Quality of Stored 'Marsh' and 'Ruby Red' Grapefruit after High-temperature, Forced-air Treatment

W.R. Miller and R.E. McDonald

U. S. Department of Agriculture, Agricultural Research Service, 2120 Camden Road, Orlando, FL 32803

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Abstract. 'Marsh' and 'Ruby Red' grapefruit (*Citrus paradisi* Macf.) tolerated a high-temperature, forced-air, vapor heat treatment of 43.5C for 260 minutes, a treatment applied for security against the Caribbean fruit fly [*Anastrepha suspensa* (Loew)]. Fruit did not develop symptoms of quality deterioration during subsequent storage. With 'Marsh' fruit, 99% and 96% were sound, whereas with 'Ruby Red' 98% and 94% were sound after storage at 10C for 28 days or 10C for 28 days plus 7 days at 21C, respectively. Differences in means for percentage of sound fruit were not significant for cultivar or vapor heat treatment. After the final storage period, there was significantly more (2.4-fold, $P \leq 0.05$) aging observed on 'Ruby Red' fruit than on 'Marsh', averaged over all treatments. Vapor heat did not affect aging of 'Ruby Red' but increased aging of 'Marsh' fruit. Decay was reduced to $\approx 22.0\%$ in vapor heat-treated fruit from 5.0% for nontreated fruit. The efficacy of thiabendazole to control stem end rot was increased on vapor heat-treated fruit compared with nontreated fruit. After the final inspection, the appearance of 'Marsh' fruit was fresher (index 2.0) than that of 'Ruby Red' fruit (index 2.3), but the appearance of vapor heat-treated and nontreated fruit was similar. Peel color of 'Ruby Red' fruit was not affected by the vapor heat treatment, but, after 4 weeks at 10C plus 1 week at 21C, 'Marsh' fruit that were not treated were greener than those treated with vapor heat. The vapor heat treatment tested is a potentially viable quarantine procedure for Florida grapefruit that can be applied without adversely affecting fruit quality during normal storage.

Grapefruit exported from Florida to Japan and to domestic markets in states with quarantine restrictions must be certified free from the Caribbean fruit fly (CFF). At present,

cold treatment (PPQT Manual, 1976) and fruit harvested from fly-free zones are the only quarantine procedures used by the Florida citrus industry. The cold treatment is successful only when the fruit are temperature-conditioned so as not to develop chilling injury (CI) during or following the treatment (Hatton and Cubbedge, 1982). The cold treatment is generally successful when applied as recommended; however, the industry sometimes finds some fruit damage due to CI on low temperature-treated fruit. Therefore, alternative treatments, such as hot water (Miller et al., 1988; Sharp and Chew, 1987), hot air (Sharp, 1989), vapor heat (VH)

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Table 1. Juice characteristics^a and peel thickness of 'Marsh' and 'Ruby Red' grapefruit before and after vapor heat (VH) treatment at 43.5C for 260 min and storage for 4 weeks at 10C plus one additional week at 21C.

Storage treatment	Cultivar (CV)	df	TSS (%)	TA (%)	pH	Peel ^b (mm)
Initial	Marsh		9.9	1.5	3.07	7.4
	Ruby Red		11.2	1.5	3.07	5.7
	CV	1	2.4 ^{NS}	0.0 ^{NS}	0.0 ^{NS}	4.2*
	Error	2	1.3	1.3	0.0	1.2
4 weeks at 10C plus 1 week at 21C	Marsh, control		9.9	1.4	3.13	7.4
	VH		9.6	1.2	3.20	7.6
	Ruby Red, control		11.6	1.6	3.07	6.7
	VH		11.5	1.4	3.13	6.9
	CV	1	9.7*	6.9*	0.01*	1.4*
	VH	1	0.1 ^{NS}	7.8*	0.01*	0.2 ^{NS}
	Error	6	0.5	0.8	0.001	0.1

TSS = Total soluble solids concentration; TA = titratable acidity expressed as percentage of citric acid.

^aAverage of peel thickness.

^{NS}*Nonsignificant or significant at $P < 0.05$.

