Concomitant Decay Reductions when Mangoes Are Treated with Heat to Control Infestations of Caribbean Fruit Flies

RAYMOND G. McGUIRE, Agricultural Research Service, U.S. Department of Agriculture, Subtropical Horticulture Research Station, 13601 Old Cutler Road, Miami, FL 33158

ABSTRACT

McGuire, R. G. 1991. Concomitant decay reductions when mangoes are treated with heat to control infestations of Caribbean fruit flies. Plant Dis. 75:946-949.

Four heat treatments for quarantine control of Caribbean fruit flies (*Anastrepha suspensa*) in mango (*Mangifera indica*) did not affect fruit quality but variably controlled two postharvest diseases. Immersion of fruit in water at a constant temperature of 46 C for 90–115 min significantly reduced anthracnose (*Colletotrichum gloeosporioides*) on three cultivars by 60–87%. Stem end rot (*Diplodia natalensis*) also was reduced 61–88% by this treatment. Treatment by forced air at 46 C for 195 min or at 48 C for 150 min reduced anthracnose on two cultivars, but an immersion for 150 min in which the water temperature gradually rose to 48 C, following a gradient identical to that created by forced air treatment, had no effect on disease severity. Although all heat treatments led to increased weight loss during 2 wk of storage, fruit treated by gradient hot water immersion were least affected. Hot air treatment and gradient hot water immersion slightly accelerated the softening of fruit, and all heat treatments hastened the development of yellow pigmentation. Immersion in water at a constant temperature of 46 C is recommended for the disinfestation of mangoes because it most effectively controls disease without reducing market quality. Forced air treatment at 48 C, however, is tolerated by the fruit and is more effective than forced air at 46 C for disease control.

Within the continental United States, the mango (*Mangifera indica* L.) can be commercially grown only in the subtropical areas of southern Florida. This production is insufficient to meet national demands, however, and mangoes are imported from nations in the Caribbean Basin. Four species of fruit flies interfere with this commerce. The Caribbean fruit fly (*Anastrepha suspensa* (Loew)) is endemic in South Florida and the Caribbean Islands, and the West Indian fruit fly (*A. obliqua* (Macquart)) is common in the Greater and Lesser Antilles, Mexico, and Central and South America (4). The Mexican and the Mediterranean fruit flies (*A. ludens* Loew and *Ceratitis capitata* (Wiedemann), respectively) are also found in Mexico (4).

Quarantine regulations have been developed by several countries and states to prevent the importation of fruit flies in plant products. Treatment with ethylene dibromide, effective for many years against fruit fly infestations (13,19), is no longer registered for use in the United States, Japan, and other countries. The U.S. Food and Drug Administration has, however, approved the use of ionizing radiation for the control of insect pests infesting fresh fruits (28). γ-Irradiation of mangoes is effective for control of *A. suspensa* (29), and the diseases anthracnose and stem end rot, caused by *Colletotrichum gloeosporioides* (Penz.) Penz. & Sacc. in Penz. and *Diplodia natalensis* Pole-Evans, respectively, can also be reduced (26). Radiation intensities from 750 to 1,500 Gy that significantly reduce disease may produce scalding and internal breakdown, however. This damage is reduced when 200 Gy is used after a 3-min immersion of the mangoes in water at 53 C (25).

Heat alone has been used for controlling postharvest diseases of fruit (2). It was first reported for the control of anthracnose decay of mango in 1962 (12); the common treatment was an immersion for 5 min at 55 C (21). Eventually, however, a range of treatment temperatures and times was proposed because of cultivar differences in fruit sensitivity to heat (6,8,10,11,23,25). The only postharvest treatment used commercially for decay control on mango in South Florida is a drench in water at 53 C for 3–5 min.

