauba wax formulation, TFC 213, containing 5% carnauba wax and fatty acid soaps (8% total solids; EcoScience Produce Systems Corp., Orlando, Fla.) was applied by hand-wiping fruit in applicable treatments at 6.4 mL·cm⁻². In the combination treatment, wax was applied as soon as fruit had cooled to 30 °C, within 90 min of their removal from heat. After treatment, fruit were stored at 12 °C for 7 days then removed to 20 °C for ripening. In the second test of four treatments, all fruit were heated, and the effects of reconditioning fruit for 24 h at 20 °C before 7 days of storage at 12 °C and of delaying waxing until removal to 20 °C were compared, again in a split-plot design. The combination treatment in the first test was appropriated as the control in the second test. After 7 days of storage at 12 °C, all fruit were removed to 20 °C to ripen. Each treatment of both tests consisted of 20 fruit that were initially and individually weighed. The treatment procedure was replicated a total of six times throughout the season.

After their transfer from 12 to 20 °C for ripening, fruit were examined daily, and the day was noted when gentle finger pressure applied from both sides simultaneously could indent the fruit =0.5 cm. This subjective measure of firmness corresponded to a resistance by the fruit of 13 to 23 N; at harvest, resistance averaged 95 N. As fruit softened and were subjectively estimated to be ripe, their quality was evaluated. Fruit were weighed a second time. They were then rated for the percentage of surface decay and for surface blackening caused by chilling injury (CI) with a 12-point visual acuity scale (Horsfall and Barratt, 1945). Firmness of each fruit was measured with an Instron Universal Testing Instrument (model 1011; Instron Corp., Canton, Mass.) fitted with a compression anvil of 12 mm diameter; resistance to pressure was recorded after a compression of 3 mm. Peel color was evaluated with a Minolta CR-200 Chroma-meter (Minolta Corp., Ramsey, N.J.) calibrated with a standard white reflective plate and recording in the tristimulus L* a* b* system (lightness where 100 is white and 0 is black, chroma where 100 is most intense and 0 is least intense, and hue angle where 0° is red-purple, 90° is yellow, 180° is blue-green, and 270° is blue, respectively); measurements were taken across an area =50 mm² with diffuse illumination at a viewing angle of 0° under CIE illuminant C conditions (McGuire, 1992).

Tene ripe fruit were selected per treatment for an analysis of the pulp. Individual fruit were peeled, and ~25 g of pulp was forced through a sieve with holes =1 mm² (16 mesh) to remove seeds. The pH of the pulp was measured, and 1.5 g was transferred to a centrifuge tube and spun at 5000×g for 15 min; a refractive index was determined on the supernatant for calculation of the total percentage of soluble solids (SSC). Twenty grams of pulp was titrated with 0.1 M NaOH to determine the total percentage of acids.

Within each test, the data were compared using PROC analysis of variance (ANOVA) in SAS (1985). One split-plot analysis compared the co-effects of heat and wax; a second split-plot analysis, on heated fruit only, compared reconditioning and time of wax application. Horsfall/Barratt rating values, after analysis, were converted to percent surface area decayed or percent surface area injured.

Measurement of internal gases. Internal concentrations of O₂ and CO₂ were measured from guavas treated as above and stored at 12 °C for 1 week before ripening at 20 °C. Concentrations in comparable treated fruit not temporarily cold-stored were examined for comparison. Before waxing, if required, but
after any prescribed heating, a sleeve-type rubber stopper was attached to the surface of each fruit. The sleeve portion of the stopper was affixed to the fruit surface with silicone rubber sealant to form an airtight chamber 15 mm in diameter \times 15 mm in height (2.65 mL). Although fruit may have been subsequently coated, the area within the chamber was free of any film, and gas exchange through the stomates was presumed to be unhampered and the sample representative of concentrations beneath the fruit peel. Beginning the day after treatment and continuing daily for 3 weeks, 1 mL of gas was withdrawn from the chamber by inserting an 18-gauge (\approx 0.1 mm bore diameter) needle through the stopper. This gas was then injected through a port into an SRI 8610 gas chromatograph (SRI Instruments, Torrance, Calif.) equipped with a CTR I column (Alltech Assoc., Deerfield, Ill.) with helium as the carrier gas. Areas under the peaks were summed, and, based on retention times, concentrations of \text{O}_2 and \text{CO}_2 were determined as percentages of the sum. Three fruit were averaged per treatment. The treatment procedure was replicated a total of three times (separate from quality trials) over 3 months.

