Quality Changes During Storage and Ripening of 'Tommy Atkins' Mangos Treated with Heated Forced Air

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Abstract. Freshly harvested mangos (*Mangifera indica* L.) treated with forced air at 51.5C for 125 minutes then stored for 1, 2, or 3 weeks at 12C, followed by 21C until soft-ripe, were compared with nontreated fruit for quality changes. Treated fruit lost 1.0% more fresh weight than nontreated fruit and developed trace amounts of peel pitting. Total soluble solids concentrations for treated and nontreated fruit were similar ($\approx 13\%$), as was peel color at the soft-ripe stage. Treated fruit generally reached the soft-ripe stage ≈ 1 day earlier than nontreated fruit regardless of storage duration and had a lower incidence and severity of stem-end rot and anthracnose. The trace of pitting on treated fruit likely will not influence consumer acceptance.

Florida-grown mangos must be subjected to a quarantine treatment for Caribbean fruit fly (CFF) larvae [*Anastrepha suspensa* (Loew)] before shipment to certain domestic or export markets [Animal and Plant Health Inspection Serv. (APHIS), 1986]. Following the ban of ethylene dibromide as a post-harvest fumigant by the U.S. Environmental Protection Agency in 1984 (Federal Register, 1984), a hot-water immersion quarantine treatment for interstate trade of Florida-grown mangos (Sharp and Spalding, 1984) and importation of Haitian-grown 'Francis' (Sharp et al., 1988) and Mexican-grown mangos (Sharp et al., 1989a, 1989b) was approved (APHIS, 1986).

Alternative quarantine treatments using low temperature, irradiation, vapor heat, or high-temperature air are accepted quarantine methods for other fresh fruits (APHIS, 1986). However, low temperatures cannot be used for mangos because they develop chilling injury. Vapor heat (treatment with condensation on fruit) effectively disinfested the mangos of the melon fly (*Dacus cucurbitae* Coquillett) without injuring the fruit (Sunagawa et al., 1987). Vapor-heat treatments of

Florida mangos at 46C for 3 h effectively killed CFF larvae (G.J. Hallman, personal communication).

Armstrong et al. (1989) developed a high-temperature forced-air quarantine treatment that was effective against tephritid fruit flies in papayas without causing detrimental effects to fruit quality. The forced-air treatment was less injurious to papayas than the double-stage water immersion or quick run-up vapor heat disinfestation quarantine treatments (Armstrong et al., 1989). High-temperature forced air (51.7C for 125 min) effectively disinfested 'Tommy Atkins' and 'Keitt' mangos of CFF (J.L.S., unpublished data) and 'Marsh' grapefruit (*Citrus paradisi* Macf.) without adversely affecting fruit condition (Sharp, 1989).

The purpose of our study was to determine the effects of a high-temperature forced-air treatment, without free moisture on fruit, on quality of 'Tommy Atkins' mangos following subsequent storage and ripening.

'Tommy Atkins' mangos were harvested during June and July 1989 from commercial groves located near Homestead, Fla., and brought to the U.S. Dept. of Agriculture Subtropical Horticultural Research Laboratory in Miami. The mangos were graded for maturity, color, and size; misshapen or bruised fruits were removed. All fruit used in our three separate tests (replications) were mature, hard, and green with a slight yellow blush. Fruit weights were recorded before and after treatment, and after storage and ripening. One-half of each lot was treated with high-temperature forced air, and the other half was not treated (control fruit). The forced-air treatment facility was designed to main-