Larvae and eggs of *A. suspensa* and *A. obliqua* are effectively killed when infested mangoes are immersed for 1 hr in water at 46.1 C (16,22). This treatment is currently accepted by the U.S. Animal and Plant Health Inspection Service (APHIS) (27). Treatment with vapor heat, in which saturated water vapor is circulated among the fruit (1), has also been approved by APHIS for eradication of *A. ludens* from mangoes, but the fruit must be exposed to the heat for 6 hr after pulp temperatures reach 43.3 C (27). Another alternative is the use of forced hot air (17). Like vapor heat, treatment with hot air raises the temperature of fruit slowly, but the dew point temperature is maintained below the level at which surface condensation would form. Tests are underway to develop this technique as a quarantine treatment for mangoes.

In this study, phytotoxicity and the reduction of decay that results from treatment of mangoes by hot air or constant temperature hot water are compared with that of another procedure. With this third technique, the water temperature in a bath follows a program of gradual heating that simulates the heat development within the hot air chamber. Gradual heating in water can reduce the phytotoxicity in grapefruit associated with constant temperature hot water immersions (R. G. McGuire, *unpublished*).

MATERIALS AND METHODS

Fruit of the mango cultivars Tommy Atkins, Keitt, and Palmer were obtained from June through September 1990, graded but otherwise unprocessed, from a packinghouse in South Florida. In each of four replications, fruit were initially washed and separated into five treatments, including forced air at 46 C, forced air at 48 C, water immersion at a constant 46 C, water immersion with a gradual temperature increase to 48 C, and control fruit that were not heated. Each treatment contained 90 fruit with an average weight of 511 g for Tommy Atkins in test I, 523 g for Tommy Atkins

Accepted for publication 18 March 1991 (submitted for electronic processing).

in test II, 640 g for Keitt, and 565 g for Palmer. All treatments were completed within 3 days during which the fruit were stored at 13 C until their removal to 22 C 24 hr before treatment. Individual fruit were weighed immediately before treatment.

For treatment with forced hot air, 30 fruit were placed into each of three plastic bins of dimensions 60 × 40 × 31 cm with bottoms of steel grating. The bins were stacked in the hot air chamber, and air at either 46 or 48 C (from 58 to 90% relative humidity [RH]) was forced through the column of fruit at an average 0.4 m^3 per second for 3.25 or 2.5 hr, respectively. The heating of the chamber was controlled by a computer program using the temperatures in the outer 1 mm of three fruit at the base of the column as input. These temperatures were monitored every 60 s with copper constantan thermocouples (17). In the treatment at 48 C, data from another group of thermocouples, which monitored the chamber temperature, were collected for a computer file that was subsequently used in setting the temperatures of a group of six 10-L water baths. A computer program to control the baths by following a preset variable rate of temperature increase was written by A. C. Rodriguez, L. Kneeburg, and J. Gaffney (USDA-ARS, Gainesville, FL) and modified by G. Millard (USDA-ARS, Miami, FL).

Temperatures of 15 fruit per treatment were monitored as described previously at a site near the surface of the central seed (17). All heat treatments were continued for 25 min after core temperatures of the fruit reached 44 C. Fruit in the air treatment at 48 C and the gradient hot water immersion reached 44 C after approximately 125 min for a total treatment time of 2.5 hr. The air treatment at 46 C required 3.25 hr. A hot water immersion appliance was used for the treatment of fruit in water at the constant temperature of 46 C (18). Because of size differences, fruit of Tommy Atkins, Keitt, and Palmer were immersed in the hot water for 90, 105, and 115 min, respectively. Control fruit were held in water at 24 C for a time equal to that of the hot water immersions. The treated fruit were stored at 13 C for 7 days then ripened for 7 days at 24 C.

The ripened fruit were evaluated for weight loss and rated for injury and decay with the visual acuity scale of Horsfall and Barratt (5). Firmness of each fruit was measured at two sites with an Instron model 1011 fitted with a compression anvil of 12 mm diameter; resistance to pressure was recorded after a compression of 3 mm and averaged per fruit. Color evaluations were made at four sites around the equator of each fruit with a Minolta CR-200 chroma meter recording in the Hunter "*L a b*" system (3). As recommended by Little (7), hue angle (arctangent b/a) and saturation index $[(a^2 + b^2)^{1/2}]$ were calculated, then average values were determined for individual fruit for subsequent statistical analyses.

