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Postharvest Quality of Early Season Grapefruit after Forced-air Vapor Heat Treatment

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Abstract. **'Marsh' and 'Ruby Red' grapefruit *(Citrus paradisi* Macf.) were harvested in Florida during Oct. and Nov. 1990, degreened in an ethylene chamber, exposed to vapor heat (VH) treatment (43.5 ± 0.1C for ≈240 min), and evaluated for deterioration in quality and development of injury after various storage regimes. Symptoms of aging averaged 6% and 8% of the surface on 'Ruby Red' and 'Marsh' fruit, respectively, and the VH treatment had reduced the incidence of aging by 45% after 5 weeks of storage (4 weeks at 16C plus 1 week at 21C). Total decay, mostly stem-end rots *(Diplodia* spp. and *Phomopsis* spp.), remained relatively low (≈5%) in both treated and nontreated fruit after 5 weeks of storage. The VH treatment had little effect on change in peel color during treatment or subsequent storage. After the final inspection, 'Marsh' fruit was higher in total soluble solids and titratable acidity than 'Ruby Red' fruit, but these quality indicators and pH were not affected by the VH treatment. VH treatment did not adversely affect the quality of 'Marsh' or 'Ruby Red' grapefruit harvested early in the season; hence, VH should be considered as a viable quarantine treatment for Florida grapefruit.**

Quarantine regulations require that grapefruit exported from Florida to Japan and South Korea and for domestic shipments to Arizona, California, and Texas must be certified free from infestation by the Caribbean fruit fly (CFF) *[Anastrepha suspensa* (Loew)]. Approved quarantine treatments (Animal and Plant Health Inspection Service, 1976) for disinfestation of the CFF for Florida grapefruit include: 1) fumigation with methyl bromide, 2) cold treatment, and 3) harvesting fruit from fly-free zones. Each of these approved treatments are subject to certain commercial limitations in their usage. Methyl bromide causes peel injury at dosages needed to kill the CFF. Grapefruit conditioning and cold treatment (Hatton and Cubbedge, 1982) are recommended for use on fruit harvested after the arbitrary date of about 1 Jan. (considered by the trade as late-season fruit compared to early season fruit, which requires degreening), when fruit peel will tolerate the stress of cold treatment. Certified fly-free zones do not contain enough fruit to supply season-long export market demands for certified fly-free fruit. Therefore, for shipments that require quarantine treatment for the CFF, shippers usually harvest from fly-free zones early in the production season and apply the conditioning and cold treatment to grapefruit from other production areas harvested late in the season.

Recently, investigators have evaluated the entomological and horticultural feasibility of using various kinds of heat to develop alternative treatments for disinfesting grapefruit of the CFF and yet not cause physical or physiological damage to peel, pulp, or juice. Such treatments include: 1) immersing grapefruit in heated water (Gould, 1988; Miller et al., 1988; Sharp and Chew, 1987), 2) forced heated air (Sharp, 1989), and 3) forced vapor-heated air (Hallman et al., 1990; Miller et al., 1991). Vapor heat is not a new quarantine treatment for grapefruit. It was tested and used in 1929 to disinfest oranges and grapefruit shipped from Florida of the Mediterranean fruit fly *(Ceratitis capitata* Wiedemann), and against the Mexican fruit fly *(A. ludens* Loew) in Mexico (Baker et al., 1944). A vapor heat treatment of a constant 43.5C, with an air flow rate of 0.4 $m^3 \cdot sec^{-1}$ and relative humidity (RH) near 100%, until core temperature of fruit reaches and remains at 43.3 to 43.5C for 50 min, provides security against the CFF (Hallman et al., 1990). This treatment did not injure 'Marsh' grapefruit harvested late in the 1988-89 season (Miller et al., 1991) or 'Marsh' or 'Ruby Red' (a thinner-peel cultivar) (Miller and McDonald, 1991) harvested later in the season from the 1990-91 crop year. The purpose of our present study was to determine if 'Marsh' and 'Ruby Red' grapefruit harvested early in the season, when the peel is less resistent to stress and requires degreening, will tolerate forced-air VH treatment without injury or quality deterioration.