tain the desired treatment environment (temperature/relative humidity/air velocity) and to prevent the accumulation of free water on the fruit surface during treatment (Gaffney and Armstrong, 1990). The treatment consisted of exposing mangos to air at a maximum of 51.5C (± 0.2 C) for 125 min at an airflow of $\approx 0.4 \text{ m}^3 \cdot \text{s}^{-1}$. During treatment, incoming air temperature was increased to maintain a 2-degree differential between the incoming air and the fruit surface to prevent condensation. Treatment time continued until the fruit core temperature had reached and maintained 43.5C for 20 min. Total treatment time was 125 min for each of the three tests. Copper/constantan thermocouples (36 gauge; 0.127 mm in diameter) were inserted 1 mm below the peel surface of six fruit and adjacent to the seed in six fruit to monitor fruit surface and near-core temperatures, respectively. Temperatures were recorded by computer and used to control air temperatures entering the test chamber. Mangos used for monitoring pulp temperatures were placed among fruit located at the end opposite from incoming heated air to ensure that all fruit reached the target temperature. After treatment, fruit were placed at ambient room temperature (≈ 25 C) and, when at equilibrium, were washed with tap water on a roller brush bed and dried with warm air. Mangos were placed into full-telescoping, fiberboard boxes, eight fruit per box, in a single layer. Packaged mangos were taken to the U.S. Horticultural Research Laboratory, Orlando, Fla., within 5 h after treatment, initially inspected, and stored at 12C and $90\% \pm 5\%$ relative humidity (RH). Twenty-four treated and 24 nontreated mangos were removed, inspected, and evaluated after 1, 2, or 3 weeks of 12C storage. After inspection, the fruit were ripened at 21C. Fruit were observed daily during ripening, and those mangos that had reached the soft-ripe stage were given a final evaluation.

Mangos were weighed during each inspection and subjectively evaluated for peel color, peel discoloration, surface pitting, firmness, decay, and freshness of appearance.

Peel color was subjectively scored on a scale of 1 to 5, where 1 = 100% green (no ground color, i.e., yellow or red), 2 = 1% to 25%, 3 = 26% to 50%, 4 = 51% to 75%, and 5 = 76% to 100% ground color. Peel discoloration (scald) and pitting were scored on a scale of 1 to 5, where 1 = none, 2 = less than 2%, 3 = 3% to 10%, 4 = 11% to 25%, and 5 = greater than 25% of surface area. Firmness was subjectively rated on a scale of 1 to 5, where 1 = overripe [very soft, very slight resistance to moderately applied finger pressure (MAFP)], 2 = soft-ripe (eating stage, slight resistance to MAFP), 3 = fairly soft (moderate yield to MAFP), 4 = fairly hard (slight yield to MAFP), and 5 = hard (no yield to MAFP). External appearance (freshness) of fruit was rated on a scale of 1 to 3, where 1 = fresh (smooth surface, good color with gloss), 2 = fairly fresh (smooth surface, slightly dull color and moderate gloss), and 3 = old (rough

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Table 1. Fruit quality characteristics of 'Tommy Atkins' mangos after treatment with 51.5C air for 125 min and stored for 1, 2, or 3 weeks at 12C, then held at 21C until soft-ripe.

Storage duration/ treatment	Wt loss (%)	Pit ^z rating	SER rating	ANTH rating	Fruit eliminated (%) due to		
					SER	ANTH	Decay ^y
Initial							
Control	0.0	1.0 a ^x	1.0 a	1.0 a	0.0	0.5 a	0.0
Heated	0.0	1.1 b	1.0 a	1.1 b	0.0	0.0 a	0.0
1 Week							
Control	2.1 a	1.0 a	1.0 a	1.3 a	0.0	0.6 a	0.0
Heated	3.1 a	1.6 b	1.0 a	1.2 b	0.0	0.0 a	0.0
1 Week then soft-ripe							
Control	5.6 a	1.0 a	4.0 a	3.7 a	69.4 a	34.7 a	72.2 a
Heated	5.3 a	1.6 b	2.1 b	2.1 b	25.0 b	0.0 b	25.0 b
2 Weeks							
Control	3.3 a	1.0 a	1.2 a	2.5 a	4.9 a	5.6 a	8.3 a
Heated	4.3 b	1.8 b	1.2 a	1.8 b	4.2 a	0.7 b	4.2 a
2 Weeks then soft-ripe							
Control	5.2 a	1.0 a	4.3 a	4.2 a	76.4 a	50.0 a	79.2 a
Heated	5.8 b	1.8 b	2.6 b	2.7 b	36.1 b	6.9 b	40.3 b
3 Weeks							
Control	4.3 a	1.0 a	2.7 a	3.8 a	36.1 a	30.6 a	45.8 a
Heated	5.3 b	1.9 b	2.2 b	2.8 b	30.6 a	12.5 b	30.6 b
3 Weeks then soft-ripe							
Control	5.2 a	1.0 a	4.6 a	4.4 a	84.7 a	61.1 a	88.9 a
Heated	5.9 b	1.7 b	3.3 b	3.0 b	50.0 b	11.1 b	52.8 b

