Carambola Quality after Ethylene and Cold Treatments and Storage

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Abstract. Carambolas (*Averrhoa carambola* L.) must be treated with an approved insect quarantine procedure such as cold treatment before shipment to certain markets. Condition and quality of mature-green (MG) and slightly yellow (SY) fruit were determined after they were: 1) treated with ethylene at 0.1 ml·L⁻¹ for 48 hours (C₂H₄), 2) subjected to cold treatment (CT) at 1 °C for 15 days, and 3) held in storage at 5 °C for 7 days plus 3 days at 15 °C. Ethylene-treated fruit were softer and yellowness was enhanced compared with non-C₂H₄-treated fruit. MG fruit were firmer and lost more mass following CT and storage than SY fruit. C₂H₄ treatment increased the severity of peel scald, stem-end breakdown (SEB), and fin browning but had no effect on pitting. CT increased the severity of scald and pitting, and the severity of SEB, but did not affect fin browning. Peel scald, pitting, SEB, and fin browning were more severe in MG than in SY fruit at the final evaluation. C₂H₄-treated fruit had lower total soluble solids concentration, higher titratable acidity and pH, and a less preferred flavor and texture than control fruit. We conclude that carambola fruit should be selected at harvest at the slight-yellow stage (3% to 25% of surface area) instead of at the mature-green stage. Fruit to be cold-stored should not be C₂H₄ treated due to enhanced mold development and severity of SEB.

Carambola production in the United States is mainly limited to the most southern areas of Florida and Hawaii (Hawaii Agricultural Statistics Service, 1994). New carambola plantings and the maturity of existing plantings in the United States have doubled production in the last 10 years (Campbell et al., 1985; J. Crane, personal communication). The incentive to growers to increase production is the increasing demand for carambolas in more distant domestic and export markets where quarantine certification is often required. The principal unwanted pest in Florida carambolas is the Caribbean fruit fly (CFF) (*Anastrepha suspensa* Loew). Methyl bromide (MB) fumigation is not a viable quarantine treatment for carambolas because fruit condition and marketability are compromised by MB treatment (Hallman and King, 1992). Research with vapor heat (Hallman, 1990, 1991), hot water (Hallman, 1989), and forced hot air (Sharp and Hallman, 1992) indicates that carambola will not tolerate heat treatments without serious damage.

Cold treatment (CT) at 1.1 °C for 14 d (Gould and Sharp, 1990) was found effective

against the CFF in carambola fruit. CT is now an approved quarantine treatment for carambolas produced in Florida and shipped to California (Gould, 1996). However, carambolas deteriorate relatively rapidly after CT during postharvest storage, even when held under the recommended 5 °C (Campbell et al., 1987, 1989). Wan and Lam (1984) reported that carambola is a chilling-sensitive fruit; and unripe fruit are more sensitive to chilling injury (CI) than riper fruit, with symptoms distinctly expressed after 5 to 7 weeks of storage at 5 °C. Shippers report a severe decline in quality in some lots of carambolas during and immediately after CT or after shipping and storage at terminal markets. O'Hare (1993) indicates that fruit maturity at harvest is an important factor related to postharvest condition during refrigerated storage.

Fruit selection by peel color is easy when they are harvested following the yellow color break, but selecting mature-green carambolas is more difficult. Postharvest yellowing of the peel is enhanced when mature-green or color-break fruit are exposed to C₂H₄ (J. Brecht, personal communication).

The effects of exposure to exogenous C₂H₄ prior to CT on carambola quality is not known and there is no published literature on treating carambolas with C₂H₄ to promote ripening. The purpose of this study was to determine the quality of green and color-break carambola fruit after C₂H₄ treatment, followed by CT and subsequent storage.