On three occasions 'Marsh' and 'Ruby Red grapefruit, harvested from three separate groves in the Indian River production area of Florida, were obtained at the packinghouse from field bins within 24 h of picking. Fruit were not subjected to any postharvest application of fungicides. Fruit selected were free from defects and ranged in size (diameter) from 40 count (10.0 cm) to 36 count (10.5 cm) per standard-size citrus box. They were taken to the U.S. Horticultural Laboratory in Orlando, Fla., and held for 72 h in an environmentally controlled degreening room at 30C ± 1C, 95% RH, with 5 ppm ethylene. Fruitwere removed when the peel was yellow, as determined by visual inspection. After degreening, all fruit were placed at ambient conditions (≈ 26C) until they reached the same temperature. This usually took less than 12 h. One-half of the fruit in each 'Marsh' and 'Ruby Red' lot was subjected to the VH treatment, the other half was not treated. The experimental forced-air test chamber (Gaffney and Armstrong, 1990; Gaffney et al., 1990) was set to maintain air at a near constant 43.5C at the fruit surface, with RH near 100% so that moisture condensed on the surface of fruit, and with an airflow rate of 0.4 $m \cdot set^{1}$. Within the test chamber, 66 fruit were placed into each of four plastic bins (56.5 × 35.9 × 27.3 cm). The bins were interlocked into each other ≈2 cm and had fully open tops and 78% mesh bottoms, forming a tunnel through which all air passed. Treatment continued until fruit center pulp temperatures reached 43.5C and had remained at 43.4 ± 0.1C for 50 min. During treatment, fruit and air temperatures were recorded at 5-min intervals. Fruit temperatures were monitored with thermocouples, inserted two each (center or 1 mm deep into the flavedo) into each of three fruit. Air temperatures were recorded on its entry into the chamber and 6 mm above the surface of three fruit located at the air exit side of the fruit mass under treatment. The fruit not treated with vapor heat were held at ambient conditions until the heat treatment was completed. When fruit were removed from the forced-air, vapor-heat test chamber, they were placed at ambient conditions until pulp temperatures equilibrated to ≈ 20C. Fruit were washed with soap (Mold Strip 25; Fresh Mark, Ocoee, Fla.), and 1000 ppm thiabendazole (TBZ) was applied by drip system to one-half of each cultivar/treatment combination. All fruit were then waxed (Citrus export wax; FMC, Lakeland, Fla.). The experiment was a 2 × 2 × 2 factorial design with eight treatment combinations–'Marsh' or 'Ruby Red' grapefruit with or without vapor heat, and with or without TBZ. The fruit sample size for each treatment combination was three boxes of 40 fruit each; therefore, each test (replication) included 480 fruit of each cultivar. Fruit were packed in 0.028-m^3 (4/5 bushel), full-telescoping, fiberboard export boxes with two ventilation holes on each long side panel for storage.

All fruit were inspected after treatment (initial) and reinspected after 2 or 4 weeks at 16 ± 1C (RH 90%) and finally after 1

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Table 1. Condition of 'Marsh' and 'Ruby Red' grapefruit treated with or without vapor heat (VH) and with or without thiabendazole (TBZ) (1000 ppm) after 2 and 4 weeks of storage at 16C and after 1 additional week at 21C.