^zPit = pitting, SER = stem-end rot, and ANTH = anthracnose ratings: where 1 = none, 2 = trace, 3 = slight, 4 = moderate, and 5 = severe.

^yPercentage decay may not equal sum of SER and ANTH because some fruit were eliminated with both severe SER and ANTH.

^xMean separation within column groups (treated or nontreated by storage or ripening time) by F test, $P < 0.05$.

Table 2. Fruit characteristics and days to soft-ripe stage for 'Tommy Atkins' mangos after treatment with 51.5C air for 125 min and then stored for 1, 2, or 3 weeks at 12C followed by holding at 21C until soft-ripe.^z

Storage/ treatment	Firmness (N)	Freshness rating ^y	Peel color rating ^x	Pulp color ^w			TSS (%)	Days to soft-ripe ^v
				'L'	'a'	'b'		
1 Week then soft-ripe								
Control	0.5 a	2.2 a	5.0 a	64.9 a	8.3 a	61.1 a	12.7 a	9.6 a
Heated	0.8 b	1.6 a	4.8 b	67.0 b	5.7 b	49.4 a	13.2 a	7.0 a
2 Weeks then soft-ripe								
Control	0.6 a	2.1 a	4.9 a	66.4 a	7.4 a	61.5 a	12.5 a	6.0 a
Heated	0.7 b	1.7 b	5.0 a	68.1 b	5.4 b	40.6 b	13.3 b	5.2 a
3 Weeks then soft-ripe								
Control	0.5 a	2.6 a	5.0 a	66.0 a	5.7 a	60.2 a	13.2 a	3.1 a
Heated	0.7 b	2.1 b	5.0 a	68.0 b	4.5 b	61.0 a	13.0 a	2.4 b

^zMean separation within column groups (treated or nontreated by storage time) by F test, $P \leq 0.05$.

^y1 = Fresh, 2 = fairly fresh, and 3 = not fresh.

^x1 = green, 2 = less than 25% yellow/red, 3 = 26% to 50%, 4 = 51% to 75%, and 5 = greater than 75% yellow/red peel area.

^wHunter color values.

^vDays for fruit to reach the soft-ripe stage after being placed at 21C.

surface, dull color without gloss).

The severity of rot for each fruit was scored on a scale of 1 to 5 based on the area of the fruit affected (Miller et al., 1986). Each fruit was scored for both anthracnose (ANTH) (*Colletotrichum gloeosporioides* Penz) or stem-end rot (SER) (*Diplodia natalensis* P. Evans). Any fruit with a decay severity of 5 was eliminated from the test.