Table 2. Condition^a of 'Marsh' and 'Ruby Red' grapefruit exposed to vapor heat (VH) treatment at 43.5C for 260 min or not treated and with and without TBZ (1000 ppm) after storage for 4 weeks at 10C plus 1 week at 21C.^b

Cultivar (CV) and treatment	df	Sound (%)	Aging (%)	Decay (%)			Appearance index	'a' y value
				SER	Misc	Total		
4 weeks at 10C								
Marsh, control		98.3	0.0	0.6	1.1	1.7	1.7	-2.9
TBZ		99.2	0.0	0.0	0.6	0.8	1.5	---
VH		97.8	1.7	0.3	0.3	0.6	1.9	-1.5
VH, TBZ		99.2	0.6	0.0	0.3	0.3	1.5	---
Ruby Red, control		96.4	1.4	1.1	1.1	2.2	1.9	2.0
TBZ		97.8	1.1	0.3	0.8	1.1	1.8	---
VH		98.9	0.3	0.0	0.8	0.8	2.1	2.0
VH, TBZ		98.9	1.1	0.0	0.0	0.0	2.0	---
CV	1	3.1 ^{NS}	3.1 ^{NS}	0.3 ^{NS}	0.3 ^{NS}	0.8 ^{NS}	1.8*	64.9*
VH	1	1.4 ^{NS}	1.4 ^{NS}	3.1 ^{NS}	3.1 ^{NS}	19.5*	0.4*	4.7 ^{NS}
TBZ	1	8.7 ^{NS}	0.3 ^{NS}	3.1 ^{NS}	5.6*	10.5*	0.8*	---
CV × VH	1	100.3 ^{NS}	12.5*	1.4 ^{NS}	0.3 ^{NS}	0.8 ^{NS}	0.0 ^{NS}	0.5 ^{NS}
CV × VH × TBZ	1	1.4 ^{NS}	5.5*	0.3 ^{NS}	0.0 ^{NS}	0.1 ^{NS}	0.1 ^{NS}	---
Error	48 (6) ^x	4.3	1.2	0.9	1.0	2.0	0.1	0.2
4 weeks at 10C plus 1 week at 21C								
Marsh, control		93.6	0.0	3.9	2.5	6.4	2.2	-3.0
TBZ		96.7	0.0	1.4	2.0	3.3	1.7	---
VH		96.1	1.7	1.9	0.3	2.2	2.1	-1.2
VH, TBZ		98.6	1.1	0.0	0.3	0.3	1.9	---
Ruby Red, control		91.1	2.2	3.9	2.8	6.7	2.3	1.6
TBZ		94.8	1.9	1.4	1.9	3.3	2.2	---
VH		93.6	0.6	4.4	1.4	5.8	2.4	1.4
VH, TBZ		97.2	1.9	0.8	0.0	0.8	2.3	---
CV	1	19.5 ^{NS}	17.0 ^{NS}	12.5 ^{NS}	0.8 ^{NS}	22.2 ^{NS}	2.3*	52.2*
VH	1	31.3 ^{NS}	1.4 ^{NS}	12.5 ^{NS}	38.3*	125.3*	0.1 ^{NS}	1.4*
TBZ	1	160.5*	0.3 ^{NS}	125.3*	14.7 ^{NS}	200.0*	0.9*	---
CV × VH	1	38.3 ^{NS}	22.2*	12.5 ^{NS}	0.1 ^{NS}	17.0 ^{NS}	0.0 ^{NS}	1.4*
Error	48 (6) ^x	13.4	2.4	5.0	4.5	10.3	0.1	0.3

^aPercentage of fruit with symptoms of aging, stem end rot (SER), miscellaneous (misc), rots (green mold, sour rot), Appearance, 1 = good; 2 = fair; 3 = poor.

^bHunter index value for red and green; the higher the negative value, the greener the fruit.

* () df for 'a' value.

^{NS}*Nonsignificant or significant at $P \leq 0.05$.

(Baker, 1952; Hallman et al., 1990; Miller et al., 1989), and combinations of hot water/cold treatment (Gould, 1988) have been under investigation as alternative quarantine treatments for the CFF in grapefruit.

Vapor heat as a quarantine procedure for the control of pests in Texas citrus was developed ≈ 1929 (Baker, 1952). Later it was investigated for use in California (Sinclair and Lindgren, 1955) and, although it is an

approved procedure, it has generally not been commercially used for citrus. Recently, interest has been renewed in VH as a potential quarantine treatment for Florida citrus as ethylene dibromide was banned. A VH regimen of 43.5C for 5 h applied at a relatively low airflow rate ($\approx 0.19 \text{ m}^3 \cdot \text{s}^{-1}$) was found to provide quarantine security in CFF-infested, late-season, Florida-produced 'Marsh' grapefruit (Hallman et al., 1990). Freshly

harvested 'Marsh' grapefruit were not injured during this treatment, and the fruit were determined to be consumer-acceptable after subsequent storage (Miller et al., 1989). Most testing has been conducted on 'Marsh' because the Far Eastern market generally prefers white-fleshed grapefruit. The purpose of this study was to determine and confirm the tolerance of white- and red-fleshed grapefruit, the latter a thinner-peel cultivar, to VH treatment with and without an application of thiabendazole (TBZ) after VH treatment.

