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A REFEREED PAPER

RESPONSE OF FLORIDA GRAPEFRUIT TO SHORT-DURATION HEAT TREATMENTS USING VAPOR HEAT OR HOT WATER DIPS

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Abstract. **Heat-treatments have been evaluated and utilized commercially to reduce postharvest decay, chilling sensitivity, and maintain quality of perishable horticultural products. Recent studies exposing grapefruit (*Citrus paradisi* Macf.) to short-duration, high-temperature water [e.g., 133 to 144 °F (56 to 62 °C) for 20 seconds] have shown promise at reducing subsequent development of mold (*Penicillium*) and increasing resistance to chilling injury (CI). Among the most prevalent citrus decay organisms in Florida are the stem-end rots (*Diplodia natalensis* and *Phomopsis citri*). Whereas *Penicillium* species invade citrus tissue through wounds, the stem-end rot organisms develop latent infections within the button tissue that are more protected from physical and chemical treatments. Here we report on efforts to identify heat-treatments that do not result in visible grapefruit peel injury, while reducing subsequent postharvest decay from natural infections. 'Marsh' or 'Ruby Red' grapefruit were exposed to liquid or vapor water at temperatures between 122 and 149 °F (50 to 65 °C) for 0 to 120 seconds. Fruit tolerance to heat injury followed a time × temperature relationship that usually shifted slightly between experiments. However, washing and waxing the fruit immediately after the heat-treatment greatly reduced the development of visible heat injury. Grapefruit could usually tolerate a 10-second exposure to 138 °F (59 °C) water, but extending exposure time to 120 seconds required lowering the temperatures to 127 °F (53 °C) to prevent peel injury. While some time × temperature combinations significantly reduced stem-end rot (SER), only one did not result in significant peel injury. In one experiment, hot water treatment of 138 °F (59 °C) for 10 seconds was non-injurious and resulted in about 90% reduction in SER incidence (to 3.5%). Injurious treatments were associated with elevated fruit respiration. Simulated commercial degreening conditions before or after the heat-treatments had no affect on the development of peel injury.**

Heat-treatments have been widely evaluated and utilized commercially to kill insects (Shellie and Mangan, 2000), reduce postharvest decay (Schirra et al., 2000), and reduce chilling sensitivity (Rodov et al., 1995) of perishable horticultural products. In Florida, as far back as the 1960s, hot water treatments were studied for their potential to reduce postharvest decay of citrus (Hayward et al., 1962). Smoot and Melvin (1963) reported that hot water treatments at 128 °F (53 °C) for 5 min effectively reduced decay of oranges that were not degreened (implying that the treatment did not effectively reduce decay of degreened oranges), and tangerines with or without degreening. However, results with grapefruit at different maturities were inconsistent.

Recently, there has been increased interest in the potential effectiveness of even shorter-duration (<2 min) heat treatments at higher temperatures (133 to 144 °F). In Israel, a short-duration, hot water brushing system (~133 °F (56 °C) for 20 s) has been developed for use on citrus (Porat et al., 2000a, b). Besides its ability to remove dirt from commodities, the equipment has been shown to reduce surface microorganism populations by up to 4 log and can reduce natural decay (primarily *Penicillium digitatum* mold) by about half. Not only did the treatment reduce decay on fruit inoculated with *P. digitatum* before treatment, but also when fruit were inoculated 1 to 3 d after the heat treatment (up to 95% less decay than untreated fruit; Porat et al., 2000b). Thus, defensive mechanisms were induced within the fruit that inhibited growth of the decay organisms. Though effective on *Penicillium* molds, it is unclear if these short-duration, high temperature treatments will effectively reduce stem-end rot (SER) without causing injury to the fruit. In Florida, Hayward et al. (1962) showed that a 4 min, 120 °F (49 °C) hot water treatment greatly reduced postharvest decay due to *Penicillium* mold, but had no effect on decay due to stem-end rot (SER). The present studies were initiated to, 1) determine the tolerance of Florida grapefruit to different short-duration, high-temperature vapor heat or hot water treatments, and 2) evaluate the ability of these treatments to reduce naturally occurring decay (especially SER) on Florida grapefruit.