With each treatment, the \text{CO}_2 level increased after 2 or 7 days, dependent on initial storage temperature, which indicated the initiation of ripening. Based upon the times of these increases, results were classified as occurring before or after ripening had begun. Within these two periods, average gas concentrations were analyzed by PROC ANOVA in SAS comparing the effects of storage at 12 °C, heating, and waxing or the effects of reconditioning and time of wax application on heated, waxed fruit. Concentrations of \text{O}_2 and \text{CO}_2 before and after the initiation of ripening were correlated (PROC CORR in SAS) with quality attributes.

Results

Quality evaluation. Hot-water treatment significantly affected (\(P \leq 0.05\)) every quality attribute except firmness and external color of ripe fruit and the pH of the ripe guava pulp (Table 1). Since finger pressure determined when quality was evaluated, measurements of firmness were generally within the range of 13 to 23 N for each treatment at the time of evaluation. Significant differences in the number of days required by fruit to ripen, however, suggest that firmness, too, would be different for heated and nonheated fruit on any particular day. Regardless of whether or not fruit were waxed, hot-water treatment delayed ripening by \approx 2 days and increased the percentage of fruit that did not ripen. Heat treatment also increased the subsequent severity of CI due to storage at 12 °C and of decay expressed at 20 °C, increased weight loss, and reduced the percentage of acids and SSC within the pulp.

Waxing fruit within 90 min of heat treatment significantly influenced every quality character except surface decay and weight loss (Table 1). Regardless of whether or not fruit were heated, waxed fruit remained firmer, ripening was delayed by \approx 3 days with a concomitant increase in the percentage of fruit not ripening, and CI at 12 °C was significantly exacerbated. Waxing fruit remained darker with a less intense, greener hue. Regardless of heat treatment, waxed fruit had a lower acidity and SSC and generally did not appear to ripen normally. Although heating alone did not appreciably affect the percentage of fruit that failed to ripen, which was \approx 2%, the combination of heating and nearly immediate waxing increased the proportion not ripening to 45%. Reconditioning fruit at 20 °C for 24 h immediately after heat treatment significantly affected (\(P \leq 0.05\)) firmness, the percentage of fruit that did not ripen, decay, and (at \(P \leq 0.10\)) pulp characteristics (Table 2). Regardless of when wax was applied, the reconditioning of heat-treated fruit allowed fruit to soften more normally, although the time required to ripen could not be statistically differentiated. The percentage of fruit that did not ripen was significantly lower with reconditioning, decay was reduced, and the pulp of ripe fruit had a higher percentage of acids with a concomitantly lower pH.

Delaying the waxing of fruit until storage at 12 °C was complete significantly (\(P \leq 0.05\)) improved all quality characteristics, except peel color (Table 2). Although fruit coated after 12 °C storage were not as dark, and color intensity was somewhat greater, their greenish hue remained unchanged. Regardless of reconditioning, delaying the wax application to heated fruit allowed them to soften and ripen more quickly and reduced the percentage of fruit that failed to ripen. The surface development of CI and decay in the subsequent storage periods was reduced, as was weight loss since fewer days were required to ripen at 20 °C. Delayed waxing also significantly increased the percentage of acids in the pulp with a concomitant reduction in pH and the SSC. Combining the delayed waxing of fruit with reconditioning appeared numerically to offer some advantages for quality maintenance, but the benefits were not statistically significant.

