Hot-Air Quarantine Treatment for Carambolas Infested with Caribbean Fruit Fly (Diptera: Tephritidae)

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ABSTRACT A single-stage quarantine treatment using air at 47 ± 0.2°C was developed to disinfest Florida-grown carambola, *Averrhoa carambola* L., 'Arkin' of eggs and larvae of Caribbean fruit fly, *Anastrepha suspensa* (Loew). Treating infested fruits for 30, 45, and 60 min with air at 47 ± 0.2°C at a mean air flow rate of 0.75 m^3/s reduced the number of surviving puparia that developed from treated eggs and larvae. Initial mean ± SEM fruit center pulp temperature was 22.8 ± 0.1°C. The temperatures were 38.9 ± 0.7, 43.3 ± 0.4, and 44.9 ± 0.4°C at 30, 45, and 60 min of heating respectively, when mortalities were 79.2, 98.5, and 100%. Probit analysis of the data estimated the mean fruit center pulp temperature needed to reach 99.9968% (Probit 9) mortality as 44°C (range, 42.4–44.8°C), which required a mean 64.8 min. A large-scale confirmatory test resulted in no survivors based on normal appearing puparia when 214,801 *A. suspensa* in 3,850 infested carambolas were heated with air at 47 ± 0.2°C at an average air flow rate of 0.75 m^3/s until the fruit center pulp temperature reached ≥45.5°C. The heating time required to reach ≥45.5°C ranged from 90 to 120 min. Initial mean relative humidity was 51%; it increased to ≈85% at 90 min, and remained there until the confirmatory test was completed.

KEY WORDS Insecta, Tephritidae, quarantine treatment, heated air

CARAMBOLA, *Averrhoa carambola* L., requires quarantine treatment after harvest for shipment from Florida to citrus-growing states such as Texas and California and the importing country of Japan. Treatment is required to disinfest carambola of Caribbean fruit fly, *Anastrepha suspensa* (Loew), immatures (Swanson & Baranowski 1972). Quarantine treatments developed to disinfest carambolas of Caribbean fruit fly immatures are cold-temperature storage (Gould & Sharp 1990), hot-water immersion (Hallman & Sharp 1990), and vapor heat (Hallman 1990). The former treatment requires 15 d of exposure and the latter treatments frequently cause unacceptable damage.

Herein, we report results of studies required by USDA on the efficacy of hot air as a quarantine treatment against Caribbean fruit fly eggs and larvae in Florida-grown carambolas.

Materials and Methods

'Arkin' carambolas (141.9 ± 2.2 g; range, 70.2–246.9 g) were provided by J. R. Brooks and Son, Inc., Homestead, Fla. The Caribbean fruit flies were reared on two larval diets. One colony had been reared for >190 generations on an agar-based diet (wheat germ substituted for defatted wheat germ) and another had been reared for >120 generations on a corncob-based diet (Burditt et al. 1974). Carambolas in commercial cartons without lids were placed on racks in an outdoor infestation cage (4 by 3 by 2.5 m) containing ≈200,000 Caribbean fruit flies. About 85% of the flies were from the colony reared on the agar diet; the remainder was from the colony reared on the corncob-based diet. Carambolas were exposed to flies for oviposition for 6–7 d, removed, manually wiped clean of surface debris, randomized to ensure similar infestation levels for treated and untreated carambolas, and either treated immediately or held in a room at 24 ± 1°C for 1 d and then treated to kill all stages. According to Lawrence (1979), at 26 ± 2°C, 60 ± 5% RH, and under a photoperiod of 14:10 (L:D), the egg stage lasts an average of 68.5 ± 2.1 h, whereas the first, second, and third instars last 1.8 ± 0.1, 1.7 ± 0.03, and 2.9 ± 0.7 d, respectively. When a larva is mature, the larval skin becomes a puparia that encloses the pupa. Herein, we use normal appearing puparia as the criterion for effectiveness of the treatment.

Treatment Box. Plywood (1.3 cm thick) was formed into a box (61 [length] by 44 [width] by 122 cm [height]) open at both ends and provided with a hinged door for access to load and remove fruits (Fig. 1). The box was placed upright inside the treatment area of the hot-air treatment device (Sharp et al. 1991). To ensure uniform heating, carambolas were put onto 10 expanded, flat,

