

Effect of Pre- and Postharvest Factors on Fresh Grapefruit Peel Breakdown

MARK A. RITENOUR^{1*}, BRIAN J. BOMAN¹, CUIFENG HU¹, JACQUELINE K. BURNS²,
AND JEAN BERTRAND CONTINA³

¹University of Florida, IFAS, Indian River Research and Education Center, 2199 S. Rock Road,
Ft. Pierce, FL 34945

²University of Florida, IFAS, Citrus Research and Education Center, 700 Experiment Station Road,
Lake Alfred, FL 33850

³Pan-American Agricultural School, Zamorano, Honduras

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During the 2006–07 and 2007–08 fresh citrus seasons, reports of peel breakdown problems were more frequent and severe than usual. Plots were established during the 2007–08 season in commercial groves using standard fresh fruit growing practices to evaluate pre- and postharvest factors influencing peel breakdown. Preharvest treatments included up to three foliar potassium (K) sprays (March, October, and January) or withholding irrigation for up to 2 months before harvest. In one commercial block, foliar mono-potassium phosphate (MKP) was applied at 23.5 lb MKP per acre (0–52–34; 8 lb K₂O per acre) with 4 lb per acre low-biuret urea (46–0–0) applied at a total volume of 125 gal per acre. In another block, the grower applied 3 gal per acre of a commercial 3–18–18 formulation at a total volume of 250 gal per acre. Postharvest treatments included holding fruit for 3 days at 30%, 55%, or 100% (including wetting the fruit) RH before washing and storing at 70 °F under ambient RH. In the first block, preharvest foliar MKP treatments applied 2 months or more before harvest did not significantly reduce peel breakdown. However, stem-end rind breakdown was significantly reduced in the second block with foliar 3–18–18 applied 2, 3, or 4 weeks before harvest. Blocking irrigation and rainfall for 49 days before harvest increased peel breakdown, whereas wetting the fruit after harvest and maintaining high postharvest RH reduced peel breakdown.

Practically every season, reports of various peel breakdown disorders on fresh citrus appear at harvest, in the packinghouse, or worse, at destination markets. During the recent 2006–07 and 2007–08 seasons, peel breakdown problems were particularly severe and did not appear to be caused by chilling injury or post-harvest pitting (Petraček et al., 1995). Symptoms of peel pitting usually appeared during the winter months, especially after cool and/or windy weather (Agusti et al 1997; Alferez et al., 2005; Vercher et al., 1994), and progressed into the spring as stem-end rind breakdown (SERB; Ritenour and Dou, 2003), when trees were flushing/flowering and temperatures were warming. Recent studies have shown that sudden changes in relative humidity (RH; e.g., from 30% to 90%) after harvest can cause peel pitting of Florida citrus (Alferez and Burns, 2004; Alferez et al., 2005). The importance and impact of this phenomenon under commercial conditions is not known.

Of the preharvest factors, plant nutrition (especially N and K) and water stress have been suggested as potential factors influencing the susceptibility of citrus fruit to postharvest peel breakdown (Alferez et al., 2005; Grierson, 1965). For example, SERB has been reported by some to be more severe when fruit are harvested from water-stressed trees compared to non-stressed trees, whereas others have found no significant relationship (Grierson, 1965). In

addition, researchers in other countries have found that nutritional imbalances involving high N and low K may predispose fruit to SERB (Chapman, 1958; Grierson, 1965). While no conclusive relationship between plant water stress, low K, high N, and SERB development under Florida conditions has been determined, consistent trends in previous data support further study.

Low plant K levels have also been associated with other citrus peel disorders such as creasing and pineapple orange peel pitting (Petraček et al., 1995). Increased K fertilization has been reported to increase fruit size, weight, vitamin C content, and fruit storage potential. Though high levels of K fertilization may have some negative effects, such as decreased sugar to acid ratio and color development, foliar K applications have been reported to increase size by 0.1 to 0.2 inches without decreasing sugar to acid ratios, Brix, acid or juice contents and with no increase in peel thickness (Boman, 1997; Boman and Hebb, 1998).