Cultivar (CV) and treatment		Fruit in category (%)					Appearance index	'a*' Value[x]
		Sound	Slight[z] aging	Total aging	SER[y]	Total decay		
2 Weeks at 16C								
Marsh		96.6	2.0	2.4	0.9	1.1	1.1	0.6
Ruby Red		96.5	1.9	2.3	1.0	1.5	1.0	---
VH		96.5	1.2	1.7	1.6	2.0	1.1	0.7
No VH		96.5	2.6	3.0	0.4	0.6	1.0	0.5
TBZ		96.3	1.9	1.9	1.6	2.0	1.0	0.8
No TBZ		96.7	2.8	2.8	0.4	0.6	1.1	0.4
Factors	df							
CV	1	0.4[NS]	0.4[NS]	0.1[NS]	0.4[NS]	0.8[NS]	0.1*	---
VH	1	0.0[NS]	34.7*	31.3*	28.1*	31.3*	0.0[NS]	0.2[NS]
TBZ	1	3.1[NS]	12.5[NS]	14.7[NS]	28.1*	31.3*	0.1*	0.4[NS]
CV × VH	1	42.0*	42.0*	83.4*	5.6[NS]	7.0*	0.0[NS]	---
VH × TBZ	1	28.1*	1.4[NS]	2.2[NS]	12.5*	14.7[NS]	0.0[NS]	0.5*
Error	48(6)[w]	5.9	5.1	4.5	1.8	1.8	0.0	0.1
4 Weeks at 16C								
Marsh		91.7	5.2	5.7	2.2	3.0	1.8	0.4
Ruby Red		93.8	2.9	3.7	2.1	3.1	1.5	---
VH		93.8	2.8	3.3	2.6	3.4	1.7	0.6
No VH		91.7	5.4	6.1	1.7	2.6	1.6	0.1
TBZ		92.6	3.5	4.2	2.7	3.7	1.7	0.6
No TBZ		92.9	4.6	5.1	1.6	2.3	1.6	0.2
Factors	df							
CV	1	73.0*	94.5*	73.0*	0.4[NS]	0.0[NS]	1.3*	---
VH	1	73.0*	118.8*	145.9*	12.5[NS]	12.5[NS]	0.0[NS]	0.7*
TBZ	1	2.2[NS]	19.5[NS]	14.7[NS]	22.2*	28.1*	0.0[NS]	0.4[NS]
CV × VH	1	45.9[NS]	31.3[NS]	94.5*	5.6[NS]	8.7[NS]	0.1[NS]	---
CV × TBZ	1	31.3[NS]	31.3[NS]	45.9*	5.6[NS]	1.4[NS]	0.2[NS]	---
VH × TBZ	1	0.8[NS]	14.7[NS]	14.7[NS]	17.0*	22.2*	0.3[NS]	---
Error	48(6)[w]	12.9	9.4	10.4	4.4	4.4	0.1	0.1
4 Weeks at 16C + 1 week at 21C								
Marsh		88.6	6.8	7.8	3.3	4.1	1.9	0.4
Ruby Red		89.0	4.9	5.8	4.2	6.1	1.8	---
VH		89.8	4.2	4.8	4.4	6.2	1.9	0.8
No VH		87.8	7.5	8.8	2.9	4.0	1.9	0.1
TBZ		88.1	5.8	6.7	4.3	6.1	1.9	0.5
No TBZ		89.4	5.9	6.9	3.0	4.1	1.9	0.3
Factors	df							
CV	1	2.2[NS]	68.1*	68.1*	19.5[NS]	45.9*	0.1[NS]	---
VH	1	73.0[NS]	200.0*	292.0*	45.9*	73.0*	0.0[NS]	1.3*
TBZ	1	31.3[NS]	0.4[NS]	1.4[NS]	31.3*	45.9*	0.0[NS]	0.1[NS]
CV × VH	1	118.8*	138.9*	253.1*	14.7[NS]	25.1[NS]	0.0[NS]	---
CV × TBZ	1	4.3[NS]	3.1[NS]	5.6[NS]	0.8[NS]	0.1[NS]	0.0[NS]	---
VH × TBZ	1	10.5[NS]	8.7[NS]	8.7[NS]	25.1[NS]	38.3*	0.0[NS]	0.1[NS]
Error	48(6)[w]	22.1	15.1	17.0	8.0	8.4	0.1	0.1