The data were analyzed with an analysis of variance and means separation (Ryan-Einot-Gabriel-Welsch multiple F test) in SAS (14). Except for hue angle, which was converted from a scale of −90 to 90° into one of 0 to 180° that is more appropriate for mangoes, data were analyzed directly. Horsfall-Barratt rating values, after analysis, were converted to percent decay.

RESULTS

At a setting of 48 C, air within the hot air chamber averaged 47.8 ± 0.7 C after an initial 30-min temperature increase (Fig. 1). Water temperatures in the gradient water baths followed the identical profile, and the rate of temperature increase within the fruit was basically the same for treatment by both techniques. This rate was slower than that for fruit treated in water at a constant 46 C (46.1 ± 0.3 C). Averaged across all three cultivars, pulp temperatures reached 44.9 ± 0.3, 45.0 ± 1.0, and 44.5 ± 1.1 C after treatment by constant temperature water immersion, forced air, and gradient water immersion, respectively. Peel temperatures approximated the temperatures of each heating regime.

On all cultivars and with all treatments, the severity of anthracnose was greater than that of stem end rot. Although anthracnose lesions began to appear during cold storage, the severity of the disease increased as the fruit ripened. On fruit not treated with heat, anthracnose decay averaged 2–42.5% (Table 1). In none of the cultivars did the gradient hot water immersion significantly reduce anthracnose below the level found in the control. Hot air treatment significantly reduced anthracnose on two cultivars, although at 48 C, this was only a 43% reduction for Keitt and 45% for Palmer. Immersion in water at a constant temperature of 46 C gave the best control of anthracnose for each cultivar: 60–65% for Tommy Atkins, 79% for Keitt, and 87% for Palmer.

Stem end rot also was controlled most

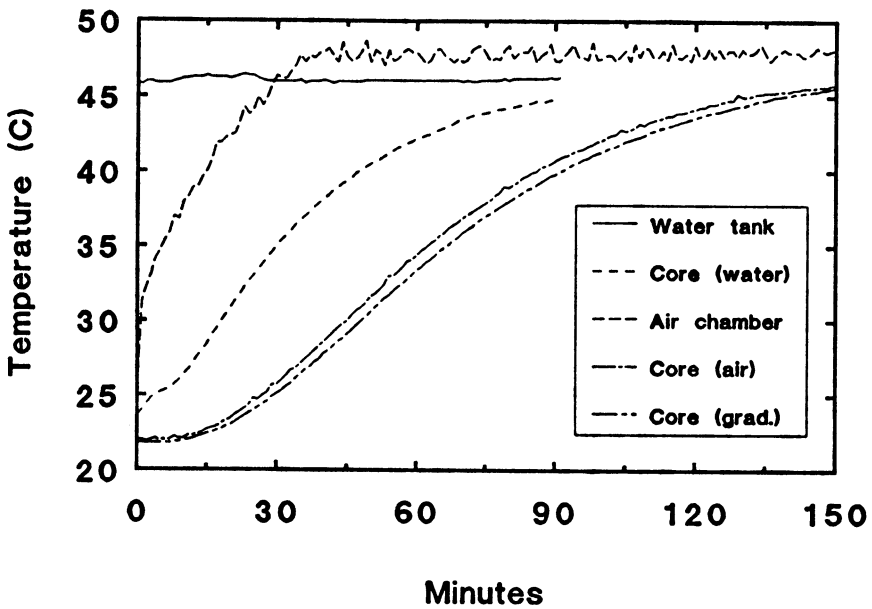

Fig. 1. Comparison of heat development within mango fruit, cv. Tommy Atkins (average weight 511 g), during treatment by immersion in water at a constant 46 C and by forced air and gradient water immersion to 48 C.