Materials and Methods

Plant material. Mature carambola ('Arkin') fruit were harvested six times during the season from three plots (replications) of five trees

each in a completely randomized split-block design. Carambola fruit, either mature-green (MG, 100% green) or slightly yellow (SY, <25% yellow) were hand-harvested from a grove near Homestead, Fla., on 2 and 9 Aug. 1994, respectively. Because this grove did not set sufficient fruit to satisfy our research requirements for subsequent tests, a grove at Pine Island, Fla., was used to continue the experiment. MG and SY fruit were harvested at Pine Island on 19 and 23 Jan., and 6 and 13 Apr. 1995, respectively. For each of the six harvests, 200 fruit (40 per tree) were picked from each of the three plots and taken to the U.S. Horticultural Research Laboratory, Orlando, Fla., where they were sorted to eliminate defective fruit and to establish uniformity of size and color.

Fruit from each plot were randomized into four treatments of 20 fruit each and packed in commercial full-telescoping fiberboard carambola boxes with die-cut vent holes on all four sides. A complete factorial combination of treatments included +/- C₂H₄ and +/- CT. The boxes had 20-cell honeycomb dividers and top- and bottom-expanded polystyrene pads covering fruit. Fruit were not washed, waxed, or treated with fungicide or wrapped in tissue paper. Each harvest for MG or SY fruit consisted of three-box replications (one for each of three plots) for each of the four treatment combinations.

Fruit treatment. Fruit were treated with C₂H₄ (0.1 ml·L⁻¹) at 25 °C and 90% ± 5% relative humidity (RH) for 48 h, then placed at 1 or 5 °C (RH 90% ± 5%). Fruit not C₂H₄-treated were placed directly into CT at 1 °C or stored at 5 °C. CT commenced when the center fruit pulp temperatures had reached 1 °C and continued for 14 d (Gould, 1996; Gould and Sharp, 1990). After the CT was completed, fruit were held at 5 °C for 7 d, then held an additional 3 d at 15 °C to simulate shipping. Fruit not cold-treated were held continuously at 5 °C (22 d), then held at 15 °C for 3 d.

Fruit evaluations. Fifteen fruit from each box were evaluated for various quality attributes at each of five inspections: following harvest, C₂H₄ treatment, CT, 7 d storage at 5 °C, and 3 additional d at 15 °C. Fruit mass loss was determined on five fruit per box at the end of each storage period. Each of the 15 fruit was inspected for firmness, color, peel scald (discoloration), pitting, stem end breakdown (SEB), browning of fin margins, and decay. Firmness was measured with an Instron Food Tester (model 1132; Instron, Canton, Mass.), calibrated to record 97 N full scale and equipped with an 11-mm-diameter cylinder probe. The force (N) required to compress the fruit surface 3 mm (peel not penetrated) at a constant speed of 5 cm·min⁻¹ was recorded. Reported values are the average of 15 fruit, each with three measurements, one on each of three fins per fruit. Peel color was measured on three fins of five fruit in each box using a Chromameter (model CR 200; Minolta Camera Co., Osaka, Japan) in the CIE (1976) L*, a*, b* (Hunter, 1975) mode and chroma (C) and hue (h+) values were calculated. Additionally, subjective peel color was assigned a value; 1 = 100%

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green; 2 = <3% yellow (breaker); 3 = 3% to 75% yellow; 4 = >75% yellow; 5 = 100% yellow/amber; and 6 = orange (overripe). Peel surface browning or bronzing was scored as scald. Scald was characterized as intensely brown mottled or blotchy areas on the surface of peel without indentation; bronzing is light to moderate golden-brown areas that developed just under the cuticle surface. Peel pitting was scored when peel tissue was stippled with pits of normal (clear) or brown (necrotic) color. Pitting and scald were rated on the extent of surface area affected: 1 = no disorder; 2 = <10% (slight); 3 = 10% to 25% (moderate); 4 = >25% to 50% (severe); and 5 = >50% (extremely severe). SEB was also rated on the extent of surface area affected where: 1 = none; 2 = <2%; 3 = 2% to 10%; 4 = >10% to 25%; and 5 = >25%. SEB is the development of senescent tissue that becomes necrotic and extremely shriveled at the stem end. Browning of fins at the margins was rated 1 = no browning; 2 = slight (the length of one fin equivalent slightly affected); 3 = moderate (>1 fin equivalent slightly affected); 4 = severe (necrotic tissue up to 2 mm deep on the margin of one fin); and 5 = extremely severe (necrotic tissue >2 mm deep on more than one fin). Decay was rated when mold growth or soft tissue was evident. Decay-causing organisms were not identified.