'Marsh' white and 'Ruby Red' grapefruit were obtained on three dates during Jan. and Feb. 1990 from a packinghouse in Vero Beach, Fla. All fruit were from groves located in Indian River or St. Lucie counties. On each occasion, fruit were taken directly from field bins before they were subjected to any packinghouse operation. This was generally within 24 h of harvest. After grading, fruit of size 40 ($8.6 \pm 0.5 \text{ cm}$) of each cultivar were divided into two lots: 240 fruit for VH treatment and 240 for nontreated control. For treatment, 66 fruit were placed into each of four plastic bins ($60 \times 40 \times 28 \text{ cm}$) with open tops and partially open (vented with 6.3-mm-diameter holes on 9.5-mm centers) bottoms. The four interlocking bins were stacked in register in the VH chamber. The VH chamber was designed to maintain an environment of controlled temperature and relative humidity (Gaffney and Armstrong, 1990). Nine thermocouples (TC) (copper-constantan, 0.2-mm diameter), located in fruit of the bottom bin in the chamber, were used to measure fruit surface, center pulp, and air temperatures. Temperature measurements were taken on fruit located at the site of exiting air of the fruit lot being VH treated. Thermocouples were inserted equidistant at the equator, 40 mm deep, into each of three fruit to measure center pulp temperature. For surface measurements, TC were inserted into the flavebo of each of three fruit 1 mm under the epidermis. Hot glue was applied at sites of TC entry into the fruit to prevent heat leakage. Additional TC were oriented 6 mm above the surface of each of three fruit at the same general location to monitor air temperature exiting the fruit load. All TC readings were automatically recorded at 5-min intervals during treatment.

Nontreated fruit were kept at ambient ($\approx 22\text{C}$) conditions until after the VH treatment (43.5C [$95\% \pm 5\% \text{ RH}$] and air flow rate of $0.4 \text{ m}^3 \cdot \text{s}^{-1}$ for 260 min) was completed. After treatment, all fruit, treated and nontreated, were washed with a nonfungicidal soap and half of each treated or nontreated lot of 'Marsh' and 'Ruby Red' was treated with TBZ (1000 ppm) applied in an aqueous spray before waxing. All fruit were waxed with Flavorseal 93 (FMC, Lakeland, Fla.) solvent wax and placed 40 each into (0.28 m^3) (0.8 bu), full-telescoping vented fiberboard boxes. The design was factorial, 2 cultivars $\times$ 2 temperatures $\times$ 2 fungicide levels at three harvest dates (blocks or replications). Each of the eight resulting treatments consisted of 120 fruit (three boxes of 40 fruit each). All fruit were inspected be-

fore and immediately after treatment and after 2 and 4 weeks of storage at 10C ($90\% \pm 5\%$ RH) plus one additional week at 21C ($95\% \pm 5\%$ RH). At each of the five inspections, fruit were evaluated for peel disorders, such as pitting, scald, aging (senescence), decay, general appearance of peel, subjective peel color, and fruit firmness. Pitting, scald, and aging (sunken necrotic tissue-rind breakdown-at the stem end) were rated by severity (slight, moderate, or severe) based on the amount of peel surface area affected. Decay was scored binomially and identified by visual symptoms as either stem end rots (*Phomopsis* spp. or *Diplodia* spp.) or miscellaneous rots (*Penicillium* spp. or *Geotrichum* spp.). Peel appearance, color, and fruit firmness (yield to moderately applied finger pressure) were measured subjectively and rated, 1 = good, 2 = fair, and 3 = poor. Resultants for these characteristics were quantified by calculating either the percentage of fruit affected or by averaging index values. Weight loss and objective reflectance peel color (Minolta Colorimeter, Model CR 200, Osaka, Japan) were measured on separate 15-fruit samples held under the same storage conditions. For color measurements, three locations were circled with a marker on each fruit to assure that the same areas on a fruit surface were sampled at each inspection. Peel color also was measured before VH treatment, after waxing, and after 2, 4, and 5 weeks of storage. Total soluble solids concentration (TSS), titratable acidity, pH, and peel thickness (average micrometer reading at three random sites on each of 15 fruit per treatment) were measured for each cultivar before treatment and on similar samples after the final inspection. Comparative sensory evaluations were also made for flavor of juice from random fruit from each treatment combination after 5 weeks of storage. Juice flavor was rated using a hedonic scale indexed 1 (poor) to 9 (extremely good) by an informal taste panel (seven participants) familiar with citrus fruits. Objective firmness was determined only after the final inspection by use of an Instron Food Texture System (Instron Corp., Canon, Mass., Model 1132) calibrated to record the maximum force (N) to compress the surface 5 mm with a 9-cm round, flat-faced anvil traveling at a constant speed of $5 \text{ cm} \cdot \text{s}^{-1}$.

