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# CONDITION OF FLORIDA CARAMBOLAS AFTER HOT-AIR TREATMENT AND STORAGE

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*Abstract.* **'Arkin' carambola fruit were treated with 47°, 48° or 49°C (116.6°, 118.5°, or 120.2°F) air (about 60% RH) for 90, 120 or 150 min (airflow rate approximately 0.4 $m^3 \cdot sec^{-1}$) for the purpose of establishing the threshold boundary for stress tolerance from exposure to these potential quarantine treatments. After treatment at these temperature/time combinations and storage for 1 or 2 weeks at 4.4°C ± 0.5° (40°F) plus 3 days at 15.6°C ± 0.5° (60°F), treated carambolas were found to deteriorate more rapidly than nontreated fruit. Treated fruit lost more weight, had more stem-end breakdown and rib-browning, and generally had a more undesirable flavor than nontreated control fruit. The higher treatment temperatures slowed chlorophyll depletion of the peel. Fruit treated at 47°C were generally more acceptable than those treated at 48° or 49°C.**

Carambola (*Averrhoa carambola* L.) is a tropical fruit produced in south Florida that has recently experienced rapid growth in market demand. Concurrently, both production and new plantings of this crop have increased. Carambola acreage in Dade County was about 60 acres (24.3 ha) for 1985 (2) and has increased to 435 acres (176 ha) in 1990 (3). Shippers of carambolas are supplying domestic markets, such as New York and California, and are interested in developing an export trade (Craig Campbell, J. R. Brooks & Son, personal communication). As the market for carambolas continues to expand geographically, so does the need for developing quarantine treatments to protect against insects such as the Caribbean fruit fly (CFF), *Anastrepha suspensa* (Loew), in markets with quarantine restrictions. Fruit shipments to markets with quarantine restrictions must be treated by an approved procedure and be certified free of infestation. There was no quarantine treatment of carambolas for CFF until recently when a cold treatment was developed, consisting of exposing fresh fruit to 1.1°C (34°F) for 15 days (4). This treatment was approved in 1989 by the USDA Animal and Plant Health Inspection Service for interstate shipment of carambolas from Florida to states having quarantine restrictions. Hot-water immersion (5,6), vapor heat and methyl bromide fumigation (Hallman, unpublished data), and forced hot air (Sharp, unpublished data) are techniques which are also being tested experimentally for CFF control on carambolas. Sharp (unpublished data) indicates that CFF mortality (probit 9) in carambolas occurs when fruit core temperatures reach and remain at 43.5° (110°F) for about 20 min. The threshold of stress tolerance of freshly harvested carambola exposed to heat treatments to kill CFF is not known. Therefore, the objective of this study was to determine the threshold of carambola's tolerance to temperature and application time during hot-air treatment sufficient to kill the CFF. Sharp found the ranges of temperature and time used in this study effective for probit 9 mortality of CFF.

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## Materials and Methods

Carambolas (cv. Arkin, a sweet variety) were obtained on 3 occasions during the summer of 1989 directly from a packinghouse in Homestead, Fla. Commercially graded large-size (average about 160 g) fruit (green or with slight color break) were wrapped in tissue paper and packed in commercial fiberboard boxes at the packinghouse. Care was taken to ensure that fruit for each test were all of the same cultivar. Fruit were taken to the U.S. Subtropical Horticultural Research Laboratory, Miami, Fla., removed from boxes and divided into 2 lots for treatment and nontreated controls. There were 9 temperature/time (T/T) treatment combinations: 47°C for 90, 120, or 150 min; 48°C for 90, 120, or 150 min; and, 49°C for 90, 120, or 150 min. For each of the 3 tests (replications), 30 fruit (two, 15-fruit subsamples) were treated at each T/T combination. Nontreated fruit consisted of 90 fruit for each test, 6 boxes of 15 fruit each. Each separate treatment lot was placed into plastic bins along with sufficient filler fruit to assure that a full complement of fruit was present in the hot-air chamber during treatment. The hot-air facility was designed to function by gradually increasing the fruit surface temperature relative to incoming air temperature so that free moisture would not condense on the fruit surface. Incoming air temperature increased stepwise, based on a 2° difference between surface air temperature and incoming air temperature, until the treatment temperatures of 47°, 48° or 49°C were reached. Incoming air temperature was held at the preset temperature for 90, 120 or 150 min. Fruit core and surface temperatures were measured during treatment by placing 6 thermocouples (TC) (copper/constantan, 36-gauge) into 6 separate fruit: 3 at the center of 3 fruit and 3 located 1mm under the peel of 3 fruit. Hot glue was used to seal the injury where the TC had been inserted into the fruit. To ensure that fruit farthermost from incoming air reached treatment temperature, all thermocouples were placed in fruit located at the side away from the incoming air. In addition, incoming air temperature and the airflow rate (maintained at about 0.4 $m^3 \cdot sec^{-1}$) were monitored continuously during delivery of air into the chamber. After treatment, fruit were not washed or treated with a fungicide. All fruit, treated and nontreated, were rewrapped in tissue paper and placed 15 each into commercial fiberboard boxes with honeycomb interlocking pulpwood cushioning between each fruit. After treatment and repackaging the fruit were transported by automobile to the U.S. Horticultural Research Laboratory in Orlando, Fla., for storage and evaluation.