Materials and Methods

Vapor heat on 'Marsh' grapefruit (Mar. 2002). In a preliminary experiment, 'Marsh' grapefruit were obtained on 18 Mar. 2002 from a Vero Beach, Fla. packinghouse. The fruit

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had good color and were not degreened. Fruit were washed at the Indian River Research and Education Center (IRREC) the same day and held at ambient temperatures overnight. The following day the fruit were transported to the United States Department of Agriculture (USDA), Citrus & Subtropical Products Laboratory in Winter Haven, Fla. where vapor-heat treatments were administered using a Biosteam prototype unit (Biosteam Technologies, Inc., San Antonio, Texas). The device controls temperature by adjusting vapor pressure inside the treatment chamber. Because the atmosphere was broken each time fruit were placed inside the chamber, taking 2 to 5 min for the desired temperature to be reestablished, administering short-duration heat treatments was difficult. Actual timing of the treatments began when the chamber reached the desired temperature. Control fruit received no heat treatment. Each time × temperature treatment consisted of 30 fruit (replicates). After the treatment, fruit were dried with a fan and transported back to the IRREC where they were coated with a shellac wax (HS 590, FMC Food Tech, Lakeland, Fla.) the following day and then held at 50 °F (10 °C) with 90% relative humidity (RH). Peel scalding and fruit decay was evaluated 6 and 13 d, respectively, after the heat treatments. Peel scalding for each fruit was rated on a scale from 0 (no scalding) to 10 (entire peel surface scalded). Most peel scalding was clearly visible after 6 d at 70 °F (21 °C).

Hot water dips of 'Marsh' and 'Ruby Red' grapefruit (May 2002). Late-season grapefruit were obtained from a Vero Beach, Fla. packinghouse on 1 May 2002. During washing at the IRREC the following day, it was discovered that the bins contained a mixture of 'Marsh' and 'Ruby Red' grapefruit. Because such late-season grapefruit were difficult to obtain, it was decided to continue with the heat treatments using replicates containing a random mixture of both varieties.

For all hot water dip treatments at the IRREC, about 24 gallons (90 L) of rapidly stirred water was heated using gas burners. Fruit were treated by placing about 20 fruit (one replicate) into slatted crates which allowed good water circulation past the fruit. Fruit were then dipped in water at one of six temperatures between 122 °F (50 °C) and 149 °F (65 °C) for between 10 and 180 s. Control fruit for all hot water treatments were dipped in water at ambient temperatures (~80 °F; 27 °C) for 120 s. Each treatment had three replicates. During the treatments, water temperature dropped less than 0.5°F (0.3 °C). The fruit were then air-dried using electric fans, placed in 28.2 L (4/5 bu) corrugated fiberboard citrus cartons, and stored at 50 °F (10 °C) with 90% RH. Most peel scalding was clearly visible after 2 to 3 weeks. Peel scalding and fruit decay were evaluated after 33 and 82 d, respectively, in storage. Peel scalding here and for the remaining experiments are reported as the percentage of fruit within each replicate showing any scald symptoms.

Hot water dips of 'Ruby Red' grapefruit (Oct. 2002). 'Ruby Red' grapefruit were obtained from a Vero Beach, Fla. packinghouse on 24 Oct. 2002 after being commercially degreened (~2 to 5 ppm ethylene at 85 °F (29 °C) for 3 d) and washed. The fruit had not been waxed. Treatments, replications, hot water dipping procedures, and storage conditions at the IRREC were as described above. Peel scalding and peel pitting was evaluated after 24 d in storage, and decay evaluated after 108 d.