Internal gases. Nontreated fruit harvested and allowed to ripen immediately at 20 °C (no 12 °C storage) developed internal levels of \text{CO}_2 that rose from 1% to 6% by day 10 when fruit were ripe (Fig. 1A). Oxygen was at its
The lowest concentration of 15% soon after ripening began, rose consistently. The remaining 77% to 81% of the atmosphere within the fruit was N₂ (not shown). Compared with untreated fruit, hot-water treatment advanced ripening by 2 days; during the ripening period, O₂ remained lower and CO₂ higher than was measured in nonheated fruit. Waxing fruit, with or without heating, initially reduced the O₂ level to 11% to 13% and doubled the amount of CO₂ recovered, which eventually peaked at 6.5%. Wax-guava did not ripen until several days after this CO₂ peak, on days 16 and 17, respectively, whereas un waxed fruit were ripe at the times CO₂ peaked.

During storage at 12 °C, unwaxed guavas maintained levels of O₂ and CO₂ of >18% and <1%, respectively (Fig. 1B). During this period, waxed fruit generally contained 15% to 17% O₂ and 1% to 2% CO₂. After removal to 20 °C on the 7th day of storage, ripening accelerated in all fruit as indicated by a sharp rise in CO₂. The ripening period was condensed compared with that of fruit not initially stored at 12 °C. Storage at 12 °C allowed O₂ to rise significantly in fruit before their removal to 20 °C, with a concomitant reduction in the percentage of CO₂ (Table 3). Fruit previously stored at 12 °C contained significantly more O₂ during ripening as well.

Regardless of storage at 12 °C, waxing significantly reduced O₂ within fruit before ripening was initiated, and, at this time, both heating and waxing caused CO₂ to rise significantly with a significant interaction between the two. Neither heating nor waxing significantly affected the atmospheric gases within fruit during ripening, however (Table 3). Before ripening, the levels of O₂ and CO₂ in fruit stored at 12 °C were highly correlated (r = −0.992); this relationship was lost, however, as fruit ripened (r = −0.581). Oxygen levels before ripening were inversely correlated (r ≤ −0.950) with injury, firmness, date of ripening, the percentage of fruit not ripening, and pH and directly correlated (r ≥ 0.950) with the darkness (L*) and chroma (C*) of peel color and the concentration of acids and sugars in the pulp.

Delaying the waxing of heat-treated guavas until their removal from storage at 12 °C allowed O₂ levels to remain elevated until ripening was initiated at 20 °C (Fig. 1C). Delayed waxing and reconditioning fruit for 24 h at 20 °C before cold storage, and the interaction of these effects, significantly affected the level of CO₂ in these heat-treated fruits (Table 3). Both effects caused CO₂ to rise, peaking as high as 9.5% with concomitant reductions in O₂ (Fig. 1C). As was previously the case, waxed fruit did not ripen until several days after CO₂ peaked. Within this test, in which all fruit were heated and waxed, O₂ and CO₂ before and after ripening was initiated were correlated at −0.937 and −0.965, respectively. Although the SSC of ripe fruit was correlated (r = 0.942) with O₂ before ripening, other significant relationships with decay, firmness, the number of fruit not ripening, and pH were related to O₂ levels after ripening was initiated. Less signifi-

Fig. 1. Concentrations of O₂ and CO₂ within guavas during postharvest storage and ripening. A) Fruit ripened at 20 °C, B and C) fruit stored at 12 °C for 7 days then ripened at 20 °C. Fruit in A and B: (○) neither heated nor waxed, (□) waxed with 5% carnauba wax, (■) hot-water treated at 46.1 °C for 35 min, and (●) waxed 90 min after hot water treatment. Fruit in C were all heated then: (○) waxed 90 min after hot water treatment immediately before storage at 12 °C. (▲) waxing delayed until storage at 12 °C was complete, (■) reconditioned for 24 h at 20 °C before waxing and storage at 12 °C and (●) reconditioned with delayed waxing. Means of three replications. Treatments in Figs. 1B and 1C correspond to those in Tables 1 and 2, respectively; treatments in Fig. 1A have no tabular counterpart.
Table 3. Effects of storage at 12 °C, hot water treatment (35 min at 46.1 ± 0.2 °C), and waxing on O₂ and CO₂ concentrations in guavas before and after initiation of ripening.

