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

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ABSTRACT Immersing carambolas, *Averrhoa carambola* L., infested with larvae of *Anastrepha suspensa* (Loew) (Diptera: Tephritidae) in 46–46.4°C water for 45 min provided probit 9 security (99.9968% mortality) with >99% confidence based on a confirmatory test in which >190,000 larvae (mostly third instars) were killed. The treatment shortened the shelf life of the sweet cultivars 'Arkin,' 'Demak,' 'Butts Dwarf,' 'Key West,' 'Sri Kembayan,' 'Fwang Tung,' 'B-10,' 'Hart,' and 'Wheeler' by 15–40%. Tart 'Golden Star' and 'Star King' carambolas turned soft and were an off-yellow color compared with nontreated fruits within a few days after treatment. The sweet cultivar 'Hew 1' developed brown spots within 15 min after removal from the hot water.

KEY WORDS Insecta, *Anastrepha suspensa*, commodity treatment, quarantine security

CARAMBOLAS (STARFRUIT), *Averrhoa carambola* L., are hosts of the Caribbean fruit fly, *Anastrepha suspensa* (Loew), in Florida; as such, they should not be shipped to areas where this fly does not exist and could become established. Quarantine treatments of carambolas would permit them to be shipped to uninfested areas. A cold-temperature quarantine treatment has been developed whereby the fruit are kept at 1°C for 15 d (Gould & Sharp 1990). Immersing mangoes, papayas, and bananas in hot water has been used to kill immature tephritids in the fruits without prohibitively harming fruit quality (Armstrong 1982, Couey & Hayes 1986, Sharp et al. 1989).

Here we report use of hot-water immersion to kill immature stages of the Caribbean fruit fly in carambolas.

Materials and Methods

Carambolas used in the experiments were from the USDA, Subtropical Horticulture Research Station, Miami, or supplied by J. R. Brooks & Son, Homestead, Fla.

The Caribbean fruit flies used in the research were from two colonies. One had been reared for >190 generations on an agar-based diet (wheat germ substituted for defatted wheat germ) and another had been reared for >210 generations on a corncob-based diet (Burditt et al. 1974).

Market Quality of Treated Carambolas. Undamaged, freshly picked carambolas were immersed for 40–85 min in a water bath (Model 260, Precision Scientific, Chicago) or a hot-water immersion appliance (Sharp 1989) containing water at 43.3–43.7, 46–46.4, and 49–49.4°C to determine if hot-water immersion reduced fruit quality or shelf life. Treated and control (untreated) carambolas were stored at 13°C for 7–17 d and then held at 24°C to observe color, ripening, and rot.

Color of the treated and control carambolas was determined in the Judd-Hunter system (Francis 1980) by a colorimeter calibrated with a white #05-1456 standard (Pacific Scientific, Colorgard System, Model 05, Silver Spring, Md.). Color data were analyzed by analysis of variance (SAS Institute 1985).

Estimation of Probit 9. Carambolas ('Arkin,' 'Butts Dwarf,' and 'Demak') were placed in an outdoor infestation cage (4 by 3 by 2.5 m) containing approximately 200,000 Caribbean fruit flies. About 85% of the flies were from the colony reared on the agar diet; the remainder were from the colony reared on the corncob-based diet. The carambolas remained in the cage for 3–7 d and were placed in a holding room at 24°C for another 3–7 d to allow larvae to develop to the third instar. The infested carambolas were randomly separated into six groups (on one occasion only five groups were used). An untreated group used to estimate the number of fruit fly immatures present in the carambolas was placed in cages at 25°C over bins containing sand (Burditt & von Windeguth 1975). Emerging larvae dropped into the sand and pupated. The other five groups (four in one case) of carambolas were immersed in 46–46.4°C water for 5–25 min (on one occasion a 30-min immersion was used). The heated carambolas were placed in cages to recover surviving larvae in the same manner as were the untreated fruits. The difference between the number of larvae recovered from the untreated group of carambolas and the number of larvae recovered from each heated group of carambolas was the estimate of the number of larvae

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killed for each treatment. The experiment was done nine times with 'Arkin' carambolas and once each with 'Demak' and 'Butts Dwarf.'

Data were analyzed with the PROBIT procedure (SAS Institute 1988). Probit 9 (99.9968%) mortality and 95% fiducial limits (FL) were estimated using formulae in Finney (1971).

