Comparative Responses of Preharvest GA-treated Grapefruit to Vapor Heat and Hot Water Treatment

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Abstract. 'Marsh' grapefruit (*Citrus paradisi* Macf.) produced in Florida must be certified for security against unwanted pests before entry into some domestic and export markets. Application of heat by hot water (HW) has been shown to cause severe injury to grapefruit; however, direct comparisons between forced vapor heat (VH) and HW have been lacking. Grapefruit preharvest-treated with gibberellic acid (GA) or not treated, were postharvest-treated with VH or HW such that the surfaces of fruit were exposed to the same rate of temperature increases and treatment durations. Condition and quality attributes were then compared with ambient air (AA) and ambient water (AW) controls after storage. After 4 weeks' storage at 10 °C plus 1 week at 20 °C, scald affected 5% of HW and 20% of VH-treated fruit. No scald developed on control fruit. At the end of storage, mass loss for HW and VH fruit was ≈5%. HW-treated fruit had a 5-fold higher incidence of aging than VH fruit; however, control fruit showed significantly more aging than all heat-treated fruit. Gibberellic acid (GA) and the heat treatments reduced decay relative to the control. GA-treated fruit remained greener during storage than control fruit. These findings indicate that VH and HW treatments at the temperatures and durations to control the Caribbean fruit fly (*Anastrepha suspensa*, Loew) will likely cause peel injury to 'Marsh' grapefruit produced in Florida, regardless of treatment with GA.

Grapefruit produced in Florida must be subjected to an approved quarantine treatment for security against infestations of Caribbean fruit fly (CFF). Approved quarantine treatments for grapefruit include fumigation with methyl bromide (MB), cold (Hallman and Chalot 1993), and harvesting fruit from fly-free groves (State of Florida Caribbean Fruit Fly Protocol) (U.S. Dept. of Agriculture, 1994). Most grapefruit shipped from Florida to markets requiring quarantine certification is harvested from designated fly-free zones. MB is scheduled to be phased out in the United States by the year 2001.

Heat treatments are used for quarantine security against insects of fresh citrus (U.S. Dept. of Agriculture, 1994). Heated forced air is approved against *Anastrepha* spp. for grapefruit imported into the United States from Mexico, and static vapor heat (VH) is approved for similar insects for grapefruit from Mexico (U.S. Dept. of Agriculture, 1994). Considerable research has been conducted on the effect of VH (Brown et al., 1991; Hallman et al., 1990; Miller et al., 1991), and hot water

(HW) (McDonald et al., 1991; McGuire, 1991; Miller et al., 1988; Sharp, 1985) on Florida-grown grapefruit. In general, these reports indicated that VH is a viable quarantine treatment for Florida grapefruit, but HW treatment caused excessive damage. Since VH is saturated moisture we expected that grapefruit would respond similarly to heat from either VH or HW if both treatments were applied at similar temperatures and durations.

Gibberellic acid (GA) applied preharvest to grapefruit retards the yellowing of the peel and maintains increased peel resistance to ovipositioning by the CFF (Greany et al., 1995). GA application to groves may become an integral part of the Fly Free Protocol in Florida. Fruit treated with GA may differ in tolerance to heat stress compared with fruit not treated. The objective of this study was to determine the effect of subjecting GA-treated and control grapefruit to VH treatment of sufficient severity to control CFF (Hallman et al., 1990), and using the recorded temperature and time profiles from VH treatment experiments as input temperature/time control for the HW treatment.

Materials and Methods

Harvesting and fruit preparation. 'Marsh' grapefruit were harvested from a commercial grove located in St. Lucie County, Fla., on 9 Jan., 27 Feb., and 13 Mar. 1995. Trees were treated with GA (Abbott Laboratories, North Chicago, Ill.) (a.i.) at 24.7 g·ha⁻¹ with 0.05% Silwet L-77 v/v (OSi Specialty Chemicals, Danbury, Conn.) applied just before fruit color

break. Fruit were harvested from control trees located just beyond wind drift of the same grove. GA-treated and control fruit were each harvested from three tree plots within the same grove. Fruit samples were replicated on the tree plots for each of three harvests. Fruit were picked randomly from tree canopies and ranged 9 to 10 cm in diameter. Fruit were not degreened, but were washed on a commercial brush bed-washer with Moldstrip 25 (Fresh Mark, Orlando, Fla.). VH treatment commenced ≈24 h after harvest. HW and ambient water (AW) treatments were conducted 48 h after harvest, and ambient air (AA) control fruit were held at room temperature [≈20 °C; relative humidity (RH) 90 ± 5%] until all treatments were completed.