Samples of the same fruit were also transported to Gainesville, Fla. on 25 Oct. and stored at 10°C for 3 d before heat treatments were administered. In this case, treatments consisted of three replications of 20 fruit each. The fruit were dipped in water at 122, 127, 133, 138, or 144 °F (50, 53, 56, 59 or 62 °C) for 60 s. As a control, fruit were dipped in water at 81.5 °F (27.5 °C). All dipping treatments in Gainesville were conducted using a laboratory scale fruit heating system (Model HWH-2, Gaffney Engineering, Gainesville, FL) capable of maintaining water temperatures up to 191 °F (55 °C), to a stability within ±3.6 °F (2.0 °C) of the initial water temperature for the first 4-5 min after submerging up to 32 kg of fruit with an initial fruit temperature of 20 °C. After dipping, the fruit were air-dried using an electric fan and stored at 20 °C with 95% RH for 1 week. Fruit respiration was measured each of the first six days after dipping using a static system. Peel scalding was evaluated on the seventh day.

Hot water dips of 'Ruby Red' grapefruit before or after degreening (Nov. 2002). To investigate the effect of degreening on fruit sensitivity to the heat-treatments, 'Ruby Red' grapefruit were harvest on 22 Nov. 2002 at the IRREC in Fort Pierce, Fla. and transported to Gainesville, Fla. on the same day, stored overnight at 50 °F (10 °C), and then exposed to one of the following treatments:

1) Degreening followed by a hot water dip
2) Hot water dip followed by degreening
3) Hot water dip only
4) Degreening only
5) Control (no hot water dip or degreening)

Hot water dips were conducted for 60 s using 144 °F (62 °C) water. Fruit were degreened for 3 d at 85 °F (29 °C) with 95% RH and 2-3 ppm ethylene. Fruit that were not degreened were held at 68 °F (20 °C) 95% RH while the other treatments were being degreened. Each treatment had three replicates of 20 fruit each. Following the treatments, fruit were stored at 68°F (20 °C) with 95% RH. Half of the fruit were evaluated for peel scalding after 7 d, and the remainder evaluated after 10 d.

Hot water dips of 'Marsh' grapefruit (Apr. 2003). 'Marsh' grapefruit were harvested from a commercial grove in Ft. Pierce, Fla. on 2 Apr. 2003 and held overnight at the IRREC at ambient temperatures. Treatments, replications, and hot water dipping procedures were as described above at the IRREC. Immediately after dipping, fruit were washed, waxed, placed into 28.2 L (4/5 bu) corrugated fiberboard citrus cartons, and stored at 50 °F (10 °C) with 90% RH. Peel scalding and fruit decay was evaluated after 19 and 69 d, respectively, in storage.

Statistical analysis. Percentage data were transformed to arcsine values and analyzed by ANOVA using SAS (PROC GLM) for PC (SAS Institute, Inc., Cary, N.C.). When differences were significant ($P < 0.05$), individual treatment means were separated using Duncan's Multiple Range Test ($P = 0.05$). Means presented are untransformed values.

Results and Discussion

Vapor heat on 'Marsh' grapefruit (Mar. 2002). Vapor heat treatments significantly affected both peel scalding (Table 1) and postharvest decay (data not shown) during storage at 50 °F (10 °C). Thirteen days after treatment, average scalding ranged from 0.00 in the control to 7.71 on fruit exposed to 138 °F (59 °C) water for 180 s (Table 1). A general time × temperature effect on scalding was observed. Exposure to 138 °F

Table 1. Peel scalding of 'Marsh' grapefruit after exposure to vapor heat on 19 March 2002 at different temperatures and durations. Fruit were evaluated after 13 days at 50 °F (10 °C) with 90% RH. Bolded values are significantly different from the control.

	Average peel scalding[z]			
Temperature	20 s[y]	60 s	120 s	180 s
122 °F (50 °C)	0.15 j[x]	**4.74 def**	0.35 ij	**4.08 efg**
127 °F (53 °C)	0.61 ij	0.23 j	0.35 ij	1.52 hij
133 °F (56 °C)	**2.10 hi**	**3.25 fgh**	**5.20 cde**	**7.65 a**
138 °F (59 °C)	0.58 ij	**6.48 abcd**	**1.66 hij**	**7.71 a**
144 °F (62 °C)	**3.26 fgh**	**5.43 bcde**	**2.78 gh**	**7.451 a**
149 °F (65 °C)	**7.00 ab**	**7.16 ab**	**6.88 abc**	**6.23 abcd**
Ambient		0.00 j		

[z]Scalding rated from 0 (no scalding) to 10 (entire peel surface scalded).
[y]Seconds.
[x]Values followed by unlike letters are significantly different by Duncan's multiple range test at $p < 0.05$.