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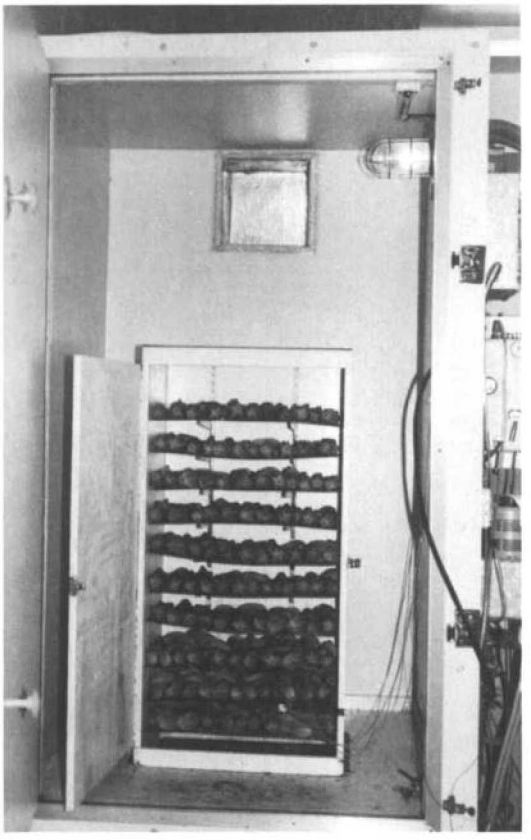

Fig. 1. Carambolas placed on screens supported by metal brackets fastened inside the treatment box.

metal screens (39 by 56 cm each) supported 10 cm above each other inside the box by standard adjustable metal shelf brackets.

Estimate of 99.9968% Mortality. Carambolas were weighed individually. For each 30-, 45-, and 60-min test, the three largest carambolas each had a no. 36-gauge thermocouple (type t, copper constantan) wire placed at a point in the pulp center and at the surface of the peel to measure temperature. For a 30-min test, 1,272 carambolas were treated and 983 untreated carambolas served as controls to estimate the number of treated larvae; for a 45-min test, 1,240 carambolas were treated and 977 carambolas served as controls; and for a 60-min test, 1,263 carambolas were treated and 974 carambolas served as controls. Treated and untreated carambolas were placed in separate cages over bins containing sand that was sifted two to three times each week for 4 wk to recover puparia (Burditt & von Windeguth 1975). The difference between the number of puparia recovered from the untreated group of carambolas and the number of puparia recovered from the treated group of carambolas was the estimate of the mortality at each time period. Because the number of fruits used in the controls differed from the numbers of fruits that were treated, the average number of larvae recovered per fruit from the controls was multiplied by the number of treated fruits to derive the adjusted number of treated immatures. The experiment was repeated five times each for 30, 45, and 60 min. Mean ± SEM air flow rate over the carambola surfaces was 0.75 ± 0.0 m^3/s (range, 0.7–0.8 m^3/s).

Table 1. Time–temperature mortality relationships for Caribbean fruit fly eggs and larvae in carambolas treated with air at 47 ± 0.2°C estimated by probit analysis

Time, min	Treated immature population	No. puparia recovered	% Mortality
30	5,036	3,989	79.2
45	5,092	5,016	98.5
60	4,910	4,910	100.0

Mortality (in probits) = 3.0644 ± 0.916; SE (intercept) = 0.1043; and SE (slope) = 0.0032. Probit 9 = 64.8 min; 95% FL = 62.7–67.2 min.

Data were analyzed with the PROBIT procedure (SAS Institute 1985). Probit 9 (99.9968%) mortality and 95% fiducial limits (FL) were estimated using formulae in Finney (1971).

Confirmation of 99.9968% Mortality Estimate. Carambolas were infested, weighed, and handled in a manner as described before. Infested carambolas (300–400) evenly placed on the 10 screens were treated for each of 12 replicates. In total, 3,850 carambolas were treated with air at 47 ± 0.2°C until the fruit center pulp temperatures measured ≥45.5°C, and 1,200 carambolas served as controls. Treated and untreated carambolas were held in separate rooms and placed in cages over bins of sand. Sand was sifted two to three times each week for 4 wk to recover all puparia.

Results and Discussion

Results of the mortality estimates for Caribbean fruit fly eggs and larvae in 3,775 treated carambolas were based on an estimated treated population of 15,038 immatures from 2,934 untreated and infested carambolas (Table 1). From the probit equation, the projected treatment time for 99.9968% mortality was 64.8 min (lower and upper FL were 62.7 and 67.2 min, respectively) when the mean fruit center pulp temperature was 44°C (range, 42.4–44.8°C). Eclosion of flies from puparia that had been collected from the untreated carambolas was 83 ± 7% indicating that mortality was not because of handling and other procedures. An estimated total of 214,801 Caribbean fruit fly immatures was killed with no survivors in 3,850 carambolas treated with air at 47 ± 0.2°C for 90–120 min until the fruit pulp center temperatures reached ≥45.5°C in the confirmatory test. We have 99.97% confidence that the true (unknown) survival rate due to the hot