The rate at which the interior of an object heats is inversely proportional to its thickness. However, due to the five-pointed star shape of carambolas, it is not possible to measure fruit diameter directly without bisecting the carambola. A nondestructive estimate of the thickness of carambolas was needed.

A total of 147 'Arkin' carambolas (weight range, 68–255 g) were weighed and bisected, and the shortest distance from the surface to the geometric center of the fruit was measured. The data were analyzed with the General Linear Models Procedure (SAS Institute 1985, 183–260).

Confirmatory Tests. 'Arkin' carambolas were infested in the same manner as carambolas used to establish probit 9. Eleven to 16% of the carambolas from each lot of fruit were randomly selected as an untreated group to estimate the level of infestation. The remaining carambolas were immersed in water at 46.0–46.4°C for 45 min and allowed to cool in relatively still ambient air at 24°C before being placed in cages to recover surviving larvae.

After >100,000 larvae of the Caribbean fruit fly had been subjected to the heat treatment, the experiment was modified in that one-half of the heated carambolas was allowed to cool in 24°C ambient air (as before) and the other half was placed in circulating water at 13°C immediately after removal from the hot-water immersion to determine if rapid cooling might result in survival of some larvae. Rapid cooling of hot fruit is a recommended packing house procedure because it delays ripening and retards decay (Baird & Gaffney 1976). One hour later, the carambolas were placed in cages to recover surviving larvae.

Temperatures at the center of carambolas immersed in water at 46–46.4°C for 45 min were monitored with a datalogger (Model 2285B, John Fluke Manufacturing Company, Everett, Wash.). Copper-constantan thermocouples (#36 gauge) were inserted to the center of carambolas, and approximately 0.15 ml of hot melt glue (Thermogrip, Emhart Consumer Group, Reading, Pa.) was applied to the insertion hole. After the experiment, the carambolas were dissected to determine the exact location of the thermocouples.

Results and Discussion

Market Quality of Treated Carambolas. Tart carambolas, 'Golden Star' and 'Star King,' did not tolerate immersion in water at any temperature that was tested. (Tart carambolas contain approximately five times as much oxalic acid as sweet carambolas [Campbell & Koch 1988].) A few days after treatment, tart carambolas turned a dull yellow ($\bar{x}$ ± SEM, Lh = 47.0 ± 10.3; ah = −2.42 ± 1.46; bh = 14.7 ± 3.84 in the Judd-Hunter System; in contrast with the normal yellow of ripe fruit ($\bar{x}$ + SEM, Lh = 43.4 ± 9.20; ah = 0.42 ± 4.80; bh = 20.9 ± 4.88).

Also, heat-treated, tart carambolas became soft about the same time the color changed. Although soft and dull yellow, tart carambolas did not rot as fast as untreated tart carambolas; however, they were unmarketable. Therefore, hot-water immersion is not recommended as a quarantine treatment for tart carambolas. In any case, tart carambolas make up a minor and decreasing portion of the carambola market (C. A. Campbell, personal communication).

The sweet cultivar 'Hew 1' developed brown spots over the fruit surface about 15 min after removal from the hot water regardless of the temperature. When immersed in hot water, fruits of other sweet cultivars, 'Arkin,' 'Demak,' 'Key West,' 'Butts Dwarf,' 'Fwang Tung' 'B-10,' 'Hart,' 'Sri Kembayan,' and 'Wheeler,' were indistinguishable from the controls after immersion at 46–46.4°C for 40–55 min and during storage at 13°C for up to 17 d. However, shelf life for these cultivars when heated was reduced by 2–4 d after removal from cold storage compared with control fruit. At harvest, mature carambolas normally were marketable for about 6–12 d at 24°C. The immersion temperature of 49–49.4°C for 40 min reduced shelf life of sweet carambolas by 3–10 d compared with controls in two tests with 'Arkin,' 'Fwang Tung,' and 'Demak.' This reduction was considered excessive; no further experiments were conducted at 49°C.