Total soluble solids concentration (TSS), titratable acidity (TA), and pH were determined by standard methods on 15 fruit per replication at the end of storage. Flavor and mastication texture ratings were conducted on random samples of fruit slices for each treatment using a modified hedonic scale ranging from 10 (extremely unacceptable) to 100 (extremely acceptable) by at least seven untrained panelists. Flavor or mastication texture ratings of 50 are the minimum acceptable for commercial marketing.

Data were analyzed with initial fruit color, MG or SY, as the main plots, and with C_2H_4 treatment and CT as the subplots. F test and analysis of variance statistical procedures were conducted on means of the main factors and their interactions ($P \leq 0.05$) after the final

storage period using SAS (release no. 6.11; SAS Institute, Cary, N.C.) procedures.

Results

Mass loss. Mass loss was slightly but significantly higher for MG than for SY fruit at each inspection during storage (data not shown), and mass loss was 4.1% and 3.6% for MG and SY fruit, respectively, at the end of storage (Table 1). The interaction of peel color $\times C_2H_4$ was significant, indicating increased mass loss for MG fruit that were exposed to C_2H_4 compared with SY fruit with or without exposure to C_2H_4 (Table 2).

Firmness. At harvest, compression force measurements were 38.1 N and 33.7 N for MG and SY fruit, respectively. Following storage, objective measurements indicated that C_2H_4 -treated fruit were less firm than the controls (Table 1). SY fruit were also less firm than MG fruit and CT had no effect on fruit firmness during storage. Since the C_2H_4 treatment included 48 h at 25 °C, whereas non- C_2H_4 -treated fruit were placed directly at 1 or 5 °C, the additional time at high temperature likely contributed to decreased fruit firmness.

Peel color. The subjective values for peel color of MG and SY fruit were 1.0 and 2.5, respectively, at harvest. After C_2H_4 treatment, the values for MG and SY fruit had increased to 2.0 and 3.0, respectively, and differed significantly ($P \leq 0.05$). At the end of storage, the subjective color values for MG and SY fruit were 3.1 and 3.8. The corresponding significant a^* value for MG fruit indicates that they were greener than SY fruit (Table 1). The effect of C_2H_4 treatment on peel color development remained significant, with subjective values of 2.5 for the controls and 4.4 for C_2H_4 -treated fruit, at the end of storage. The corresponding L^* , a^* , and b^* values also indicate that C_2H_4 -treated fruit were less dark and yellower than the controls (Table 1). CT had a relatively minor retarding but significant effect on the L^* and b^* CIE (1976) values (Table 1). The effect of C_2H_4 treatment on the increased yellowing (in the a^* value) of CT and non-CT fruit was quite large, as indicated by

the interaction of $C_2H_4 \times CT$ (Table 2).

Peel quality. Scald was significantly less severe on SY than on MG fruit (Table 1). Ethylene treatment and CT each significantly increased the severity of peel scald. Symptoms of scald, including dark-brown surface discolorations, affected 88% of MG fruit and 66% of SY fruit; bronzing of peel affected 18% and 40% of MG and SY fruit, respectively.

Pitting was significantly more severe on MG than on SY fruit (Table 1). Ethylene treatment had no effect on the severity of pitting, but CT significantly increased the severity. There was no significant interaction of main effects for pitting.

SEB was more severe on MG fruit than with SY fruit (Table 1). Ethylene treatment and CT increased the severity of SEB. SEB was more severe following exposure of fruit to $C_2H_4 + CT$ than for control fruit with or without CT (Table 2).