[z]Slight, affecting an area of peel <3 mm in diameter.
[y]SER = stem-end rots.
[x]CIE (1976) 'a*' value, degree of green to red.
[w]Degrees of freedom for error term for 'a' value.
[NS,*]Nonsignificant or significant mean squares at $P = 0.05$.

additional week at 21 ± 1C (RH 95%). At each inspection fruit were evaluated for symptoms of aging, peel pitting, peel scald, decay, peel freshness, subjective firmness, and peel color. Symptoms of aging (stem-end rind breakdown) (Smoot et al., 1971) were rated 1 = slight, 2 = moderate, or 3 = severe, based on the area of peel affected. Aging symptoms rated slight (area < 3 mm in diameter) were scored but considered not to affect grade of fruit or to be objectionable to consumers, whereas areas scored moderate (3 to 6 mm) or severe (> 6 mm) were considered objectionable. Pitting and peel discoloration were rated 1 = slight (<10%), 2 = moderate (11% to 25%), or 3 = severe (> 25%) based on fruit surface area affected. Decay was scored when visible symptoms were observed and was listed by type of decay, such as stem-end rots (SER), green mold, and miscellaneous rots. Fruit freshness was rated 1 = very fresh, 2 = fairly fresh, and 3 = not fresh (dull, without gloss). Subjective firmness was scored 1, 2, or 3 based on the degree of resistance of fruit to moderately applied finger pressure. Subjective color was rated 1 = yellow, with gloss; 2 = yellow, with low or no gloss; or 3 = yellow, with orange blush and without gloss.

Objective firmness was determined (Miller et al., 1991) with an Instron food texture machine (Instron, Canton, Mass.) from a 15-fruit sample of 'Marsh' and 'Ruby Red' before degreening and from a separate 15-fruit sample from each of the eight treatment combinations after the final inspection. Peel color was measured (Minolta Chroma Meter Model CR-200, with 8-mm sensor; Minolta, Osaka, Japan) from three premarked areas on five random fruit in each box of 'Marsh' grapefruit, with or without vapor heat or TBZ, after degreening and each inspection. Objective color measurements of 'Ruby Red' fruit were omitted due to the development of red blush on the peel. Total soluble solids (TSS) content, titratable acidity (expressed as percent citric acid), and pH were determined from juice of 'Marsh' and 'Ruby Red' before degreening, after heat treatment, and after 5 weeks of storage. Seven panelists scored (hedonic scale 0-100) flavor of juice from both cultivars, treated or not treated with VH, after the final inspection.

All data for each of the condition and quality characteristics included in the study were averaged over the three replications and subjected to analysis of variance procedures (SAS, 1982) to test the main effects of cultivar, heat treatment, and TBZ and their interactions.

Significantly more symptoms of rind aging developed on 'Marsh' than on 'Ruby Red' fruit after 4 or more weeks of storage, and more on fruit without the VH treatment than on those treated (Table 1). The effect of VH on the development of rind aging generally depended on cultivar. Lesions caused by aging were characteristically located at the stem end of the fruit. The majority (more than 85% after 4 or more weeks of storage) of lesions from aging were rated slight, affecting <3 mm of contiguous rind area. Vapor heat reduced and TBZ had no effect on the incidence of aging. All observed symptoms of aging affected <9% of fruit of any treatment category, and most lesions were slight or did not downgrade fruit. Therefore, since the U.S. standards for grades of Florida grapefruit limit aggregated damage from rind breakdown to <9.5 mm for U.S. No. 1 grade (U.S. Dept. of Agriculture, 1967), we did not consider this injury as detrimental to fruit grade or to sales.

Total decay incidence averaged ≈5% after the final inspection (Table 1). 'Ruby Red' fruit had significantly more (30%) decay than did 'Marsh' fruit after 5 weeks of storage, and most decay was stem-end rot *(Phomopsis* spp. or *Diplodia* spp.). However, no practical conclusion can be made regarding decay, because the incidence of rots in all treatment combinations was low. The incidence of green mold *(Penicillium* spp.) was <1%, as were other miscellaneous rots, which were not categorized separately.