Table 1. Percent surface area with anthracnose decay[x] on mango fruits after heat treatments

Treatment[y]	Cultivar			
	Tommy Atkins I	Tommy Atkins II	Keitt	Palmer
Water 24 C constant	2.1 a[z]	18.8 a	42.5 a	9.7 a
Water 48 C gradient	2.3 a	23.5 a	35.0 ab	9.1 a
Air 46 C gradient	2.2 a	19.2 a	29.1 b	6.2 b
Air 48 C gradient	1.9 a	18.8 a	24.2 c	5.3 b
Water 46 C constant	0.8 b	6.5 b	9.0 d	1.2 c

[x] Conversion from Horsfall-Barratt rating scale.

[y] Constant temperature water immersions for 90–115 min (based on weight of fruit), air at 46 C for 195 min, or air and gradient water immersion at 48 C for 150 min. Means of 90 fruit.

[z] Within columns, numbers followed by the same letter are not significantly different (P = 0.05, Ryan-Einot-Gabriel-Welsch multiple F test).

effectively by immersion in water at 46 C, although differences between treatments were less significant (Table 2). This disease did not develop in cold storage but appeared only during fruit ripening. The overall level of disease was low and variable, from 0.9 to 7.7% in control fruit. With the quantity of fruit tested, statistical differences among heat treatments in stem end rot were less significant than differences in anthracnose.

No injury developed on fruit of any cultivar as a result of these heat treatments. Except for firmness, there were no quality differences among the fruit of the various heat treatments, although heat-treated fruit were, in most cases, significantly different from those not treated with heat (Table 3). Heat-treated fruit lost significantly more weight than fruit not treated with heat. However, in the two tests with Tommy Atkins (*data not shown*), gradient heating in water produced significantly less weight loss than the other methods of heat treatment. Otherwise, statistical interactions between cultivars and treatments were not evident.

Fruit treated by immersion in water at a constant 46 C were not significantly more firm or soft than control fruit (Table 3). In contrast, hot air treatment and gradient hot water immersion accelerated fruit softening during storage. Hot air treatment at the two temperatures did not give significantly different results. With hue angles scaled from 0° (red) to 90° (yellow) to 180° (green), color differences among heat treatments were insignificant. All heat treatments, however, caused a slight but significant increase in yellow pigmentation over control fruit. The intensity of color also varied only slightly among the heat-treated fruit and the controls but, when compared with control fruit, was significantly greater after water and air treatments at 48 C.

DISCUSSION

An increasing market for tropical fruit in the United States has led to expanded importation but has increased the threat of introductions of new agricultural pests. Quarantines are increasingly important, and heat has become one of the few forms of treatment still approved. The phytotoxicity of heat treatments is of major concern. New techniques for heating fruit seek to reduce the damage attributable to heat disinfestation.

The mandated probit nine level of fly control of 3.2 survivors per 100,000 treated insects is achieved only when the core of the fruit reaches a sufficiently high temperature. However, when the center is 44 C, the outer tissue can become several degrees warmer, especially when shorter treatment times are used that require steeper heat gradients. Twenty-five minutes at 44 C is required to kill eggs of *A. suspensa*, the most resistant stage (J. Moss, *personal communication*). Once 44 C is achieved at the core, the additional treatment time further stresses the outer tissues. Heat stress can produce surface scalding of fruit and metabolic deterioration, which impairs ripening.

The heat required to kill eggs and larvae of fruit flies is too extreme for many types of fruit (2). Although heat treatment is tolerated by grapefruit, scald may be especially severe when fruit are immersed in water at a constant temperature of 46 C (9,15,20,24). Hot air treatment at 48 C appears promising for this fruit (17) because its surface is heated more slowly, and scalding may be avoided. Gradient hot water immersion at a temperature and time equal to that of hot air can also avoid phytotoxicity in grapefruit (R. G. McGuire, *unpublished*).