There was slightly but significantly more severe fin browning on MG than with SY fruit; and fin browning was more severe on C_2H_4 -treated fruit than with control fruit (Table 1). Fin browning was not affected by CT; however, by the end of storage, fin browning was rated severe on most fruit, regardless of treatment.

Mold growth. Mold grew on necrotic surface tissues of some fruit, such as SEB-affected tissue. The incidence of mold growth was higher on SY fruit and those that were C_2H_4 -treated (Table 1). The interaction of $C_2H_4 \times CT$ was significant, indicating a higher incidence of mold on C_2H_4 -treated fruit with or without CT than on control fruit; also, C_2H_4 -treated fruit with CT had the highest incidence of mold (Table 2). The exposure of fruit to the elevated temperature during C_2H_4 treatment likely contributed to increase the incidence of mold.

TSS, TA, and pH. TSS, TA, and pH were significantly affected by fruit peel color and C_2H_4 treatment during storage (Table 3). There was no significant interaction of the main effects, except for peel color $\times CT$ for TA (data not shown). TA was 0.5% and 0.7% lower for

Table 1. Mass loss, firmness, peel color, scald, pitting (Pit), stem-end breakdown (SEB), fin browning (Fin brn), and incidence of fruit with mold of mature-green (MG) or slightly yellow-peel (SY) carambolas after C_2H_4 treatment, cold treatment (CT), and subsequent storage for 7 d at 5 °C plus 3 d at 15 °C.

Treatment	Mass loss (%)	Firm (N)	Peel characteristic							
			CIE ^z color			Scald	Pit	SEB	Fin brn	Mold (%)
			L*	a*	b*					
								Rating ^y		
MG	4.1	25.6	43.8	−6.0	19.2	2.9	2.7	2.9	4.6	22.4
SY	3.6	23.9	44.2	−4.4	19.4	2.2	2.1	2.3	4.3	29.3
	*	*	NS	*	NS	*	*	*	*	*
−C ₂ H ₄	3.9	29.9	43.0	−7.0	18.7	2.2	2.4	2.3	3.9	15.9
+C ₂ H ₄	3.9	19.6	45.0	−3.5	20.0	2.9	2.5	3.0	5.0	35.7
	NS	*	*	*	*	*	NS	*	*	*
−CT	3.9	24.6	44.3	−5.4	19.6	2.0	2.2	2.5	4.3	24.4
+CT	3.9	24.6	43.7	−5.1	19.0	3.1	2.6	2.8	4.6	27.2
	NS	NS	*	NS	*	*	*	*	NS	NS
Mean	3.9	24.7	44.0	−5.2	19.3	2.5	2.4	2.6	4.4	25.8
Interactions										
Color × C ₂ H ₄	*	*	*	NS	*	NS	NS	NS	NS	NS
Color × CT	NS	NS	NS	*	NS	NS	NS	NS	NS	NS
C ₂ H ₄ × CT	NS	NS	*	*	*	NS	NS	*	NS	*

^zCIE (1976) color values.

*1 = none, 2 = slight, 3 = moderate, 4 = fairly severe, and 5 = severe.

NS. *Nonsignificant or significant at $P \leq 0.05$ by analysis of variance procedures by SAS Inst., Cary, N.C.

Table 2. Significant two-way interaction means [peel color $\times$ C₂H₄; C₂H₄ $\times$ cold treatment (CT)] for mass loss, a* (CIE 1976) color value, stem-end-breakdown (SEB) severity, and incidence of fruit with mold growth for carambola.