(59 °C) water vapor for 20 s did not cause significantly more scalding than the control, whereas scalding was apparent following exposure to the same temperature for 60 to 180 s. In some cases [e.g., 122 °F (50 °C) for 60 s], scalding was unexpectedly large, which was likely due to variability caused by difficulty in applying precise treatments using the vapor heat system.

In this experiment, decay was observed in only 6% of control fruit after 13 d storage at 50 °F (10 °C) while a few of the more severe hot vapor treatments increased decay (data not shown). No treatments resulted in significantly less decay than the control.

Hot water dips of 'Marsh' and 'Ruby Red' grapefruit (May 2002). Hot water dips of late-season 'Marsh' and 'Ruby Red' grapefruit significantly affected both peel scalding and decay after storage at 50 °F (10 °C) (Tables 2 and 3). Treatment responses between 'Marsh' and 'Ruby Red' grapefruit appeared similar. Peel scalding showed a clear time × temperature relationship: highest safe treatments were 138°F (59 °C) for 10 s, 133 °F (56 °C) for 20 to 60 s, and 127 °F (53 °C) for 120 s. In

Table 2. Peel scalding on a mixture of 'Ruby Red' and 'Marsh' grapefruit after dipping on 2 May 2002 in water at different temperatures and durations. Fruit were evaluated after 33 days at 50 °F (10 °C) with 90% RH. The jagged horizontal line separates treatments significantly different from the control from those that were similar to the control.

	Percentage of fruit with peel scalding				
Temperature	10 s[z]	20 s	30 s	60 s	120 s
122 °F (50 °C)	0.0 f[y]	0.0 f	1.7 f	0.0 f	0.0 f
127 °F (53 °C)	0.0 f	0.0 f	0.0 f	0.0 f	1.7 f
133 °F (56 °C)	0.0 f	1.7 f	0.0 f	12.5 f	57.3 d
138 °F (59 °C)	1.8 f	36.7 e	28.3 e	85.0 abc	83.7 bc
144 °F (62 °C)	31.7 e	78.8 c	89.8 abc	100.0 a	100.0 a
149 °F (65 °C)	93.3 ab	96.7 ab	100.0 a	100.0 a	100.0 a
Ambient					0.0 f

[z]Seconds.
[y]Values followed by unlike letters are significantly different by Duncan's multiple range test at $p < 0.05$.

Table 3. Stem-end rot on a mixture of 'Ruby Red' and 'Marsh' grapefruit after dipping on 2 May 2002 in water at different temperatures and durations. Fruit were evaluated after 82 days at 50 °F (10 °C) with 90% RH. The jagged horizontal line separates most treatments which were significantly different from the control from those that were similar to the control.

	Stem-end rot (%)				
Temperature	10 s[z]	20 s	30 s	60 s	120 s
122 °F (50 °C)	46.7 a[y]	38.3 ab	25.0 abcdef	27.5 abcd	26.7 abcd
127 °F (53 °C)	25.7 abcde	13.6 cdefg	25.0 abcdef	35.8 ab	18.0 abcd
133 °F (56 °C)	25.4 abcde	33.3 abc	20.2 bcdef	36.8 ab	8.3 efgh
138 °F (59 °C)	3.5 hi	8.3 fgh	5.0 ghi	5.0 ghi	0.0 i
144 °F (62 °C)	10.0 defghi	4.8 ghi	5.2 ghi	0.0 i	23.3 bcdef
149 °F (65 °C)	1.7 hi	1.7 hi	3.3 hi	18.5 bcdef	3.5 ghi
Ambient					33.3 abc

[z]Seconds.
[y]Values followed by unlike letters are significantly different by Duncan's multiple range test at $p < 0.05$.

five of the most severe treatments, peel scalding was present on 100% of the fruit.