Mangoes tolerated immersion in water at 46 C and may generally be more tolerant to heat than are grapefruit. Although phytotoxicity was not a problem in any of the tests reported here, differences in the efficacies of the treatments for disease control were great. Hot water immersion most successfully reduced anthracnose and stem end rot without affecting ripening significantly. Because this method of fly disinfestation is quicker and does not require the sophisticated electronic equipment of hot air treatment, it may still be the treatment of choice for mangoes. Hot air treatment continues to gain favor, however, and this work demonstrates that treatment at 48 C is tolerated well by mangoes, requires a correspondingly shorter time than treatment at 46 C, and better controls disease.

Table 2. Percent surface area decayed[x] from stem end rot of mango fruits after heat treatments

Treatment[y]	Cultivar			
	Tommy Atkins I	Tommy Atkins II	Keitt	Palmer
Water 24 C constant	0.9 b[z]	5.7 b	7.7 a	2.4 a
Water 48 C gradient	1.0 b	8.4 ab	2.5 bc	0.8 ab
Air 46 C gradient	2.7 a	9.1 a	2.8 bc	0.7 ab
Air 48 C gradient	1.2 b	10.7 a	8.5 ab	0.3 b
Water 46 C constant	0.2 b	1.5 c	1.0 c	0.9 ab

[x] Conversion from Horsfall-Barratt rating scale.
[y] Constant temperature water immersions for 90–115 min (based on weight of fruit), air at 46 C for 195 min, or air and gradient water immersion at 48 C for 150 min. Means of 90 fruit.
[z] Within columns, numbers followed by the same letter are not significantly different ($P = 0.05$, Ryan-Einot-Gabriel-Welsch multiple F test).

Table 3. Quality characteristics of mango fruits after heat treatments

Treatment[w]	Weight loss (%)	Firmness[x]	Color[y]	
			Hue	Intensity
Water 24 C constant	5.7 b[z]	15.21 a	92.67 a	41.36 b
Water 46 C constant	7.4 a	15.66 a	89.70 b	42.64 ab
Water 48 C gradient	6.5 ab	13.52 b	89.10 b	44.48 a
Air 48 C gradient	7.0 a	13.15 b	89.25 b	43.53 a
Air 46 C gradient	7.3 a	13.91 b	89.85 b	43.35 ab

[w] Constant temperature water immersions for 90–115 min (based on weight of fruit), air at 46 C for 195 min, or air and gradient water immersion at 48 C for 150 min. Means of four trials (360 fruit).
[x] Instron measurement in newtons; resistance to pressure of 3 mm by 12-mm-diameter anvil. Overripe < 4, underripe > 24.
[y] Values derived from measurement using Minolta VCR-200 chroma meter. Hue angle: 0° = red, 90° = yellow, 180° = green.
[z] Within columns, numbers followed by the same letter are not significantly different ($P = 0.05$, Ryan-Einot-Gabriel-Welsch multiple F test).

ACKNOWLEDGMENTS

I thank W. F. Reeder for his technical assistance and C. Campbell of J. R. Brooks and Sons, Inc., who provided the fruit used in these experiments.

LITERATURE CITED

1. Balock, J. W., and Starr, D. F. 1946. Mortality of the Mexican fruitfly in mangoes treated by the vapor-heat process. J. Econ. Entomol. 38:646-651.
2. Couey, H. M. 1989. Heat treatment for control of postharvest diseases and insect pests of fruits. HortScience 24:198-202.
3. Francis, F. J. 1980. Color quality evaluation of horticultural crops. HortScience 15:58-59.
4. Harris, E. J. 1989. Pest status: Hawaiian islands and North America. Pages 73-80 in: Fruit Flies: Their Biology, Natural Enemies, and Control. Vol. 3A. A. S. Robinson and G. Hooper, eds. Elsevier Science Publishers, Amsterdam.
5. Horsfall, J. G., and Barratt, R. W. 1945. An improved grading system for measuring plant disease. (Abstr.) Phytopathology 35:655.
6. Johnson, G. I., Sangchote, S., and Cooke, A. W. 1990. Control of stem end rot (*Dothiorella dominicana*) and other postharvest diseases of mangoes (cv. Kensington Pride) during short- and long-term storage. Trop. Agric. Guildford U.K. 67:183-187.
7. Little, A. C. 1975. Off on a tangent. J. Food Sci. 40:410-411.
8. McMillan, R. T., Jr., Spalding, D. H., and Reeder, W. F. 1987. Effectiveness of various postharvest treatments for mango decay control. Proc. Fla. State Hortic. Soc. 100:7-9.
9. Miller, W. R., McDonald, R. E., Hatton, T. T.,