One box containing 15 fruit from each of the 9 T/T combinations and 3 boxes of control fruit were inspected after 1-week storage at 4.4°C (±0.5°). They were then placed at 15.6°C (±0.5°) for 3 days and reinspected. Similarly, a separate set of fruit was inspected after 2 weeks' storage at 4.4°C and, finally, after 3 additional days at 15.6°C. Storage at 4.4°C was used because it was previously determined to be near optimum for carambolas (1). Seven fruit from each box were designated for weight loss determinations. All fruit were subjectively evaluated for symptoms of pitting, scald (peel discoloration), stem-end breakdown (SEB), browning at the margins of ribs (fins), mechanical injury, decay, firmness, and peel color. In addition to the subjective evaluations, objective evaluations of color and firmness and an informal taste evaluation were made of all sound fruit remaining after the terminal inspection.

Pitting on peel tissue developed into irregularly shaped lesions that were stippled and slightly sunken, but not discolored. Scald, an atypical peel discoloration, consisted of a random bronzed or darkened areas which were usually confined to one area of the fruit. SEB was characterized by senescent, dark brown, shriveled tissue, and generally affected only the tissue at the stem end of the fruit. Pitting, scald, and SEB severity was scored based on the percentage of surface area affected: 1 = none, 2 = <10%, 3 = 11-

Table 1. Condition of nontreated and treated carambolas after exposure to 47°, 48°, or 49°C (116.6°, 118.4°, or 120.2°F) for 90, 120 or 150 min and storage at 4.4°C (40°F) for 1 or 2 weeks plus 3 additional days at 15.6°C (60°F).