Hot water dips also reduced the development of stem-end rind breakdown (SERB; data not shown), a physiological disorder characterized by the irregular collapse and darkening of rind tissue around the stem end of citrus fruit. In all but one treatment, fruit exposed to temperatures of 138 °F (50 °C) to 149 °F (65 °C), SERB was significantly reduced (mean = 8%) compared to the control (mean = 37%).

Practically all of the decay in these fruit was associated with SER (primarily *Diplodia natalensis*; data not shown), which was highest in the control fruit and fruit exposed to the least severe treatments (Table 3). In general, decay caused by SER was reduced when dipping temperatures reached 138°F (59 °C) and above for 10 to 60 s, and 133 °F (56 °C) for 120 s. The rise in SER in two of the more severe treatments was likely due to the extensive heat-induced peel injury weakening tissue resistance to subsequent pathogen attack. Thus, heat-treatments alone can reduce decay due to natural infections of SER organisms. However, only 138 °F (59 °C) for 10 s significantly reduced SER without causing significant peel scalding. *Penicillium commune* was found growing on 22% to 54% of the fruit exposed to the most severe treatments [149 °F (65 °C) for 60 or 120 s, and 144 °F (62 °C) for 120 s] and was incapable of infecting inoculated, but otherwise healthy fruit (data not shown).

Hot water dips of 'Ruby Red' grapefruit (Oct. 2002). Hot water dips of early-season 'Ruby Red' grapefruit again showed a clear time × temperature relationship in terms of peel scalding (Table 4). In this case, the highest safe treatments were slightly lower than those observed in the previous hot water experiment. Treatments of 138 °F (59 °C) for 10 s and 133 °F (56 °C) for 30 and 60 s caused significant scalding this time, but did not in the previous experiment. Furthermore, 100% of the fruit were scalded in 10 of the more severe treatments, which was double that found in the previous experiment. In these experiments, heat-treatments had virtually no effect on the development of SERB; only two treatments were significantly different from each other and nothing was significantly different from the control (data not shown).

Table 4. Peel scalding on 'Ruby Red' grapefruit after dipping on 25 Oct. 2002 in water at different temperatures and durations. Fruit were evaluated after 24 days at 50 °F (10 °C) with 90% RH. The jagged horizontal line separates treatments significantly different from the control from those that were similar to the control.

	Percentage of fruit with peel scalding				
Temperature	10 s[z]	20 s	30 s	60 s	120 s
122 °F (50 °C)	1.7 e[y]	0.0 e	0.0 e	0.0 e	0.0 e
127 °F (53 °C)	3.3 e	1.7 e	0.0 e	5.0 e	3.3 e
133 °F (56 °C)	1.7 e	8.3 e	28.2 d	53.3 bc	95.0 a
138 °F (59 °C)	35.0 cd	55.0 b	88.3 a	100.0 a	100.0 a
144 °F (62 °C)	32.3 d	98.3 a	100.0 a	100.0 a	100.0 a
149 °F (65 °C)	100.0 a	100.0 a	100.0 a	100.0 a	100.0 a
Ambient					0.0 e

[z]Seconds.
[y]Values followed by unlike letters are significantly different by Duncan's multiple range test at $p < 0.05$.

Surprisingly, a significant number of fruit developed peel pitting resembling symptoms of chilling injury (CI) (Table 5). Pitting was not associated specifically with the oil glands and the fact that the fruit were not waxed would appear to preclude the possibility that the postharvest pitting was similar to that described by Petracek et al. (1995). Though grapefruit usually do not develop CI at storage temperatures of 50 °F (10 °C) and above, there are reports of such response (Grierson and Hatton, 1977). The fruit used in this study had received no wax or fungicide treatments, which usually provide commercial packers some protection against CI (Vakis et al., 1970; Wardowski et al., 1975). Peel pitting in this experiment ranged from 0% in the control to 75% of the fruit treated at 138 °F (59 °C) for 120 s. Most heat treatments resulted in some pitting with eight treatments resulting in significantly more pitting than the control. Heat-treatments have been reported to reduce CI in citrus (Rodov et al., 1995) and if the pitting was CI, we have no explanation as to why heat-treatment in our study produced the opposite effect.