and Ismail, M. 1988. Phytotoxicity to grapefruit exposed to hot water immersion treatment. Proc. Fla. State Hortic. Soc. 101:192-195.
10. Murthy, S. K., and Rao, K. P. G. 1983. Post harvest control of spoilage in mango (*Mangifera indica* L.) with hot water and fungicides. J. Food Sci. Technol. 20:74-77.
11. Pathak, V. N., and Shekhawat, P. S. 1976. Efficacy of some fungicides and hot water in control of anthracnose and Aspergillus rot of mango fruit. Indian Phytopathol. 29:315-317.
12. Pennock, W., and Maldonaldo, G. 1962. Hot water treatment of mango fruits to reduce anthracnose decay. Univ. P. R. Agric. Exp. Stn. J. 46:272-283.
13. Richardson, H. H. 1952. Ethylene dibromide fumigation of mangoes and almendras infested with *Anastrepha* fruit flies. J. Econ. Entomol. 45:541-545.
14. SAS Institute Inc. 1985. SAS User's Guide: Statistics. Version 5 edition. SAS Institute Inc., Cary, NC. 956 pp.
15. 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.
16. Sharp, J. L. 1988. Status of hot water immersion quarantine treatment for Tephritidae immatures in mangoes. Proc. Fla. State Hortic. Soc. 101:195-197.
17. Sharp, J. L. 1989. Preliminary investigation using hot air to disinfest grapefruit of Caribbean fruit fly immatures. Proc. Fla. State Hortic. Soc. 102:157-159.
18. Sharp, J. L. 1989. Hot-water immersion appliance for quarantine research. J. Econ. Entomol. 82:189-192.
19. Shaw, J. G., and Lopez, F. D. 1954. Ethylene dibromide as a fumigant for mangoes infested with the Mexican fruit fly. J. Econ. Entomol. 47:891-893.
20. Smoot, J. J., and Melvin, C. F. 1965. Reduction of citrus decay by hot-water treatment. Plant Dis. Rep. 49:463-476.
21. Smoot, J. J., and Segall, R. H. 1963. Hot water as a postharvest control of mango anthracnose. Plant Dis. Rep. 47:739-742.
22. Spalding, D. H., King, J. R., and Sharp, J. L. 1988. Quality and decay of mangos treated with hot water for quarantine control of fruit fly. Trop. Sci. 28:95-101.
23. Spalding, D. H., and Reeder, W. F. 1972. Postharvest disorders of mangos as affected by fungicides and heat treatments. Plant Dis. Rep. 56:751-753.
24. Spalding D. H., and Reeder, W. F. 1985. Effect of hot water and gamma radiation on postharvest decay of grapefruit. Proc. Fla. State Hortic. Soc. 98:207-208.
25. Spalding, D. H., and Reeder, W. F. 1986. Decay and acceptability of mangos treated with combinations of hot water, imazalil, and γ radiation. Plant Dis. 70:1149-1151.
26. Spalding, D. H., and von Windeguth, D. L. 1988. Quality and decay of irradiated mangos. HortScience 23:187-189.
27. U. S. Department of Agriculture. 1985. T102 and T106 in: Plant protection and quarantine treatment manual. USDA Anim. Plant Health Insp. Serv.
28. U. S. Department of Health and Human Services. 1986. Irradiation in the production, processing, and handling of food. Fed. Regist. 51:1337-1339.
29. von Windeguth, D. L. 1986. Gamma irradiation as a quarantine treatment for Caribbean fruit fly infested mangos. Proc. Fla. State Hortic. Soc. 99:131-134.