Some 'Arkin' carambolas subjected to immersion in 43.3–43.7°C water for 85 min and 46–46.4°C water for 55 min appeared to be slightly advanced in color maturity (more yellow) during storage at 13°C for 14 d, but otherwise were in the same condition as the controls. Mean color ratings at maturity were Lh = 44.23, ah = −0.32, bh = 19.68 (control); Lh = 44.24, ah = 0.42, bh = 20.44 (43.3–43.7°C immersion), and Lh = 43.40, ah = −0.036, bh = 19.45 (46–46.4°C immersion). Differences were not significant (Lh: $F = 1.06$; df = 2; 18, $P = 0.37$, ah: $F = 2.50$; df = 2, 18, $P = 0.11$, bh: $F = 1.52$; df = 2, 18; $P = 0.25$). Shelf life of carambolas in both heat treatments was reduced about equally (2–3 d) compared with unheated controls. Therefore, the higher temperature (and shorter treatment time) of 46–46.4°C was used in tests to determine an estimated quarantine security treatment time for Caribbean fruit fly.

Additional information on market quality of carambolas subjected to hot-water immersion is given by Hallman (in press).

Estimation of Probit 9. Table 1 shows mean weights of carambolas used to estimate probit 9, estimated distances to the center of the carambolas, numbers of larvae recovered from the controls, and the estimated numbers of larvae killed for each hot water immersion time interval. Results of probit

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Table 1. Results of infestations of carambolas by *A. suspensa* and mortality after carambolas immersed in 46–46.4°C water

Cultivar and replicate	Mean wt/ carambola (g)	Estimated distance to center of fruit (mm)[a]	No. carambolas/ treatment	No. larvae recovered in control	Estimated no. larvae killed/treatment time (min)				
					5	10	15	20	25
Arkin 1	158.5	17.6	19	284	26	190	262	280	284
Arkin 2	144.3	17.3	20	57	29	46	54	57	57
Arkin 3	132.5	17.0	22	148	68	89	130	146	148
Arkin 4	102.4	16.3	20	680	0	201	528	665	—
Arkin 5	86.3	15.9	20	114	43	63	108	114	114
Arkin 6	83.7	15.9	88	585	245	480	569	585	585
Arkin 7	82.5	15.8	45	204	69	96	188	203	203
Arkin 8	79.0	15.7	30	203	120	150	189	202	203
Arkin 9	69.2	15.5	36	980	—	877	973	979	979[b]
Demak	108.7	16.4	46	157	56	99	155	157	157
Butts Dwarf	123.4	16.8	32	179	58	129	172	178	179

[a] Estimation of shortest depth (mm) to geometric center of carambola = 13.9 + 0.0234 weight of carambola (g). SE of slope = 0.0028. $r^2 = 0.40$.
[b] A 30-min treatment had 980 estimated larvae killed.

analyses of individual trials are presented in Table 2. In 6 of 11 cases, χ^2 probability was greater using linear time than the logarithm (base 10) of time. In 3 of 11 cases, the opposite was true.

In probit analyses of quarantine treatment studies with heat at fixed temperatures with variable time intervals, the logarithm (base 10) of time is used, although it may not always have been stated in the methodology (Hayes et al. 1984; Sharp 1985, 1986; Yokoyama & Miller 1987; Sharp et al. 1988, 1989). In fact, the authors could find no study involving heat quarantine treatments (giving data apt for reanalysis) where probit analysis using linear time was used to estimate probit 9. The results in Table 2 suggested that use of linear time might be more accurate and stable than the logarithm (base 10) of time.

Probit 9 estimates for all of the carambolas combined were 27.5 min for linear time (95% FL 26.9–28.1 min, F probability = 0.48; slope ± SE = 0.20 ± 0.0035) and 53.7 min for the logarithm (base 10) of time (95% FL 35.6–112.5 min, F probability < 0.001; slope ± SE = 4.6 ± 0.43).

Because heat quarantine treatments must kill insects within the largest fruit that will be shipped, probit analyses were performed on the data from 'Arkin' replicates 1–3. Estimated probit 9 times were 28.1 min for linear time (95% FL 27.6–29.8 min; F probability = 0.54; slope ± SE = 0.20 ± 0.0084) and 56.6 min for the logarithm of time (95% FL 37.1–118.8; F probability < 0.001; slope ± SE = 4.53 ± 0.41). A treatment time of 45 min at 46–46.4°C was chosen for the confirmatory test, because it was approximately midway between the linear time and logarithm of time probit 9 estimates obtained from the three replicates containing large 'Arkin', and it was intuitively thought that the linear estimate might be too small while the logarithmic estimate might be too long.