While there were significant differences in decay, most decay was due to anthracnose (*Colletotrichum gloeosporioides*) associated with the pitting (data not shown). Total decay tended to be most severe on fruit treated at 138 °F (59 °C) to 149 °F (65 °C).

Table 5. Peel pitting on 'Ruby Red' grapefruit after dipping on 25 Oct. 2002 in water at different temperatures and durations. Fruit were evaluated after 24 days at 50 °F (10 °C) with 90% RH. Bolded values are significantly different from the control.

	Peel pitting (%)				
Temperature	10 s[z]	20 s	30 s	60 s	120 s
122 °F (50 °C)	10.0 efg[y]	3.8 fg	10.0 efg	1.7 fg	0.0 g
127 °F (53 °C)	3.3 fg	6.7 efg	3.3 fg	18.3 cdefg	11.7 efg
133 °F (56 °C)	1.7 fg	18.3 cdefg	13.9 defg	21.7 cdefg	**36.7 cde**
138 °F (59 °C)	21.7 cdefg	30.3 cdefg	26.7 cdefg	**66.7 ab**	**75.0 a**
144 °F (62 °C)	25.0 cdefg	28.3 cdefg	**46.7 bc**	**44.6 bcd**	6.7 efg
149 °F (65 °C)	**43.3 bcd**	**46.7 bc**	20.0 cdefg	3.3 fg	**33.3 cdef**
Ambient					0.0 g

[z]Seconds.
[y]Values followed by unlike letters are significantly different by Duncan's multiple range test at $p < 0.05$.

On fruit transported to Gainesville, stored for 3 d at 50 °F (10 °C), and then treated for 60 s at 122 °F (50 °C) to 144 °F (62 °C), significant peel scalding developed only in fruit treated at 138 or 144 °F (59 °C or 62 °C) (data not shown). Thus, fruit were able to withstand slightly higher temperatures than the fruit treated at the IRREC. This suggests that pretreatment storage conditions (3 d at 50 °F) may influence tolerance to the hot water dips. Alternatively, while both hot water dip systems provided good temperature control and water movement across the fruit, slight differences in the two systems may contribute to the slightly different results. There was no fruit decay by the completion of the experiment in Gainesville (10 d after treatment).

Fruit respiration was highest 1 d after the heat treatments and generally declined over the next 5 d (Fig. 1). Peel scalding was worst (83%) on fruit treated at 144 °F (62 °C) and the respiration of these fruit remained significantly higher than the other treatments during the 6 d evaluation. Fruit treated at 138 °F (59 °C) developed mild scalding (13%) and respiration, though high 1 d after the treatment, dropped by the second and third days to levels similar to the other, non-injurious treatments.

Hot water dips of 'Ruby Red' grapefruit before or after degreening (Nov. 2002). While pretreatment conditions may have altered heat sensitivity of fruit in the previous experiment, warm temperatures and ethylene during degreening before or after the heat treatments (144 °F for 60 s) did not significantly affect peel scalding (data not shown). Between 43% and 50% of all heat-treated fruit developed peel scalding, while none of the fruit only degreened or control fruit were scalded. There was no fruit decay by the completion of the experiment (10 d after treatment).

Hot water dips of 'Marsh' grapefruit (Apr. 2003). Late-season 'Marsh' grapefruit that were immediately washed and waxed after the heat treatments developed much less visible peel scalding (Table 6). In this case, even 149 °F (65 °C) for 10 s did not cause significantly greater scalding than the control.