<table>
<thead>
<tr>
<th>Variable†</th>
<th>Before ripening initiated</th>
<th>After ripening initiated</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>O₂</td>
<td>CO₂</td>
</tr>
<tr>
<td>12 °C storage</td>
<td>+</td>
<td>17.42</td>
</tr>
<tr>
<td></td>
<td>−</td>
<td>14.51</td>
</tr>
<tr>
<td>Heat</td>
<td>+</td>
<td>15.58</td>
</tr>
<tr>
<td></td>
<td>−</td>
<td>16.38</td>
</tr>
<tr>
<td>Wax</td>
<td>+</td>
<td>14.61</td>
</tr>
<tr>
<td></td>
<td>−</td>
<td>17.30</td>
</tr>
<tr>
<td>Heat × wax</td>
<td></td>
<td>NS</td>
</tr>
<tr>
<td>Delayed waxing</td>
<td>+</td>
<td>17.83</td>
</tr>
<tr>
<td>Reconditioning</td>
<td>+</td>
<td>15.91</td>
</tr>
<tr>
<td>Delay × Recon.</td>
<td>−</td>
<td>16.61</td>
</tr>
</tbody>
</table>

† or − signifies means with or without the effect, respectively.
‡ Treatment on heated and waxed fruit.

Significant (0.950 ≥ r ≥ 0.900) were relationships between O₂ and CI and date of ripening.

Discussion

Guavas bound for California, Japan, or other markets where the Caribbean fruit fly could become established need to be treated to kill 99.9968% of the flies infesting fruit (Gould and Sharp, 1992). Immersion for 35 min in water at 46.1 ± 0.2 °C slowed the softening, sweetening based on SSC, and color development of fruit and delayed ripening by 2 days. Heat treatment also increased susceptibility to chilling injury, decay, and weight loss in storage, but overall loss of quality was minimal.

Waxing, however, significantly reduced the percentage of O₂ within guavas, which was correlated with several quality factors. Quality of minimally treated fruit (those heated or waxed, but not both) appeared to be determined by O₂ levels before ripening begins. A period of storage at 12 °C allowed O₂ levels to rise within these fruit and tended to counteract some of the ripening delay associated with waxing. Prestorage at 12 °C reduced the variability in ripening at 20 °C within a group of fruit and compressed the period of ripening, indicating that some aspects of this process still occurred at 12 °C.

Waxing guavas within a few hours of hot-water treatment was particularly damaging. Oxygen remained low in waxed fruit during storage and levels of CO₂ failed to develop normally, indicating an interference with ripening. Reconditioning fruit for 24 h at 20 °C after hot-water treatment allowed some recovery from heat damage before the application of wax, but the benefits were slight. Of greater importance was delaying the waxing of fruit until their removal to 20 °C; with fruit better oxygenated, a great deal of recovery could occur during cold storage. Such a delay might be difficult to accommodate in a packing operation, and it negates some of the shelf-life enhancement offered by fruit coatings (Baldwin, 1994). An alternative would be application of a coating more permeable to O₂ than carnauba wax.

The ability of coatings to restrict O₂ may suggest, however, their usefulness, either alone or in combination with other treatments, in quarantine control of insect pests. Heat and cold treatments may not need to be as severe when coatings are subsequently applied (Hallman et al., 1994). The development of a more gentle treatment protocol that includes a coating procedure could potentially benefit the export and shelf-life of many delicate tropical fruits.

Literature Cited