The number of days each fruit remained at 21C until reaching soft-ripe was recorded, and the pulp firmness and color were determined objectively. Soft-ripe mangos were assayed for total soluble solids concentration (TSS) (refractometer) and pulp color (Minolta Colorimeter, Model CR 200, Osaka, Japan). After removal of a thin section of peel with a scalpel, pulp firmness was determined with an Instron Food Texture System (Model

1132; Instron Corp., Canton, Mass.) calibrated to apply a 10-kg force at 50-mm·min⁻¹ travel speed and set to penetrate the pulp 10 mm with a 9.5-mm-diameter cylinder. Each fruit was then cut through parallel to each side of the characteristically flat seed, and three color measurements were made on the flat pulp surface of each half. Additional subjective observations were made for visible discoloration of pulp tissue, especially areas containing vascular bundles. Pulp was then diced and a 100-g sample was squeezed by mechanical press to obtain juice for measuring TSS by refractometer. Pulp not destroyed was evaluated for flavor by an informal taste panel of seven individuals and scored as either 1 (acceptable) or 2 (not acceptable).

The means for all characteristics from three

tests (replications) were subjected to analysis of variance (SAS, 1982) procedures.

Treated fruit had lost significantly ($P < 0.05$) more weight than nontreated fruit after 2 weeks and this difference was maintained until the fruit became soft-ripe (Table 1). Treated fruit developed only a trace of pitting and that within 1 week after treatment. Peel pitting was manifested as small, irregularly shaped, slightly sunken, and shriveled areas. Pitting usually appeared on fruit epidermis at areas previously bruised or abraded during harvesting and handling operations. No pitting was observed on nontreated fruit. Peel discoloration, such as scald, was not observed on any treated or nontreated fruit.

SER increased with storage time and was more prevalent in nontreated than in treated fruit at the soft-ripe stage, regardless of storage duration at 12C. ANTH also increased with storage time, and the decay severity was significantly ($P < 0.05$) greater in nontreated than in treated fruit. At the soft-ripe stage, nontreated fruit had significantly ($P < 0.05$) more SER (1.6-fold) than the treated fruit. Decay (score = 5) eliminated 49% of treated or nontreated mangos after 1 week of storage and ≈71% after 3 weeks in all tests.

Treated mangos tended to reach the soft-ripe stage earlier and they were slightly firmer than nontreated fruit (Table 2). Treated fruit were fresher in appearance than nontreated fruit after storage and ripening. Peel color was similar for treated and nontreated mangos on reaching the soft-ripe stage, regardless of storage duration. The pulp of treated fruit had consistently higher 'L' values (lighter in color) and lower 'a' values (more green, less red) than nontreated fruit. There was no significant ($P < 0.05$) difference in 'b' values among treatments, except after 2 weeks. Average TSS values for soft-ripe fruit for all storage durations were 12.8% and 13.2% for nontreated and treated mangos, respectively. Treated fruit generally had higher TSS than nontreated mangos, but this difference was significant ($P < 0.05$) only for mangos ripened after 2 weeks of storage. Although treated mangos consistently were soft-ripe ≈1 day earlier than nontreated fruit, the objective firmness and pulp color values indicated that these fruit were less ripe. Perhaps the treatment caused the outer pulp to soften earlier than in nontreated fruit.

Mean flavor scores ranged from 1.1 to 1.4 on reaching soft-ripe after storage of 1, 2, or 3 weeks at 12C. There were no detectable differences between treated or nontreated fruit. Taste deteriorated slightly but not significantly as storage duration increased.

Treatment of 'Tommy Atkins' mangos at 51.5C air for 125 min followed by storage and ripening conditions did not adversely affect fruit quality. Although the high-temperature, forced-air treatment caused slight pitting (<2%), this condition should not affect fruit marketability. Pitting usually appeared at sites of abrasions caused by rough handling before treatment. The treatment did not lead to

an objectionable fruit flavor. A secondary benefit of this heat treatment was a reduction in the development of SER and ANTH rot. Our data differ from those of Spalding et al. (1988) in that they reported that a 46C or 49C water-immersion treatment reduced SER but not ANTH rot, whereas our data indicated a reduction in both types of decay. Additional testing of mangos should be conducted to determine the effects of seasonal and cultivar differences in response to high-temperature, forced-air treatments.

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