Confirmatory Test. An estimated 40,305 larvae of Caribbean fruit flies (mostly third instars) were killed in 980 infested 'Arkin' carambolas (mean weight 112.7 g, variance = 31.7 g) heated in water at 46–46.4°C for 45 min. In two subsequent tests, an estimated 48,508 larvae (mostly third instars) were killed in 600 treated 'Arkin' (mean weight 165.4 g, variance = 28.1 g) and an estimated 71,748 were killed in 900 'Arkin' (mean weight 174.4 g, variance = 28.9 g). There were no survivors in the three tests. The estimated total of 160,561 larvae of Caribbean fruit flies (mostly third instars) killed in treated carambolas (with no survivors) is equivalent to probit 9 security with 99% confidence (Couey & Chew 1986).

An additional 4,452 infested 'Arkin' carambolas (mean weight 148.5 g, variance = 24.4 g) were immersed in 46–46.4°C water for 45 min. Immediately after removal from the hot water, half of the carambolas were cooled in 13°C circulating water for 1 h and half were cooled in relatively still air at 24°C. An estimated 30,126 larvae (mostly third instars) were killed in each treatment with no survivors. However, 30,126 larvae killed with no survivors gives only 62% confidence that cooling the carambolas in 13°C water immediately after hot-water immersion met probit 9 security. Another 63,487 larvae would have to be killed with no survivors to conclude that cooling carambolas in 13°C water immediately after immersion in 46–46.4°C water for 45 min did not reduce mortality below probit 9 security with 95% confidence (see Couey & Chew 1986).

Adding 30,126 larvae killed after immersion in 46–46.4°C water for 45 min followed by ambient air cooling to the previous 160,561 estimated larvae killed yielded 190,687 killed with no survivors, which provided probit 9 security with 99.78% confidence.

Temperatures at the center of carambolas immersed in 46–46.4°C water for 45 min reached 45.1°C for large 'Arkin' carambolas (mean weight = 192.5 g, mean distance to center of fruit = 16.7 mm) and 46°C for small 'Arkin' (mean weight = 60.9 g, mean distance to center = 14.3 mm) when

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Table 2. Probit analyses of mortality of *A. suspensa* infesting carambolas immersed in 46–46.4°C water

Cultivar and replicate	Time (nontransformed)				Time ($\log_{10}$)			
	χ^2 probability	Slope ± SE	Probit 9 (min)	95% FL	χ^2 probability	Slope ± SE	Probit 9 (min)	95% FL
Arkin 1	<0.001	0.257 ± 0.040	24.8	19.6–39.8	0.81	5.89 ± 0.27	40.4	35.8–46.6
Arkin 2	0.93	0.172 ± 0.027	28.2	23.5–37.2	0.47	3.69 ± 0.50	62.8	40.4–132.8
Arkin 3	0.042	0.144 ± 0.020	34.4	26.8–53.6	<0.001	3.28 ± 0.80	103.9	35.4–>1,000
Arkin 4	<0.001	0.286 ± 0.030	26.3	22.6–33.5	0.044	8.12 ± 0.52	36.7	30.4–48.5
Arkin 5	<0.001	0.179 ± 0.035	30.8	22.5–65.3	<0.001	4.01 ± 1.10	74.7	27.4–>1,000
Arkin 6	0.76	0.219 ± 0.010	24.2	22.8–25.8	0.002	4.46 ± 0.39	45.2	30.3–91.0
Arkin 7	0.006	0.190 ± 0.035	28.7	21.2–57.2	<0.001	4.05 ± 1.07	67.2	25.8–>1,000
Arkin 8	0.089	0.137 ± 0.017	33.2	26.2–49.6	<0.001	3.03 ± 0.68	98.4	34.8–>1,000
Arkin 9	<0.001	0.190 ± 0.085	24.3	16.3–>1,000	0.065	6.03 ± 0.90	28.4	20.7–67.8
Demak	0.004	0.222 ± 0.038	25.3	19.2–45.5	<0.001	4.48 ± 1.05	52.0	23.0–>1,000
Butts Dwarf	0.88	0.214 ± 0.016	25.9	23.6–28.9	0.028	4.55 ± 0.50	50.2	30.9–134.6

the initial temperature inside the fruit was 24°C. Although small carambolas did heat faster than large carambolas, the difference was not reflected in higher mortality of Caribbean fruit fly in the smaller carambolas in this study (Table 2).

