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

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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. Waxed 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 ($r \leq -0.950$) with injury, firmness, date and percentage of fruit ripening, and pH and directly correlated ($r \geq 0.950$) 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-

yas (*Carica papaya* L.) alters the levels of internal gases, retards ripening, and extends shelf-life (Baldwin et al., 1992). Previous work has also demonstrated the efficacy of fruit coatings in modifying the levels of O₂ and CO₂ within guavas (Hallman et al., 1995) and in prolonging the shelf-life of these fruit (McGuire and Hallman, 1995).

The objective of this research was to combine heat and wax treatment of guavas and to measure the impact of treatment on fruit quality. The quality attributes were subsequently related to levels of O₂ and CO₂ within the variously treated fruit.

Materials 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 $\mu\text{L}\cdot\text{cm}^{-2}$. 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* C* h° 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 bluish 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).

Ten 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 $5000 \times g$ 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 comparably treated fruit not temporarily cold-stored were examined for comparison. Before waxing, if required, but

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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 cylindrical 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 upon retention times, concentrations of O_2 and CO_2 were determined as percentages of this 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 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 O_2 and 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,

Table 1. Quality of guavas as affected by hot-water treatment (35 min at 46.1 ± 0.2 °C) and application of carnauba wax.

Quality of ripe fruit	Statistics ^a			Storage at 12 °C for 7 days, 20 °C to ripen			
				No hot-water treatment		Hot-water treated	
	Heat	Wax	H $\times$ W	No wax	Wax	No wax	Wax
Firmness (N)	NS	**	NS	14.0	22.2	14.4	22.6
Time to ripen at 20 °C (days)	*	**	NS	5.0	7.8	7.1	10.5
Not ripening (%)	*	***	*	0.0	16.6	1.6	44.9
Surface injury (%)	**	**	NS	1.7	22.4	10.6	28.7
Surface decay (%)	***	NS	*	9.2	8.7	14.7	17.3
Weight loss (%)	**	NS	NS	9.2	10.0	13.3	12.7
Color darkness (L*)	NS	**	NS	60.8	53.0	58.1	52.2
Intensity (C*)	NS	***	NS	41.0	32.8	40.7	32.5
Hue (h°)	#	**	NS	91.9	99.6	88.1	97.8
Pulp pH	NS	**	#	4.04	4.14	4.01	4.26
Total acids (%)	*	***	#	0.76	0.70	0.75	0.64
Soluble solids (%)	*	**	#	9.01	8.16	8.83	7.03

^aFrom analysis of variance: H $\times$ W = interaction of heat and wax effects.

NS, #, *, **, ***Nonsignificant or significant at $P \leq 0.10$, 0.05, 0.01, or 0.001, respectively. Means of six replications.

Table 2. Quality of hot-water-treated (35 min at 46.1 ± 0.2 °C), waxed guavas as affected by reconditioning at 20 °C for 24 h before storage at 12 °C and application of carnauba wax before or after storage at 12 °C.

Quality of ripe fruit	Statistics ^a			Storage at 12 °C for 7 days, 20 °C to ripen			
				No reconditioning		Reconditioning	
	Recondition	Wax time	R $\times$ T	Wax Pre 12 °C	Wax Post 12 °C	Wax Pre 12 °C	Wax Post 12 °C
Firmness (N)	*	***	NS	22.6	17.6	20.1	15.6
Time to ripen at 20 °C (days)	NS	*	NS	10.5	7.5	8.4	6.5
Not ripening (%)	**	**	NS	44.9	17.4	26.7	3.7
Surface injury (%)	NS	*	NS	28.7	15.4	25.2	13.9
Surface decay (%)	*	**	NS	17.3	7.8	11.9	4.1
Weight loss (%)	NS	*	NS	12.7	10.8	12.5	10.8
Color darkness (L*)	NS	*	NS	52.2	54.1	52.9	54.4
Intensity (C*)	NS	#	NS	32.5	34.7	33.3	34.7
Hue (h°)	NS	NS	NS	97.8	100.1	98.9	98.6
Pulp pH	#	*	NS	4.26	4.10	4.18	3.95
Total acids (%)	#	*	NS	0.64	0.73	0.71	0.75
Soluble solids (%)	NS	**	NS	7.03	8.28	7.54	8.13

^aFrom analysis of variance: R $\times$ T = interaction of reconditioning and waxing time effects.

NS, #, *, **, ***Nonsignificant or significant at $P \leq 0.10$, 0.05, 0.01, or 0.001, respectively. Means of six replications.