| Storage/treatment temp/ treatment/time | Wt loss (%) | Color[z] (sub) | 'a'[y] | SEB[x] | RB[w] | Firmness (N) | TASTE[v] |
|---|---|---|---|---|---|---|---|
| *1 week at 4.4°C* | | | | | | | |
| Control | 1.2 | 3.3 | -4.0 | 1.1 | 1.5 | – | – |
| 47° | 2.5 | 3.3 | -3.3 | 1.0 | 1.8 | – | – |
| 48° | 2.6 | 3.4 | -3.5 | 1.1 | 1.7 | – | – |
| 49° | 2.4 | 3.3 | -4.4 | 1.2 | 1.8 | – | – |
| 90 min | 2.5 | 3.3 | -3.8 | 1.1 | 1.7 | – | – |
| 120 min | 2.8 | 3.4 | -3.4 | 1.1 | 1.9 | – | – |
| 150 min | 2.2 | 3.3 | -3.6 | 1.1 | 1.7 | – | – |
| Time | NS | NS | NS | NS | NS | – | – |
| Temp | NS | NS | NS | NS | NS | – | – |
| Time x Temp | NS | NS | ** | NS | NS | – | – |
| *1 wk at 4.4°C plus 3 days at 15.6°C* | | | | | | | |
| Control | 2.4 | 3.9 | -2.2 | 1.2 | 1.8 | 1.8 | 6.2 |
| 47° | 3.6 | 4.4 | -0.9 | 1.7 | 2.3 | 2.2 | 4.5 |
| 48° | 3.8 | 4.2 | -0.4 | 1.7 | 2.2 | 2.2 | 3.9 |
| 49° | 3.5 | 3.5 | -1.7 | 1.6 | 2.2 | 2.2 | 3.5 |
| 90 min | 3.7 | 3.9 | -1.4 | 1.6 | 2.1 | 2.3 | 4.9 |
| 120 min | 4.0 | 4.1 | -0.7 | 1.7 | 2.3 | 2.2 | 3.7 |
| 150 min | 3.2 | 4.1 | -0.9 | 1.7 | 2.3 | 2.1 | 3.1 |
| Time | NS | ** | NS | NS | NS | NS | – |
| Temp | NS | NS | NS | NS | NS | NS | – |
| Time x Temp | NS | NS | ** | NS | NS | NS | – |
| *2 wk at 4.4°C* | | | | | | | |
| Control | 1.9 | 3.3 | -3.8 | 1.1 | 1.5 | – | – |
| 47° | 2.9 | 3.4 | -2.7 | 1.2 | 1.6 | – | – |
| 48° | 3.2 | 3.4 | -3.2 | 1.4 | 1.7 | – | – |
| 49° | 2.9 | 3.4 | -3.6 | 1.3 | 1.8 | – | – |
| 90 min | 3.2 | 3.5 | -3.3 | 1.3 | 1.7 | – | – |
| 120 min | 3.1 | 3.5 | -2.9 | 1.3 | 1.8 | – | – |
| 150 min | 2.7 | 3.3 | -3.4 | 1.3 | 1.8 | – | – |
| Time | NS | NS | NS | NS | NS | – | – |
| Temp | NS | NS | NS | NS | NS | – | – |
| Time x Temp | NS | NS | NS | NS | NS | – | – |
| *2 wk at 4.4°C plus 3 days at 15.6°C* | | | | | | | |
| Control | 3.0 | 4.2 | -1.3 | 1.2 | 1.9 | 1.9 | 6.4 |
| 47° | 3.9 | 4.3 | 0.0 | 1.4 | 2.1 | 2.6 | 5.8 |
| 48° | 4.3 | 4.1 | -0.8 | 1.6 | 2.3 | 2.6 | 4.7 |
| 49° | 3.9 | 3.8 | -1.5 | 1.6 | 2.3 | 2.7 | 4.2 |
| 90 min | 4.2 | 4.3 | -0.5 | 1.5 | 2.2 | 2.6 | 5.3 |
| 120 min | 4.0 | 4.1 | -0.5 | 1.4 | 2.3 | 2.6 | 4.8 |
| 150 min | 3.8 | 3.9 | -1.3 | 1.5 | 2.3 | 2.7 | – |
| Time | NS | ** | ** | NS | NS | NS | – |
| Temp | NS | ** | NS | NS | NS | NS | – |
| Time x Temp | NS | NS | NS | NS | NS | NS | – |

[z]Color index value, 1 = green, 2 = breaker, 3 = 3-75% yellow, 4 = trace of green on ribs, and 5 = 100% yellow.
[y]Hunter color value.
[x]Stem-end breakdown index, 1 = none, 2 = <10%, 3 = 11.25%, 4 = 26-50%, 5 = >50% of surface area affected.
[w]Rib-browning index, 1 = none, 2 = <10%, 3 = 11-25%, 4 = 26-50%, 5 = >50% of surface area affected.
[v]Taste index, 1 = poor, to 9 = extremely good.