Table 2. Mean temperature (°C) measured at the fruit pulp center and fruit surface of carambolas, dry-bulb temperature, and percent relative humidity during the confirmatory test

Time, min	Pulp center	Fruit surface	Dry bulb	Treatment area
Start	22.8 ± 0.3	23.4 ± 0.5	29.5 ± 1.0	50.6 ± 9.3
1–10	23.9 ± 0.2	26.9 ± 0.4	35.8 ± 1.3	55.2 ± 3.8
11–20	27.8 ± 0.4	32.1 ± 0.5	40.7 ± 1.4	54.7 ± 1.6
21–30	32.5 ± 0.5	36.7 ± 0.7	44.9 ± 1.3	57.1 ± 1.8
31–40	37.0 ± 0.6	40.4 ± 0.7	46.8 ± 0.7	63.3 ± 3.3
41–50	40.4 ± 0.5	42.6 ± 0.5	47.1 ± 0.4	71.2 ± 3.7
51–60	42.6 ± 0.5	43.9 ± 0.4	46.9 ± 0.3	77.1 ± 3.8
61–70	44.0 ± 0.4	44.8 ± 0.3	47.0 ± 0.0	80.4 ± 3.7
71–80	44.9 ± 0.3	45.3 ± 0.3	47.0 ± 0.0	83.7 ± 3.0
81–90	45.4 ± 0.3	45.6 ± 0.3	47.0 ± 0.0	84.7 ± 4.0
91–100	45.4 ± 0.3	45.6 ± 0.3	47.0 ± 0.0	83.2 ± 4.4
101–110	45.5 ± 0.2	45.6 ± 0.2	47.0 ± 0.0	83.3 ± 3.9
111–120	45.5 ± 0.2	45.6 ± 0.2	47.0 ± 0.0	83.2 ± 2.5

For each mean temperature, data were recorded every 12 s and averaged for each 10-min period.

air treatment is ≤32 per million (Couey & Chew 1986), which exceeded the 99.9968% security requirement (Baker 1939).

Mean temperatures of fruit pulp centers, peel surfaces, dry bulb and dew point, and relative humidity during treatments are presented in Table 2. Initial fruit pulp center temperature averaged 22.8°C and was 45.5°C at a mean of 110 min of heating (range, 90–120 min).

To ensure efficient heating with air, carambolas were arranged so that air circulated around the fruit surfaces. Carambolas were placed on the screens above each other so ≈3 cm of air space was provided between layers. Air movement around the carambolas was not impaired when 30–40 fruits (184.5 ± 3.4 g each) were placed on each screen of 10 arranged vertically in the treatment box. Efficient heating was not obtained when carambolas were loaded into heat resistant plastic boxes because fruits collapsed and air flow was stopped around fruit surfaces. When the movement of air around the carambolas was stopped, lethal temperatures of ≥45.5°C were not reached in the fruit pulp centers after 4 h of heating at 47 ± 0.2°C.

The market quality of uninfested 'Arkin' carambolas treated with hot air was studied by Miller et al. (1990). They evaluated the fruit for weight loss, pitting, scald, stem-end breakdown, browning at the margins of ribs, mechanical injury, decay, firmness, and peel color after the carambolas had been treated with air at 47, 48, and 49°C each for 90, 120, and 150 min and following cold storage at 4.4°C for 1–2 wk plus 3 d at 15.6°C. They reported that carambolas treated with air at 47°C for 90 or 120 min and then refrigerated were generally more acceptable to consumers than fruits treated at 48 or 49°C. Based on the limitation that carambolas will tolerate hot air at 47°C for up to 120 min and based on the estimate that fruit center pulp temperature ≈44°C provided 99.9968% mortality, we developed our treatment.

The hot-air treatment provides a new quarantine method that disinfests carambolas of Caribbean fruit fly immatures. Compared with other quarantine treatments for carambola such as a refrigeration treatment (Gould & Sharp 1990) that requires 15 d of exposure at 1.1°C, a hot-water immersion treatment (Hallman & Sharp 1990) that shortens shelf life and produces phytotoxicity, and a vapor-heat treatment (Hallman 1990) that occasionally produces phytotoxicity, the hot-air treatment is a relatively fast treatment and does not damage fruit quality. Also, it is a new treatment being developed successfully for Florida-grown grapefruit (Sharp 1989), mangoes, and avocado. Hot air is an approved quarantine treatment for Hawaiian-grown papayas for shipment to the mainland United States (APHIS 1989) based on work by Armstrong et al. (1989).

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