VH treatment. Sixty-six GA and control fruit each were placed into two separate plastic containers sized (56.5 × 36.5 × 27.3 cm, L × W × H), to hold fruit during treatment. In each container, 45 fruit were inspected before VH treatment, and peel color CIE (1976) L*, a*, b* (model CR-200 with an 8-mm aperture sensor; Minolta Chromameter, Osaka, Japan) with chroma [C* = (a*² + b*²)^{1/2}] and hue angle (h° = arctangent of b*/a*) values, and fresh mass were determined on 15 of these fruit. A five-fruit sample of GA and control fruit was used for determining volume displacement of fruit before and after treatment, after waxing and after 1 week of storage at 10 °C to assess peel puffiness from possible water absorption. Remaining filler fruit (filled to complement of 66) were discarded after treatment. Three type T (copper-constantan, AGW 32, 0.2019 mm in diameter) thermocouples were inserted into each of three individual fruit in each of the two containers; one was inserted to the center core (40 mm into the fruit perpendicular to the equatorial surface); another was inserted just under the cuticle; and the third was positioned to record temperature 5 mm above the fruit surface. The two containers of fruit were arranged into the VH facility for treatment as described by Gaffney and Armstrong, (1990). Air flow within the chamber was maintained at 0.4 m³·min⁻¹; and 100% RH maintained free moisture on the fruit surface during treatment.

HW treatment. Fruit were placed into plastic containers as those used for the VH treatment. The hot water bath facility (Gaffney Engineering Co., Gainesville, Fla.) was a computer-controlled, self-contained system with two hot water bath reservoirs. Three thermocouples were placed in a single fruit located in the center of the fruit mass (middle layer of fruit) within each container. Thermocouples were positioned as described in VH-treated fruit, and the entry was sealed with hot glue to prevent water seepage into the fruit. The temperature of the water bath was maintained identical to the surface time/temperature profile obtained from the VH treatment. Hence, the surface temperatures to which HW-treated fruit were exposed were similar to the time/temperature profile for the VH-treated fruit.

AW and AA controls. Ambient water controls were immersed in tanks of water (≈20 °C) for the same duration of time as required for

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Fig. 1. Typical temperature/time profile of grapefruit surface during vapor heat and hot water treatments, and grapefruit core temperatures by treatment.

the VH or HW treatments. In addition, 50 fruit were held in ambient air (20 °C, 50% RH) until all other postharvest treatments were completed.

Posttreatment storage and inspection. All fruit were treated with thiabendazole (TBZ) (1000 mg·L⁻¹) applied in an aqueous spray followed by waxing with Flavorseal 93 (FMC Corp., Lakeland, Fla.) after heat treatment. Forty-five fruit of each treatment were packed, 15 each, into 0.14-m³ commercial, full-telescoping fiberboard boxes. Fruit were inspected after 1, 2, and 4 weeks at 10 °C, plus 1 additional week at 20 °C. At each inspection, fruit were rated for peel condition and quality attributes were determined. Peel pitting, aging (development of necrotic tissue at the stem end, also known as postharvest stem-end rind breakdown), scald, and general appearance of peel and calyx were subjectively rated (Miller and McDonald, 1991). Objective fruit color was measured on five fruit per box with the Minolta chroma meter. Fruit mass was recorded on five fruit per box after each inspection. The number of decayed fruit was recorded per box, and rotted fruit were removed and decay was identified by visible symptoms.

Total soluble solids (TSS), titratable acid-

ity (TA), and pH were determined on 15 fruit after harvest and from 15 fruit per treatment after the final storage period. Objective firmness (model 1132; Instron Food Testing System, Canton, Mass.) was determined after 5 weeks of storage on 15 fruit per treatment, using a 9-cm-diameter flat anvil moving at 5 cm·min⁻¹ to achieve a 5-mm compression. After the final storage duration, comparative sensory evaluations of pulp and juice flavor, and of mastication texture were rated by at least seven informally trained panelists using a modified hedonic scale of 1 (poor) to 100 (extremely good).

Five fruit from each treatment were designated for determining fruit volume. These fruit were waxed after prestorage treatment. Each fruit was weighed and the volume determined by water displacement before treatment, after treatment, after waxing, and after 7 d of storage at 10 °C.

A complete factorial combination of treatments included +/- GA and heat treatments of VH, HW, AW, and AA. Data were averaged over fruit and subjected to analysis of variance procedures for mean comparisons of the main factors of GA and treatments (AA, AW, VH, HW), and their interactions.