25%, 4 = 26-50%, and 5 = >50%. Rib discoloration (not wind scarring) at the margins of the ribs was scored: 1 = none, 2 = slight (slight area on 1 rib), 3 = moderate (damage to 2 ribs), and 4 = severe (damage 3.0 mm or more from rib apex on 1 or more ribs). Mechanical injury was noted when present. Superficial mold tended to grow on injured surface tissue and was scored when observed: 1 = none, 2 = mold, without indication of severity. Decay was scored binomially: 1 = none, 2 = decay. No determination was made to identify decay-causing organisms. Both mold and decay could be scored on the same fruit. Subjective firmness was rated: 1 = firm (no yield to moderately applied finger pressure (MAFP) ), 2 = fairly firm (moderate resistance to MAFP) and, 3 = flacid (no resistance to MAFP). Peel color was scored: 1 = 100% green, 2 = breaker (slight yellow blush), 3 = 3-75% yellow, 4 = trace of green on ribs, and 5 = 100% yellow/orange.

Objective firmness was measured by using an Instron Food Texture System (Instron, Inc., Canton, Mass.). The machine was calibrated to read 10 kg full scale, with a crosshead travel speed of 5 cm/min and set to measure peak load after penetrating the fruit surface 3 mm with a 11.2-mm-diameter cylinder. Objective color was determined by a colorimeter (Minolta, model CR 200, Osaka, Japan) set to read Hunter color 'L', 'a' and 'b' values. One measurement was made on 3 ribs each of 7 fruit from each sample box.

All values were averaged over the 3 replications and subjected to analysis of variance procedures (7).

## Results and Discussion

Nontreated fruit lost about 1% less weight than treated fruit after each storage duration regardless of temperature or duration of treatment (Table 1). The higher weight loss of treated fruit was probably due to elevated temperature and increased transpiration during exposure to the relatively high airflow rate in the test chamber. Subjective peel color scores indicate no difference between nontreated fruit and treated fruit after 1 and 2 weeks' storage at 4.4C, however, after subsequent holding for 3 days at 15.6°C (60°F), fruit treated at 49°C tended to show more green color in peel than fruit treated at other temperatures. This observation is also supported by the Hunter color 'a' value (green-red), tending to be more negative (more green) for fruit treated at 49°C compared to the 47° and 48°C treatments. In general, control fruit tended to retain green peel color similarly to those treated at 49°C. There was no observed practical difference among treatments in the degree of 'L' (lightness or darkness of color) or 'b' value (yellow-blue) or in comparison to the 'b' value for nontreated fruit (data not shown).

Stem-end breakdown developed during storage and consisted of severe necrotic, dark brown peel areas, usually shriveled and covered from 1 to 25% of the surface area (Fig. 1). This condition was always confined to the stem end of the fruit. Slight SEB was present on a few fruit at harvest. This condition developed on treated fruit, regardless of treatment temperature or time, during storage at 15.6°C (60°F), but there was no SEB on control fruit.

The margins of ribs on carambolas are vulnerable to bruising during the normal handling operations of picking, grading and packaging. They are also highly susceptible to preharvest wind-scarring, a condition that is readily

Fig. 1. Stem-end Breakdown on Carambola, cv. Arkin.

identifiable. Wind-scarring on rib margins was observed on most fruit, but this condition was not scored or included in the score for the condition discussed herein as "rib-browning". Rib-browning is crusty and brown necrotic tissue at the margins of ribs. Some fruit had slight symptoms of senescence or browning at the margins of ribs prior to treatment and storage. There was no significant statistical difference in degree of rib-browning among treatments. However, the authors observed that treated fruit had more severe symptoms of rib-browning than control fruit even though the data does not quantify this observation. Rib-browning increased during 15.6°C (60°F) storage. Both rib-browning and SEB severely downgraded fruit appearance and would likely limit consumer acceptance. Objective fruit firmness measurements taken at terminal inspections indicate, but do not significantly show, that nontreated fruit were less firm than treated fruit. Mean differences in taste scores were not analyzed statistically due to too few samples (degrees of freedom). However, flavor ratings decreased with increasing treatment temperature and time. A rating of less than 5 was considered unacceptable. Besides nontreated fruit, only fruit exposed to 47°C for 90 min were deemed acceptable in flavor.