The fact that no larvae of an estimated 190,687 in carambolas survived immersion in water at 46–46.4°C for 45 min suggests that a shorter time interval might satisfy quarantine security and that the linear estimate of probit 9 was closer to the true value than the logarithmic (base 10) estimate. A shorter hot-water immersion time will save energy and time and might reduce damage to the carambolas.

References Cited

Armstrong, J. W. 1982. Development of hot-water immersion quarantine treatment for Hawaiian-grown 'Brazilian' bananas. J. Econ. Entomol. 75: 787–790.

Baird, C. D. & J. J. Gaffney. 1976. A numerical procedure for calculating heat transfer in bulk loads of fruits and vegetables. ASHRAE Trans. 82: 525–540.

Burditt, A. K., Jr., & D. L. von Windeguth. 1975. Semi-trailer fumigation of Florida grapefruit infested with larvae of the Caribbean fruit fly, *Anastrepha suspensa* (Loew). Proc. Fla. State Hort. Soc. 88: 318–323.

Burditt, A. K., Jr., D. L. von Windeguth & R. J. Knight, Jr. 1974. Induced infestation of fruit by the Caribbean fruit fly, *Anastrepha suspensa* (Loew). Proc. Fla. State Hortic. Soc. 87: 386–390.

Campbell, C. A. & K. E. Koch. 1988. Sugar/acid composition and development of sweet and tart carambola. J. Am. Soc. Hortic. Sci. 114: 455–457.

Couey, H. M. & V. Chew. 1986. Confidence limits and sample size in quarantine research. J. Econ. Entomol. 79: 887–890.

Couey, H. M. & C. F. Hayes. 1986. Quarantine procedure for Hawaiian papaya using fruit selection and a two-stage hot-water immersion. J. Econ. Entomol. 79: 1307–1314.

Finney, D. J. 1971. Probit analysis, 3rd. ed. Cambridge University Press, London.

Francis, F. J. 1980. Color quality evaluation of horticultural crops. HortScience 15: 14–15.

Gould, W. P. & J. L. Sharp. 1990. Cold-storage quarantine treatment for carambolas infested with the Caribbean fruit fly (Diptera: Tephritidae). J. Econ. Entomol. 83: 458–460.

Hallman, G. J. In press. Quality of carambolas subjected to hot water immersion quarantine treatment. Proc. Fla. State Hortic. Soc. 102.

Hayes, C. F., H. T. G. Chingon, F. A. Nitta & W. J. Wang. 1984. Temperature control as an alternative to ethylene dibromide for the control of fruit flies (Diptera: Tephritidae) in papaya. J. Econ. Entomol. 77: 683–686.

SAS Institute. 1985. SAS/STAT guide for personal computers, version 6 ed. SAS Institute, Cary, N.C.

1988. SAS Technical Report P-179, Additional SAS/STAT Procedures, Release 6.03. SAS Institute, Cary, N.C.

Sharp, J. L. 1985. Submersion of Florida grapefruit in heated water to kill stages of Caribbean fruit fly, *Anastrepha suspensa*. Proc. Fla. State Hortic. Soc. 98: 78–80.

1986. Hot-water treatment for control of *Anastrepha suspensa* (Diptera: Tephritidae) in mangos. J. Econ. Entomol. 79: 706–708.

1989. Hot-water immersion appliance for quarantine research. J. Econ. Entomol. 82: 189–192.

Sharp, J. L., M. T. Ouye, R. Thalman, W. Hart, S. Ingle & V. Chew. 1988. Submersion of Francis' mango in hot water as a quarantine treatment for the West Indian fruit fly and the Caribbean fruit fly (Diptera: Tephritidae). J. Econ. Entomol. 81: 1431–1436.

Sharp, J. L., M. T. Ouye, W. Hart, S. Ingle, G. Hallman, W. Gould & V. Chew. 1989. Immersion of Florida mangos in hot water as a quarantine treatment for Caribbean fruit fly (Diptera: Tephritidae). J. Econ. Entomol. 82: 186–188.

Yokoyama, V. Y. & G. T. Miller. 1987. High temperature for control of Oriental fruit moth (Lepidoptera: Tortricidae) in stone fruits. J. Econ. Entomol. 80: 641–645.

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