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ETHYLENE TREATMENT OF CARAMBOLAS PRIOR TO QUARANTINE COLD TREATMENT

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Abstract. **Carambolas must be subjected to a quarantine cold treatment (CT) for the control of Caribbean fruit fly (CCF) (*Anastrepha suspensa* Loew) prior to shipment to certain domestic or export markets. Carambola trees produce several crops of fruit each season and fruit of more than one crop may be present at harvest. Shippers may harvest mature fruit with peel color ranging from green to various shades of yellow. We found mature green peel (MGP) fruit to have increased severity of the peel disorders scald, pitting, stem-end breakdown, and necrotic tissue at the margins of thc fins compared with slight yellow peel (SYP) fruit. Ethylene treatment prior to CT increased the severity and incidence of these same condition attributes, caused fruit to be softer, and decreased the acceptability of flavor and texture. Carambola shippers can reduce the development of peel disorders and maintain better flavor and texture in the marketplace by harvesting fruit with 3% to 25% yellow color with or without cold treatment compared with similarly treated MGP fruit.**

Carambolas (*Averrhoa carambola* L.) are produced in the subtropical regions of the U.S., mostly in Dade County, Florida (Campbell et al., 1985), with some small production also reported in Hawaii (Anonymous, 1994). Florida growers are interested in expanding their market area beyond the traditional eastern region of the United States. Carambolas produced in Florida and marketed in certain western states and certain Pacific rim countries must be certified as free of the CFF. Considerable research has been conducted on the development of a satisfactory treatment method that provides quarantine security against CFF but does not cause excessive damage to the fruit. Vapor heat (Hallman, 1990; 1991), forced hot air (Sharp and Hallman, 1992), hot water (Hallman, 1989), and methyl bromide fumigation (Hallman and King, 1992) have been investigated for quarantine treatment of carambola, but each caused excessive deterioration of the peel or sensory attributes. In addition, low-dose irradiation was reported effective in sterilizing CFF at 0.15 kGy in carambola (Gould and von Windeguth, 1991), and this method is currently being considered by official regulators for approval. The recommended postharvest storage temperature for 'Arkin' carambolas produced in Florida is 5C (Campbell et al., 1989a; 1989b). Gould and Sharp (1990) found that carambola stored for 15 days at 1C was efficacious for quarantine security against the CFF, and Gould (1996) reported CT could be reduced to 12 days. Cold treatment is now an approved quarantine treatment for carambolas shipped into California. Florida shippers have used the CT for carambolas over the past several seasons for shipments to California and peel damage has occurred on some fruit in cold-treated lots (C. Campbell and M. Trunk, personal communications). Conditioning carambolas at 15C for 3 days prior to CT did not ameliorate the development of peel damage during storage (Miller et al., 1991). However, film wrapping prior to CT prevented the development of most carambola peel disorders (Miller et al., 1993).

The carambola industry relies on phenotypic parameters such as shape, fully developed fins, and peel color for selecting fruit for harvest. Since carambola trees have several sets of bloom during a season, fruit of two blooms may be on trees at harvest. Fruit peel color at harvest may also range from green to various shades of yellow. The determination of mature fruit for harvest in the absence of yellow color is difficult.

Conflicting reports indicate that carambolas are nonclimacteric (Lam and Wan, 1983; Oslund and Davenport, 1983) indicating that fruit must be mature/ripe at harvest. However, other reports indicate that carambolas are climacteric (Wang, 1988; Shiesh, et al., 1987). The maturity of carambolas at harvest is a major factor in postharvest senescence (O'Hara, 1993). Mature green peel carambolas will develop yellow peel color when exposed to ethylene (100 ppm) at 26C (J. Brecht, personal communication). The objective of this study was to determine the effect of CT on the condition and quality of MGP or SYP carambolas with or without prior exposure to ethylene treatment for the enhancement of yellow peel color.

Materials and Methods

Mature green peel and SYP carambolas (cv. 'Arkin') were each harvested three times from three different plots (replications) each plot containing five trees. Mature green peel fruit were harvested when sufficient fruit were available and about 7 days prior to the harvest of SYP fruit, thus the experimental design was a randomized complete block in a split plot. MGP fruit were 100% green and SYP fruit were from 3% to 25% yellow when harvested. Fruit were harvested from a grove near Homestead, FL, on 2 and 9 August, 1994, and from a grove near Pine Island, FL, on 19 and 23 January and 6 and 13 April, 1995. Fruit from each harvest were taken to the U.S. Horticultural Research Laboratory, Orlando, FL, for treatment preparation.