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. Waxed 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 $<2\%$, 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 CO_2 that rose from $\approx 1\%$ to 6% by day 10 when fruit were ripe (Fig. 1A). Oxygen was at its

Fig. 1. Concentrations of O_2 and CO_2 within guavas during postharvest storage and ripening. A) Fruit ripened at $20^\circ C$; B and C) fruit stored at $12^\circ C$ for 7 days then ripened at $20^\circ C$. Fruit in A and B: (●) neither heated nor waxed, (□) waxed with 5% carnauba wax, (■) hot-water treated at $46.1^\circ C$ 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 $12^\circ C$, (▲) waxing delayed until storage at $12^\circ C$ was complete, (▼) reconditioned for 24 h at $20^\circ C$ before waxing and storage at $12^\circ C$, 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.

lowest concentration of 15% soon after ripening began, then rose consistently. The remaining 77% to 81% of the atmosphere within the fruit was N_2 (not shown). Compared with untreated fruit, hot-water treatment advanced ripening by 2 days; during the ripening period O_2 remained lower and CO_2 higher than was measured in nonheated fruit. Waxing fruit, with or without heating, initially reduced the O_2 level to 11% to 13% and doubled the amount of CO_2 recovered, which eventually peaked at 6.5%. Waxed guavas did not ripen until several days after this CO_2 peak, on days 16 and 17, respectively, whereas unwaxed fruit were ripe at the times CO_2 peaked.

During storage at $12^\circ C$, unwaxed guavas maintained levels of O_2 and CO_2 $>18\%$ and $<1\%$, respectively (Fig. 1B). During this period, waxed fruit generally contained 15% to 17% O_2 and 1% to 2% CO_2 . After removal to $20^\circ C$ on the 7th day of storage, ripening accelerated in all fruit as indicated by a sharp rise in CO_2 . The ripening period was condensed compared with that of fruit not initially stored at $12^\circ C$. Storage at $12^\circ C$ allowed O_2 to rise significantly in fruit before their removal to $20^\circ C$, with a concomitant reduction in the percentage of CO_2 (Table 3). Fruit previously stored at $12^\circ C$ contained significantly more O_2 during ripening as well.

Regardless of storage at $12^\circ C$, waxing significantly reduced O_2 within fruit before ripening was initiated, and, at this time, both heating and waxing fruit caused CO_2 to rise significantly with a significant interaction between the effects. Neither heating nor waxing significantly affected atmospheric gases within fruit during ripening, however (Table 3). Before ripening, the levels of O_2 and CO_2 in fruit stored at $12^\circ C$ were highly correlated ($r = -0.992$); this relationship was lost, however, as fruit ripened ($r = -0.581$). Oxygen levels before ripening were inversely correlated ($r \leq -0.950$) with injury, firmness, date of ripening, the percentage of fruit not ripening, and pH and directly correlated ($r \geq 0.950$) 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 $12^\circ C$ allowed O_2 levels to remain elevated until ripening was initiated at $20^\circ C$ (Fig. 1C). Delayed waxing and reconditioning fruit for 24 h at $20^\circ C$ before cold storage, and the interaction of these effects, significantly affected the level of CO_2 in these heated fruit during ripening (Table 3). Both effects caused CO_2 to rise, peaking as high as 9.5% with concomitant reductions in O_2 (Fig. 1C). As was previously the case, waxed fruit did not ripen until several days after CO_2 peaked. Within this test, in which all fruit were heated and waxed, O_2 and CO_2 before and after ripening were correlated at -0.937 and -0.985 , respectively. Although the SSC of ripe fruit was correlated ($r = 0.942$) with O_2 before ripening, other significant relationships with decay, firmness, the number of fruit not ripening, and pH were related to O_2 levels after ripening was initiated ($r \geq 0.950$). Less signifi-

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.

Variable ^z		Internal atmosphere (%)			
		Before ripening initiated		After ripening initiated	
		O ₂	CO ₂	O ₂	CO ₂
12 °C storage	+	*** 17.42	* 1.16	** 17.03	NS 4.03
	-	14.51	2.27	15.32	4.35
Heat	+	NS 15.58	* 2.05	NS 15.76	NS 4.15
	-	16.38	1.38	16.53	4.23
Wax	+	** 14.61	** 2.23	NS 15.98	NS 4.56
	-	17.30	1.19	16.32	3.82
Heat × wax		NS	*	NS	NS
Delayed waxing ^y	+	NS 17.83	NS 1.05	NS 15.74	** 6.29
	-	15.91	1.42	16.60	3.76
Reconditioning ^y	+	NS 16.61	NS 1.25	NS 15.90	** 5.88
	-	17.14	1.22	16.44	4.17
Delay × Recon. ^y		NS	NS	NS	*

^z+ or - signifies means with or without the effect, respectively.

^yTreatment on heated and waxed fruit.

NS, *, **, ***Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively. Means of three replications.

cant ($0.950 \geq r \geq 0.900$) 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.

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