All data were averaged over the three replications and subjected to analysis of variance procedures (SAS Institute, Inc., 1982) to test the main effects of cultivar, VH, and TBZ and their interactions.

Cultivar means for TSS, acidity, and pH were not significantly different (Table 1) at $P \leq 0.05$ before heat treatment. Mean differences in peel thickness were significant, averaging 30% higher for 'Marsh' than for 'Ruby Red'. After VH treatment and 5 weeks of storage, the difference in TSS was significant for cultivar. Mean differences for acidity and pH were slight but significant for cultivar and VH, but only cultivar was significant for difference in peel thickness.

More than 98% and 95% of the fruit re-

mained sound following 4 weeks of storage at 10C, or after one additional week at 21C, respectively (Table 2). Symptoms of aging were more prevalent on 'Ruby Red' than on 'Marsh' fruit. Incidence of aging averaged 1.7% on 'Ruby Red' and 0.7% on 'Marsh' after 4 weeks at 10C plus 1 week at 21C storage. Although the incidence of aging was relatively low, the effect of VH on aging depended on cultivar. About 1% of 'Marsh' fruit with VH had symptoms of aging, whereas no symptoms were observed on non-VH 'Marsh' fruit.

The incidence of decay was very low after 4 weeks of storage, but the effect of VH on total decay incidence was beneficial; it averaged 1.5% without VH and 0.4% with VH (Table 2). A similar and more pronounced effect of VH on decay was found after an additional week of storage at 21C, when the incidences of rot were generally higher and where VH reduced overall decay 2-fold compared with those combinations without VH. TBZ reduced total decay detected after 4 weeks and 5 weeks of storage; although the interaction of VH and TBZ was not significant at the final storage period, TBZ tended to be more effective when combined with VH than without VH.

The appearance index when averaged over all treatments indicates that 'Marsh' fruit, with a mean rating of 2.0, were slightly more fresh in appearance than 'Ruby Red' fruit (mean rating 2.3) at the final inspection. Hunter color 'L' and 'b' values were not affected by the treatments and averaged 76.7 and 54.4, respectively, over both cultivars before VH treatment and 75.7 and 54.3 after the final inspection 5 weeks later. Peel of 'Marsh' fruit was greener ('a' = -4.8) than peel of 'Ruby Red' fruit ('a' = -0.12) before VH treatment. This difference in Hunter 'a' value remained relatively constant and significantly different by cultivar throughout storage. After the final storage period, VH 'Marsh' fruit were significantly less green than those not VH-treated, and there was no difference between VH and non-VH-treated 'Ruby Red' fruit (Table 2).

Atypical pitting or scald was not observed. Before treatment with VH, fruit rated subjectively were firm to fairly firm and averaged mostly fairly firm after the final inspection (data not shown); there were no significant differences in firmness among means for main effects or their interactions. After the final inspection, fruit firmness measured 3.4 N and there were no significant differences in means among the main effects.

There were no significant differences in mean weight loss for main effects or their interactions at each evaluation (data not shown). Mean fruit weight loss for all fruit was $\approx 1.0\%$ after treatment and waxing, and averaged 3.2% at the final inspection. Finally, the mean fruit juice flavor index was 6.8 (good) at the final inspection, and there were no significant differences among main effects or their interactions.

'Marsh' and 'Ruby Red' grapefruit toler-

ated the VH treatment and a subsequent 5 weeks of storage without developing more symptoms of deterioration than nontreated fruit held under similar environmental conditions. We also found that VH tended to reduce decay, especially from SER, and green mold rot that developed at sites of mechanical injury (data not shown). The VH treatment did not increase decay caused by *Diplodia* spp., and there was a tendency for increased efficacy of TBZ combined with VH as opposed to TBZ without VH. Brown et al. (1978) found that high temperature enhanced lignification and, thus, inhibited green mold decay on citrus fruit injuries. In our study, however, the incidence of decay from green mold was very low ($< 2\%$). Additionally, the results indicate the VH treatment not only did not retard peel degreening, but suggest that it may have increased its rate. Hallman et al. (1990) found that VH at 43.5C did not cause damage to grapefruit peel, but treatment at 46C caused cell death and resulted in an undesirable peel color.

This study confirms previous findings that VH treatment at 43.5C does not damage 'Marsh' fruit (Miller et al., 1989) and shows that 'Ruby Red' grapefruit, a cultivar with thinner peel, will also tolerate this potential quarantine treatment.

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