Results

Air temperatures within the VH chamber increased gradually from 20 °C at the start, reaching 43.5 ± 0.2 °C after 95 min and remaining near constant until the end of treatment. Fruit surface temperatures reached the target of 43.5 °C in ≈95 min (range 90 to 100 min) (Fig. 1C). The core temperature of VH-treated fruit reached the target of 43.5 °C after ≈170 min (range 165 to 175 min) (Fig. 1B), whereas the core temperature of the HW-treated fruit reached 43 °C after ≈185 min then increased to and remained at 43.2 °C until the end (240 min) of the HW treatment (Fig. 1A). The surfaces of fruit during the VH and HW treatments for each of the three harvests reached similar target temperatures of ≈43.5 °C. The initial pulp temperature of VH-treated fruit was slightly higher than the initial temperature of HW-treated fruit before treatment because HW-treated fruit remained in an ambient treatment room ≈24 h longer than VH fruit before treatment.

At the end of storage, AA fruit had the highest and VH-treated fruit the lowest incidence of aging (Table 1). GA had no effect on aging. Peel scald affected 20% and 5% of VH- and HW-treated fruit, respectively, and most scald on VH and HW fruit was severe. Scald did not develop on AW or AA fruit, and GA had no influence on scald development. Peel pitting was absent on all fruit following storage. There was significantly ($P \leq 0.05$) less decay in GA-treated fruit compared with control fruit. There was less decay in VH- and HW-treated fruit than in AA or AW control fruit. About 97% of fruit rot was caused by stem end rots; mostly *Phomopsis citri* Fawc. and, to lesser extent, *Diplodia natalensis*, P. Evans. The remaining 3% of fruit rot was caused by green mold (*Penicillium digitatum*, Sacc.). There was slight, but significantly less mass loss by AW than by fruit of all other treatments by the end of storage.

At harvest, values for peel color were significantly higher and less green for control than for GA-treated fruit; L* values were 80 and 78, and a* values were -6.2 and -7.0, (hue = 96.5, 97.4; chroma = 55.0, 54.6), respectively. Peel color differences persisted throughout storage, and at the final inspection

Table 1. Percentage of grapefruit, preharvest sprayed or not sprayed with gibberellic acid (GA), with symptoms of aging, scald, decay, and percent mass loss after ambient air (AA), ambient water (AW), vapor heat (VH), or hot water (HW) treatment and storage for 4 weeks at 10 °C plus 1 additional week at 20 °C.

		Fruit affected (%)						
		Scald						Mass
Variable		Aging	Slight	Moderate	Severe	Total	Decay	loss
GA								
–		7.2	0.7	1.6	4.0	6.3	15.3	4.9
+		5.0	1.3	1.5	3.7	6.4	8.2	5.0
Treatment (T)								
AA		10.3	0.0	0.0	0.0	0.0	10.0	5.0
AW		7.5	0.0	0.0	0.0	0.0	24.3	4.6
VH		1.2	3.0	5.3	12.1	20.4	5.5	5.3
HW		5.6	1.0	0.9	3.2	5.1	7.4	5.1
Factor	df	Mean squares						
GA	1	86.0 ^{ns}	5.6 ^{ns}	0.2 ^{ns}	2.6 ^{ns}	0.1 ^{ns}	919.0*	0.1 ^{ns}
T	3	264.0*	36.2*	115.0*	591.0*	1678.0*	1309.0*	1.6*
Error		59.0	10.4	18.4	38.8	113.0	98.0	0.2

^{ns}, *Nonsignificant or significant at $P \leq 0.05$ by analysis of variance procedures.

GA-treated fruit were greener and lighter in color than control fruit (Table 2). VH- and HW-treated fruit were yellower than AA or AW fruit at the final inspection. Thus, fruit subjected to the heat treatments was yellower than controls, and there were no treatment differences in b^* values after similar storage durations.

Means for TSS and TA were 8% and 0.8%, respectively, at 5 weeks of storage and were not influenced by GA or heat treatments. Mean preference values for juice or pulp flavor were ≈ 77 and 76, respectively, at the final inspection, and they were not influenced by treatments. However, pulp texture of HW-treated fruit was significantly less preferred than that of all other treatments (Table 2). The significant GA $\times$ treatment interaction for pulp texture values was due to relatively high preference scores (81) for control, VH, and AW fruit compared to scores of 71 and 73 for HW and AA fruit, respectively. Treatment texture scores for GA-treated fruit were more scattered, ranging from 74 to 78, and were not affected by GA. Objective firmness at harvest was ≈ 31 N with no difference between control and GA-treated fruit; at the final inspection, mean firmness was 23.3 N with no difference among treatments.