Fruit appearance decreased from fresh to fairly fresh during 5 weeks (4 weeks at 16C plus 1 week at 21C) of storage (Table 1). Although 'Ruby Red' was rated slightly fresher in appearance after 2 weeks of storage, there was no difference between cultivars after fruit were held 1 additional week at 21C. The CIE (1976) 'a*' color value indicates that greenness of peel for 'Marsh'

Table 2. Quality[z] of grapefruit cultivars (CV) Marsh and Ruby Red before and after treatment with vapor heat (VH) for 240 min at 43.5C or untreated, and after storage for 4 weeks at 16C plus 1 additional week at 21C.

Cultivar and treatment		TSS (%)	TA (%)	pH	Firmness (N)	Flavor index
Initial						
Marsh		9.85	1.4	2.95	3.4	---
Ruby Red		8.90	1.2	2.97	3.6	---
Factors	df					
CV	1	5.1*	13.5*	0.0[NS]	0.3*	---
Error	13	0.0	1.4	0.03	0.1	---
Immediately after VH						
Marsh		9.77	1.3	3.00	---	---
Ruby Red		8.82	1.2	3.01	---	---
VH		9.35	1.3	2.97	---	---
No VH		9.23	1.3	3.05	---	---
Factors	df					
CV	1	5.4*	5.6*	0.0[NS]	---	---
VH	1	0.1[NS]	0.5[NS]	0.04*	---	---
Error	14	0.1	0.7	0.02	---	---
4 Weeks at 16C + 1 week at 21C						
Marsh		10.1	1.3	3.09	3.0	83.2
Ruby Red		9.0	1.2	3.12	3.0	74.7
VH		9.6	1.2	3.08	2.9	79.3
No VH		9.6	1.2	3.11	3.0	78.6
Factors	df					
CV	1	7.9*	7.5*	0.01*	0.01[NS]	431.8*
VH	1	0.1[NS]	0.0[NS]	0.01*	0.01[NS]	2.8[NS]
Error	14	0.1	0.8	0.0	0.001	16.0

[z]TSS = Total soluble solids; TA = titratable acids; flavor index >50 is acceptable.
[NS,*]Nonsignificant or significant mean squares at $P = 0.05$.

fruit was not affected by VH or TBZ after 2 weeks of storage. 'Marsh' fruit treated with VH had slightly less green in the peel than non-VH-treated fruit after 4 and 5 weeks of storage. Because the difference in the 'a*' value was less than one unit, the difference is probably not visible; therefore, it is considered slight. There was no difference in 'L*' or 'b*' color values among the main factors or their interactions for 'Marsh' fruit. No pitting or discoloration was observed on either 'Marsh' or 'Ruby Red' fruit before or after VH treatment or after any storage regime.

'Marsh' fruit averaged ≈11% and 8% higher in TSS and titratable acidity, respectively, than 'Ruby Red' fruit (Table 2). After VH treatment, fruit were slightly but significantly lower in pH than fruit not treated, and this difference remained throughout subsequent storage. After the terminal inspection, the flavor of all juice was rated acceptable; however, 'Marsh' juice was rated significantly more acceptable than 'Ruby Red' fruit. The VH treatment did not affect flavor. Finally, 'Ruby Red' fruit were slightly firmer than 'Marsh' fruit before the VH treatment, but after 4 weeks of storage at 16C, fruit firmness of both cultivars was similar.

Vapor heat treatment was not detrimental to early season 'Marsh' or 'Ruby Red' grapefruit that were degreened in an ethylene chamber for ≈72 h before treatment. These findings are similar to those reported earlier (Miller et al., 1991) for grapefruit that were harvested during the latter half of the season and that did not require degreening. Thus, VH treatment is a viable treatment for Florida-produced grapefruit. If VH treatment becomes part of the arsenal of quarantine treatments to control the CFF, the Florida citrus industry will have an alternative nonchemical treatment to complement that of harvesting from fly-free zones for early season fruit.

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