The incidence of decay, mold growth on injured or necrotic tissue, and pitting (data not shown) were not affected by treatment. Decay was usually located at a site of injury, but the organism causing rot was not identified. During prolonged storage, superficial mold grew on necrotic tissue at sites of injury and at sites of severe SEB. Slight surface pitting developed only after 2 weeks of storage and pitting occurred on fruit of only 1 of the 3 harvests and tended to be more prevalent in treated than in nontreated fruit (data not shown). Finally, there was infrequent random scald (bronzing) development on the surface of some fruit. We could not associate the scaldlike condition with any treatment; it was just as likely to be present on treated as on nontreated fruit. We concluded this scaldlike condition was due to unknown preharvest causes.

There is definite downgrading in the condition of carambolas from the hot-air treatment at the temperatures and times used in this study. The retention of green peel, increased SEB, increased browning of rib margins, and a reduction of characteristic flavor are the dominant detrimental factors resulting from these treatments. The SEB and browning of rib margins correspond to increased moisture loss due to treatment. Moisture loss may occur more rapidly from the stem end of the fruit and/or at the margin of the ribs than from the main portion of the fruit. The airflow rate to which fruit were subjected during treatment may also influence the amount of moisture loss, especially tissue at the rib margins. Decreasing airflow rates during treatment may decrease SEB and rib-browning.

Increases in treatment temperature seemed to retard the depletion of peel green color more than increased treatment time. Reducing treatment temperature below 47°C, with some corresponding increase in treatment time, may provide an environment to achieve probit 9 mortality of CFF larvae and result in a more normal degreening of peel color. Carambolas are generally harvested with green peel, but a uniform yellow color is most desirable for marketing. If they would respond to degreening by ethylene like citrus and tomatoes and change quickly to a uniform acceptable yellow, then the problem of green retention would be eliminated.

From this investigation, we conclude that treatment temperatures above 47°C are not acceptable at the treatment durations of 90, 120 or 150 min. Treatment at 47°C for 90 to 120 min is probably near the T/T threahold for stress that carambolas can tolerate. Further investigations will be conducted during the 1990-91 season which will include lowering the treatment temperature and increasing treatment duration.

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# AUTOMATIC DENSITY MEASUREMENTS FOR QUALITY SORTING OF 'MARSH' GRAPEFRUIT

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*Abstract.* **A 2-lane automatic sizer was utilized to measure the density of 'Marsh' grapefruit. Tests were conducted throughout one season to compare laboratory measurements of mass, volume, and density with those obtained from the automatic sizer. The prototype sizer used a cup conveying system with load cells (mass) and a line scan camera (dimensional). Seasonal sampling of grapefruit indicated density levels ranging from 0.74 to 0.86 g/cm³. A test panel was also established to obtain a human's perception of fruit size relative to the physical measurements collected. A linear relationship was found between their classification and actual fruit diameter.**

Quality assessment of fresh fruits and vegetables by nondestructive techniques has been the objective of numerous postharvest engineering projects (1). A multitude of sensor techniques are now available: optical (spectral reflectance, light transmittance, delayed light emission), mechanical (firmness, quasistatic or dynamic, vibrational response, ultrasonic and sonic transmission or emission), dielectric and physical (x-ray attenuation surface roughness). This research project was directed toward real-time measurement of an inferential quality indicator, density, by means of an automated weighing and dimensional measuring system.

For citrus, relatively large changes in density are observed after freeze-damage occurs. The commercial packinghouse practice has been to install a fruit separator unit, based either on flotation in an oil and water emulsion or hydrodynamic separation (3). These liquid separation procedures have limited accuracy and reduce packingline capacity (5). Electronic sensors with computer control for weight sizing have been widely adopted in the United States for certain commodities such as apples. With the recent advances in solid state cameras for optical-based dimensional measurements, the weight and dimensional measurements required for density sorting can be achieved at acquisition rates necessary for commercial citrus packing. Typically, this rate is considered 5-10 fruit/sec/lane. Questions remain unanswered as to the required accuracy for density separation (2), resolution to detect quality differences as a function of variety, season, etc., and the correlation of density with fruit quality. Regarding the latter, it has been cited for oranges that specific gravity of the whole fruit was found to correlate with the pounds-solid (4).

In this paper, results will be discussed related to the following objectives:

1. Analyze the accuracy of weight and optical-based dimensional measurements for density separation of grapefruit.
2. Measure density variations for one citrus variety, 'Marsh' grapefruit, throughout one season.

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