Characteristic	Interaction		Means
Mass loss (%)	Peel color $\times$ C ₂ H ₄		
	MG	—	3.9
	MG	+	4.3
	SY	—	3.8
	SY	+	3.6
			LSD = 0.47 ^z
a* CIE value	C ₂ H ₄ $\times$ CT		
	+	—	-3.3
	+	+	-3.6
	—	—	-7.4
	—	+	-6.5
			LSD = 0.67
SEB (severity index)	C ₂ H ₄ $\times$ CT		
	+	—	2.7
	+	+	3.3
	—	—	2.2
	—	+	2.3
			LSD = 0.27
Mold incidence (%)	C ₂ H ₄ $\times$ CT		
	+	—	30.4
	+	+	41.1
	—	—	18.5
	—	+	13.3
			LSD = 9.31

^zLSD at $P \leq 0.05$.

CT fruit than with non-cold-treated MG and SY fruit, respectively.

Flavor and texture. Exposure to C₂H₄ had a dramatic negative effect on flavor and mastication texture, however, initial peel color and CT had no influence on sensory characteristics (Table 3).

Discussion and Conclusion

Peel discoloration, pitting, SEB, and fin browning are unsightly, and are major visible indicators of deterioration that negatively affect consumer acceptance of carambola. More than 10% of the fruit surface area was affected when index values for these attributes exceeded 2.0. Although not significant, there was a trend toward less severe peel damage (scald, SEB, fin browning indices) on SY fruit than with MG fruit when carambolas were exposed to either C₂H₄ or CT. Miller et al. (1991) reported that conditioning of carambola for 3 d at 15 °C prior to CT reduced peel scald (bronzing) and SEB.

Slight pitting developed during storage at 5

°C even on control fruit. Peel pitting is a known symptom of CI and may be related to fruit maturity, storage temperature and humidity, and length of storage (O'Hare, 1993). There may also be differences in the CI response of carambolas related to factors such as cultivar and climatic conditions. The C₂H₄ treatment at 25 °C and 0.1 ml·L⁻¹ for 48 h had a detrimental affect on peel condition regardless of peel color at harvest. Although the development of fin browning was slightly retarded without the C₂H₄ treatment, it was serious, and affected 95% to 100% of fruit at the end of storage regardless of the initial peel color, C₂H₄ treatment, or CT. The severity of fin browning to fruit from exposure to CT in this study was similar to that previously reported by Miller et al. (1991) except for carambolas that were film-wrapped prior to CT (Miller et al., 1993). Fin browning is likely related to water loss.

The intensive orange/amber color development in SY fruit indicated that our C₂H₄ treatment of 48 h at 0.1 ml·L⁻¹ may have been too severe. Conversely, this treatment regime

may have been insufficient for MG fruit. However, even if the peel of carambolas had been more acceptable, both sensory flavor and texture scores for C₂H₄-treated MG and SY fruit were unacceptable, likely due to increased SEB and mold. Carambola fruit should be harvested when its peel is slightly yellow rather than green. Applying CT, when required, without C₂H₄ treatment, will likely slow quality deterioration following subsequent storage.

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Table 3. Total soluble solids (TSS), titratable acid (TA), pH and flavor and mastication texture index values for mature-green (MG) or slightly yellow-peel (SY) carambolas after C₂H₄ treatment, cold treatment (CT), and storage for 7 d at 5 °C plus 3 d at 15 °C.

Treatment	TSS (%)	TA (%)	pH	Rating	
				Flavor	Texture
MG	6.3	16.7	4.0	55.7	51.6
SY	6.9	15.3	4.1	58.7	55.8
	*	NS	*	NS	NS
-C ₂ H ₄	6.7	16.9	4.0	69.6	75.7
+C ₂ H ₄	6.5	15.2	4.1	44.8	31.7
	*	*	*	*	*
-CT	6.6	16.3	4.1	59.6	53.4
+CT	6.6	15.7	4.1	54.9	54.0
	NS	NS	NS	NS	NS
Mean	6.6	16.0	4.1	57.2	53.7
Interactions ^z					
Color $\times$ CT	NS	*	NS	NS	NS

^zInteractions not shown are nonsignificant for all quality characteristics.

NS, *Nonsignificant or significant at $P \leq 0.05$ by analysis of variance procedures by SAS Inst., Cary, N.C.