Treatments and storage. Immature, misshaped, and damaged fruit were discarded and 20 sound fruit from each of the three plots were randomized into each of six treatments. Twenty fruit each were packed into commercial, full-telescoping fiberboard carambola boxes with 20 cell honey-comb dividers and top and bottom polystyrene pads. Boxes had two die-cut holes in each of the four side panels for ventilation. Fruit were not washed or treated with any fungicide and were

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not wrapped in tissue paper. The six treatments were: 1) 5C for 15 days; 2) 1C (CT) for 15 days; 3) 25C for 48 h, then 5C for 15 days; 4) 25C for 48 h, then 1C (CT) for 15 days; 5) 100 ppm C_2H_4 at 25C for 48 h, then 5C for 15 days 6) 100 ppm C_2H_4 at 25C for 48 h, then 1C (CT) for 15 days. After completion of CT all fruit were held for 7 days at 5C plus an additional 3 days at 15C. Relative humidity was held at 90% for all storage regimes.

Fruit evaluations. All fruit were inspected after treatment preparation, after cold treatment, after storage for 7 days at 5C, and after 3 additional days at 15C. Fifteen fruit per box were evaluated subjectively for peel scald, pitting, stem end breakdown (SEB), browning at the rib margins, and decay. Scald (peel discoloration) developed as intense brown mottled or blotchy areas or light to moderate golden brown (bronzed) areas on the peel surface. Scald was rated where 1 = 0%, 2 = ≤ 10%, 3 = 11% to 25%, 4 = 26% to 50%, and 5 = ≥ 50% of surface area affected. Peel pitting was scored when tissue was stippled with clear or brown (necrotic) pits and was classified as described for scald. SEB was characterized as severe tissue breakdown (necrotic) with severe shriveling at the stem end, and was rated 1 = 0%, 2 = ≤ 2%, 3 = 3% to 10%, 4 = 11% to 25%, and 5 = ≥ 25% of surface area affected. Fin browning at the rib margins was rated as 1 =normal, 2 = slight (the length of one fin equivalent), 3 = moderate (more than one fin length slightly affected), 4 = severe (affected tissue to 2 mm deep from the margin of one fin), and 5 =extremely severe (more than one fin affected as described for severe). Decay was scored when soft or mushy tissue was observed, but decay-causing organisms were not identified.

Following harvest and the final storage, objective fruit firmness was determined using an Instron Food Tester (model 1132, Instron Inc., Canton, MA) calibrated to record 97 newtons (N) full scale with a crosshead speed of 5 cm·min^{-1}, with a 11 mm round cylinder set to penetrate 2 fins of each whole fruit 3 mm. Weight loss was determined on a five-fruit sample at each inspection. Total soluble solids (TSS), titratable acidity (TA) (expressed as oxalic acid), and pH were determined on a 15-fruit sample at harvest and at the end of storage using standard measuring methods. Flavor and mastication texture were each evaluated by seven panelists using a modified hedonic scale ranging from 10 to 100, extremely unacceptable to extremely acceptable, respectively.

Subjective peel color was scored 1 = 100% green, 2 = ≤ 3% yellow (breaker), 3 = 4% to 75% yellow, 4 = ≥ 75% yellow, 5 = 100% yellow/amber, and 6 = yellow/orange (overripe).

Data were combined on initial peel color, for MGP and SYP fruit, and analyzed by ANOVA procedures, and when significant differences for characteristics by peel color were indicated mean differences among treatments following each storage regime were separated by Duncan's multiple range test using SAS (SAS Institute, Cary, NC) procedures.

Results and Discussion

Peel condition

Scald. When averaged over all treatments, MGP fruit had more intensive (2.6) and a higher incidence (65%) of scald compared with SYP fruit, 2.0 and 46%, respectively (Table 1). Fruit exposed to ethylene and CT had the highest severity and incidence of scald, and CT fruit with or without ethylene treatment generally had a higher severity (index) and incidence (%) of scald compared with non-cold treated fruit.

Pitting. The mean pitting severity index and incidence for all treatments was higher for MGP compared with SYP fruit.

Table 1. Severity and incidence of peel scald, pitting, stem-end breakdown (SEB) and fin browning (FB) after ± ethylene (C_2H_4), or ± Cold treatment (CT) or ± delayed (~)[z] CT and storage of 7 d at 5C + 3 d at 15C for mature green (MGP) or slight yellow peel (SYP) combined or alone.