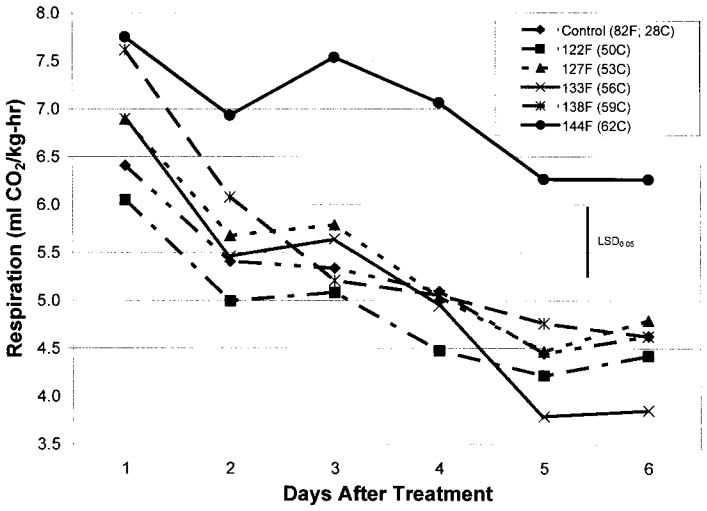

Fig. 1. Respiration of 'Ruby Red' grapefruit after a 60 second dip in water at different temperatures. Heat treatments were administered on 28 Oct. 2002 and respiration monitored for 7 days at 68 °F (20 °C; 90% RH). Vertical bar represents the 5% LSD value.

Table 6. Peel scalding on 'Marsh' grapefruit after dipping on 3 Apr. 2003 in water at different temperatures and durations. Fruit were evaluated after 19 days at 50 °F (10 °C) with 90% RH. Fruit were washed and waxed immediately after heat-treatments. The jagged horizontal line separates treatments significantly different from the control from those that were similar to the control.

	Percentage of fruit with peel scalding				
Temperature	10 s[z]	20 s	30 s	60 s	120 s
122 °F (50 °C)	0.0 f[y]	0.0 f	0.0 f	0.0 f	0.0 f
127 °F (53 °C)	0.0 f	0.0 f	0.0 f	0.0 f	0.0 f
133 °F (56 °C)	0.0 f	1.7 f	0.0 f	0.0 f	0.0 f
138 °F (59 °C)	0.0 f	0.0 f	3.3 f	11.7 ef	35.0 cde
144 °F (62 °C)	31.7 def	1.8 f	18.3 ef	68.3 ab	76.7 ab
149 °F (65 °C)	19.6 def	81.7 ab	93.1 a	67.7 abc	50.3 bcd
Ambient					0.0 f

[z]Seconds.
[y]Values followed by unlike letters are significantly different by Duncan's multiple range test at $p < 0.05$.

Scalding symptoms in these fruit were also more difficult to see. Scalding was more translucent in appearance or developed as a rougher area on the peel. The scalded areas of the peel eventually became grayish-brown and did not become as dark as in previous experiments. Immediately cooling the fruit after the heat treatment was likely an important factor in the reduced scalding, as has been observed with hot water-treated mangoes (Shellie and Mangan, 2002). In addition, waxing the fruit may slow water loss and oxidation of browning compounds in the peel that are involved in symptom development. SERB was not observed in these experiments.

SER was again the primary decay-causing organism but its occurrence was not significantly reduced by treatments that did not cause peel scalding (data not shown). Penicillium only appeared at significant levels on the three most severe treatments.

Conclusions

In the present studies, we have shown that peel scalding in Florida grapefruit demonstrates a typical time × temperature response to various heat treatments. However, the tolerance to specific heat treatments may shift depending on various pre- and post-treatment factors such as harvest time during the season, pre-treatment storage conditions, and post-treatment washing and waxing. The data also show that hot water treatments can reduce decay from SER in Florida citrus, but that in almost all cases, such treatments will result in peel scalding on the fruit. Thus, heat treatment alone does not appear to be a commercially feasible approach to reduce postharvest decay of fresh Florida grapefruit. However, recent studies suggest that combining sodium bicarbonate or other additives with hot water dip or spray treatments may reduce post harvest decay without significant peel injury (Porat et al., 2002). There is an additional advantages to use of hot water treatments on fresh citrus, in that fungicides are more effective and can be used at lower concentrations compared to unheated fungicide solutions (Schirra and Mulas, 1995). The relevance of these approaches to Florida fresh citrus will be investigated in future research.

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