After 1 week of storage at 10 °C, the volumetric displacement of AA control fruit was significantly less (3.5%) than for VH- (2.0%), HW- (2.1%), or AW- (2.3%) treated fruit. There was no effect of GA on volumetric displacement of fruit during similar storage (data not shown).

Discussion

HW-treated fruit failed to reach the target core temperature of 43.5 °C during treatment in all three tests, possibly, at least in part, because of the slight difference in initial temperature of VH and HW fruit. The objective of exposing the surface of grapefruit to similar temperatures during either HW or VH treatment was, however, achieved (Fig. 1, line C). Previously, when we exposed grapefruit to only HW, fruit were placed directly into 45 °C water for 4 h; then, core temperatures reached

43.5 °C after 2.25 h, but after 5 weeks' storage, 57% of the HW fruit were rotted compared with 6% for control fruit (Miller et al., 1988).

Both VH and HW reduced the incidence of decay. These findings are consistent with those of Brown et al. (1991), who reported that VH treatment at 43.5 °C for 4.5 h applied to grapefruit inoculated with *P. digitatum* provided partial decay control. Surface injuries are generally favorable sites for infection by postharvest decay organisms. However, the heat treatments may have promoted lignin formation and accelerated peel injury healing, which also inhibits fruit rot in grapefruit (Brown et al., 1978). McGuire (1991), however, obtained significantly more decay with HW than with forced hot air.

The overall mean for aging was 6% after 5 weeks' storage. However, the difference in aging between AA (10%) and VH-treated (1%) fruit is unexplained. The differences in the incidence of aging among treatments in this study are not consistent with previous findings by Miller and McDonald (1991) where VH-treated and control fruit aged similarly. In our current study, VH-treated fruit had $\approx 12\%$ serious scald compared with $<1\%$ in a previous study (Miller et al., 1991). McGuire (1991) compared forced hot air (no free moisture on fruit during treatment) at 48 °C with HW to grapefruit, with gradually increasing or with constant temperature for similar target temperatures. He found excessive peel injury after subsequent storage such that fruit marketing would be hindered. McGuire treated fruit until core temperatures reached 45.6 or 46.3 °C, which was higher than the sufficient core temperatures of 43.5 °C (50 min) to control the CFF. He reported excessive decay ($\approx 50\%$) following hot water immersion treatment, whereas, in our current study decay was decreased by heat treatments. The seriousness of peel disorder and decay in grapefruit following these heat treatments may be seasonal in nature and likely related to preharvest cultural factors, such as rootstock, production practices, or climatic conditions during physiological development of fruit (Grierson and Ben-Yehoshua, 1986; Reitz and Embleton, 1986).

Table 2. Peel color and pulp texture preference values for preharvest gibberellic acid (GA) treated grapefruit following ambient air (AA), ambient water (AW), vapor heat (VH), or hot water (HW) and storage for 4 weeks at 10 °C plus 1 additional week at 20 °C.

Variable	Color values			Pulp texture
	L*	a*	b*	
GA				
–	78.4	–3.0	56.5	76.4
+	76.6	–3.5	55.8	76.3
Treatment (T)				
AA	76.7	–4.1	56.2	75.8
AW	76.7	–4.0	55.2	78.6
VH	76.4	–2.3	55.5	77.7
HW	76.7	–3.1	56.0	73.3
Factor	df	Mean squares		
GA	1	58.5*	3.1*	8.3 ^{ns}
T	3	0.5 ^{ns}	8.1*	1.1 ^{ns}
GA $\times$ T	14	0.5 ^{ns}	0.2 ^{ns}	3.9 ^{ns}
Error	1.2	0.4	2.4	0.0

^{ns}, *Nonsignificant or significant at $P \leq 0.05$ by analysis of variance procedures.

Conclusion

VH treatment is approved, and the HW treatment may, in the future, be approved for use on grapefruit in the United States. Heat treatments may, however, induce peel injury during posttreatment storage. This study indicates that grapefruit is likely near the threshold for damage during heat treatments at the time/temperature regimes found effective for control of the CFF; therefore, shippers must determine whether grapefruit from their particular production area will withstand the stress of heat treatment before large scale commercial application. VH and HW treatment of 'Marsh' grapefruit should only be considered by Florida grower/shippers in the absence of less stressful quarantine treatments.

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