Treatment		Scald		Pitting		SEB		FEB	
C_2H_4	CT	Index	%	Index	%	Index	%	Index	%
MGP fruit									
-	-	2.2b[y]	50b	2.4a	57a	2.7b	90bc	4.0b	95
-	+	3.0c	79d	3.0b	74bc	2.6b	84abc	4.3c	99
-	~/-	1.6a	33a	2.3a	52a	2.1a	73a	3.7a	99
-	~/+	2.4b	63c	2.6ab	65ab	2.1a	79ab	4.0b	100
+	-	2.5bc	65c	2.5ab	62ab	3.0b	90bc	5.0d	100
+	+	4.0d	99e	3.0b	80c	3.5c	93c	5.0d	100
mean		2.6	65	2.6	65	2.7	85	4.3	99
SYP fruit									
-	-	1.4a	24a	1.9a	46a	1.8a	62a	3.5a	95
-	+	2.3c	47b	2.3a	49a	2.0a	56a	3.9b	99
-	~/-	1.4a	26a	2.0a	51a	2.0a	71ab	3.5a	99
-	~/+	2.2bc	53b	2.2a	55a	1.8a	60a	3.7ab	96
+	-	1.8a	43b	2.2a	50a	2.5b	83bc	4.8c	100
+	+	3.1d	84c	2.2a	62a	3.0c	94c	5.0c	100
mean		2.0	46	2.1	52	2.2	71	4.1	98
Main factors and interaction[x]									
Color		*	*	*	*	*	*	*	ns
TRT		*	*	*	*	*	*	*	*
Color × TRT		ns	*	ns	ns	*	*	*	ns

[z]~delayed start of CT for 48 h.
[y]For MGP or SYP alone values followed by same letters are not significantly (P ≤ 0.05) different by Duncan's multiple range test.
[x]For MGP and SYP combined values; ns, * nonsignificant or significant (P ≤ 0.05) by ANOVA procedures.

Mature green peel fruit that were cold treated with or without ethylene (except those with delayed storage) had more severe pitting than non-ethylene fruit with or without delayed storage. For SYP fruit there were no differences among treatments for pitting (Table 1).

Stem-end breakdown. The severity and incidence of SEB were greater on MGP fruit compared with SYP fruit (Table 1). MGP fruit not exposed to ethylene that had delayed storage at 1C or 5C had the least severe SEB, and MGP ethylene treated fruit that were also cold treated had the most severe SEB. SYP fruit that were ethylene treated with or without CT had more severe SEB when compared with other treatment combinations.

Fin browning. Regardless of treatment, severe fin browning affected 95% to 100% of fruit at the end of storage (Table 1). Ethylene treatment with or without cold treatment had the most severe effect on fin browning. There was a significant interaction of peel color by treatment (TRT) but index values indicate little practical differences of importance.

Decay. There was no soft or mushy tissue on fruit at the end of storage (data not shown).There was superficial saprophytic mold growth on some necrotic tissue of some fruit. Ethylene treated fruit had mold growth on 35% of fruit compared with 15% of non-ethylene treated fruit. MGP fruit had less (19%) incidence of superficial mold growth when compared with SYP fruit(25%).

Fruit condition and quality

Firmness. MGP fruit averaged slightly but significantly firmer (27.1 N) than SYP fruit (25.5 N) (Table 2). Regardless of initial peel color, ethylene treated fruit with or without CT were softer than fruit of all other treatments (Table 2).

Weight loss. The mean weight loss for MGP fruit was slightly higher (4.4%) compared with SYP fruit (3.9%) (Table 2). Nonethylene- and cold-treated MGP fruit without delayed cold storage had less weight loss than fruit with delayed storage. For SYP fruit, those exposed to ethylene treatment with or without CT had less weight loss compared with fruit that had delayed storage.

TSS, TA, and pH. SYP fruit had higher TSS (6.8%), lower TA (0.14%) and higher pH (4.1) compared with MGP fruit (Table 2). Differences for TSS among treatments for both MGP and SYP fruit were slight. Ethylene- and cold-treated fruit had the lowest percentage of TA compared with other treatments for MGP fruit, which was different than the rankings for TA for SYP fruit. Differences indicated among treatments for pH in both MGP and SYP fruit are of little practical importance.

Flavor and texture. There was a slight but significant difference in the index value means for both flavor and texture (Table 2) by peel color (flavor values shown similar due to rounding). Fruit treated with ethylene with or without exposure to CT had the lowest acceptance values for both flavor and texture compared to all other treatments. Delayed CT also had relatively low acceptance values for flavor and texture when compared with immediate exposure to CT for both MGP and SYP fruit.

Peel color. Subjective color values of ethylene treated fruit were more yellow (4.4) than treatments without ethylene (2.6) at the final inspection (data not shown). Mean subjective color values for MGP and SYP fruit were 2.8 and 3.5, respectively, and were significantly different at the end of storage, and there was no significant interaction for color by TRT. Delayed storage at 1C or 5C had no significant effect on

Table 2. Condition and quality attributes after ± ethylene (C_2H_4), ± cold treatment (CT) or ± delayed (~)[z] CT, and storage of 7 d at 5C plus 3 d at 15C for mature green (MGP) or slight yellow peel (SYP) carambolas combined or alone.

Treatment								
C_2H_4	CT	'N'	Wt Loss (%)	TSS (%)	TA (%)	pH	Flavor index	Texture index
MGP fruit								
-	-	30.5c[y]	4.2ab	6.4b	0.166b	3.94ab	67d	74d
-	+	32.7d	3.7a	6.5b	0.154b	3.98ab	72e	76e
-	~/-	28.8b	4.9b	6.5b	0.163b	3.91a	76f	79f
-	~/+	31.7cd	5.0b	6.4b	0.149b	4.00abc	59c	70c
+	-	19.8a	4.4ab	6.3b	0.149b	4.04bc	44b	29b
+	+	19.4a	4.3ab	6.0a	0.113a	4.14c	40a	28a
mean		27.1	4.4	6.5	0.150	4.0	60	59
SYP fruit								
-	-	28.7b	3.6ab	6.8a	0.158b	4.09ab	74f	76d
-	+	27.7b	4.0b	7.0b	0.162b	4.08ab	65d	77e
-	~/-	27.9b	4.6c	6.8a	0.164b	4.06a	69e	75c
-	~/+	29.4b	4.6c	6.7a	0.152ab	4.08ab	58c	74b
+	-	19.2a	3.3a	6.8a	0.143a	4.21c	53b	35a
+	+	19.9a	3.5a	6.9ab	0.149ab	4.15bc	42a	35a
mean		25.5	3.9	6.8	0.140	4.1	60	62
Main factors and interactions[x]								
Color		*	*	*	*	*	*	*
TRT		*	*	*	*	*	*	*
Color × TRT		*	ns	*	ns	ns	*	ns

[z]~delayed start of CT for 48h.
[y]For MGP or SYP alone values followed by same letter are not significantly ($P \leq 0.05$) different by Duncan's multiple range test.
[x]For MGP or SYP combined values; ns, * nonsignificant or significant ($P \leq 0.05$) by ANOVA procedures.

the development of yellow color compared with fruit of other treatments where fruit were not exposed to ethylene.

Conclusions

Ethylene treatment of carambolas followed by CT had a greater negative effect at the end of storage on severity and incidence of most peel condition attributes (scald, pitting, SEB and FB) compared with other treatments investigated, except for severity of pitting. Ethylene treatment had more of a negative effect on MGP than SYP fruit, except for fin browning. Our findings are consistent with a recent report showing less mature carambola fruit to have a shorter shelf-life and to deteriorate more rapidly compared with more mature fruit after various storage temperatures ranging from 5 to 20C (Yon and Jaafar, 1993). Delayed storage (25C for 48 h) alone did not contribute to degradation in peel condition attributes, and delayed storage alone had a slight positive effect in reducing SEB in MGP fruit. The exposure of carambolas to 25C for 48h prior to CT may have not been sufficient to induce heat shock proteins that may delay degradation of postharvest condition or quality attributes (Paull, 1990). Exposure to 100 ppm ethylene at 25C induced ripening as indicated by yellow peel development and fruit softening.The development of yellow peel in MGP fruit was not complete and may not have been sufficient for successful marketing as final fruit color ranged from green to a pale green/yellow compared with more intense yellow color development in SYP fruit. This may indicate that a different combination of ethylene and heat may be required for improved color development in MGP fruit. Cold treatment without prior ethylene treatment lowered the risk of developing peel disorders for either MGP or SYP fruit. However, data averaged over all treatments indicate there was less injury to cold-treated SYP fruit compared with similarly treated MGP fruit for peel disorders. Therefore, harvesting SYP fruit and applying CT without prior ethylene treatment will lessen unsightly peel disorders when quarantine treatment of carambolas is required.

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