The current research was conducted to evaluate the potential effects of plant water stress and preharvest foliar K applications on peel breakdown of red and white grapefruit. In addition, the effects of holding fruit under different RH conditions after harvest and the effects of different packingline treatments on peel breakdown were also evaluated. The goal is to better predict when the disorders will occur and to develop practices to reduce or eliminate the occurrence of peel breakdown.

Materials and Methods

‘MARSH’ WHITE GRAPEFRUIT BLOCK. Trees of ‘Marsh’ white grapefruit on ‘Sour Orange’ rootstock planted in 1975 in a com-

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*Corresponding author; email: ritenour@ufl.edu; phone: (772) 468-3922

mercial grove in Vero Beach, FL, were selected for preharvest treatments during the 2007–08 season. Trees were grown using commercial fresh fruit production practices. Only healthy, uniform trees were chosen for the experiments. Each treatment contained four replicates, arranged in a randomized block design, and each replicate consisted of three trees. Trees were either sprayed with a foliar mono-potassium phosphate (MKP) solution at different times of the year, exposed to water stress, or left untreated (control). For the MKP treatments, a solution of MKP (0–52–34; 23.5 lb MKP per acre; 8 lb K₂O per acre) with 4 lb per acre low-biuret urea (46–0–0) was applied up to three times throughout the season using an air-blast sprayer at a total volume of 125 gal per acre. The MKP solution was applied postbloom (24 May 2007), late summer (11 Oct. 2007) and/or 2 months before harvest (10 Jan. 2008). To induce water stress, 13 × 17 ft plastic sheets were laid under the drip lines, centered under each tree and staked to the ground up to 49 d before harvest. Though rain and irrigation were intercepted from a large portion of the soil surface above the root zone, the trees were not visibly wilted at the time of harvest.

Fruit were harvested from the blocks three times on 3–4 Jan., 10 Mar., and 28 Mar. 2008. The first harvest occurred before the final MKP application and installation of plastic because a cold front passed through the area producing windy, low RH conditions that are often associated with increased peel disorders. The third harvest was small and included fruit from only control and water stressed trees. During the first harvest, 40 fruit from each replicate were harvested randomly from the trees, placed into ventilated plastic crates, and transported by van to the Indian River Research and Education Center (IRREC) in Ft. Pierce, FL. The fruit were washed on 4 Jan. with an alkali surfactant solution (Fruit Cleaner 395, FMC Corporation), coated with shellac wax (Sta-Fresh 590 HS, FMC Corporation) without fungicide, and then stored at 50 °F with ~90% RH. On 31 Jan. the fruit were transferred to the floor of the air-conditioned IRREC postharvest facility with a room temperature ~73 °F and 70% RH to help promote peel breakdown. Fruit were then evaluated weekly for peel breakdown and decay.

Fruit were handled similarly for the second harvest, except that 60 fruit per replicate were harvested and held at 70 °F with 55% RH for 3 d prior to washing. Furthermore, the fruit was coated with carnauba wax (Sta-Fresh 2109, FMC Corporation) and then immediately stored on the floor of the air-conditioned IRREC postharvest facility. For the third harvest, fruit were handled similar to the second harvest except that 50 fruit per replicate were used and the fruit was not waxed.

‘STAR RUBY’ RED GRAPEFRUIT BLOCK. An entire commercial block of ‘Star Ruby’ red grapefruit on ‘Sour Orange’ rootstock planted in 1978 in Vero Beach, FL, was sprayed on 31 Jan. 2008 with a pH-adjusted MKP solution (Helena Chemical Co., Ft. Pierce, FL) containing 7.2 lb K₂O and 0.96 lb N per acre at a total volume of 250 gal per acre. Control trees were left unsprayed. Each treatment contained four replicates, arranged in a randomized block design, and each replicate consisted of an entire row of trees. Trees were grown using commercial fresh fruit production practices. Two, 3, and 4 weeks after MKP application, 50 fruit per replicate were harvested randomly from healthy trees, exposed to different postharvest treatments (see below for details), stored on the floor of the air-conditioned IRREC postharvest facility (~73 °F, 70% RH), and then evaluated weekly for the development of peel breakdown and decay.

POSTHARVEST TESTS. Postharvest tests were added to the preharvest tests for the above ‘Star Ruby’ fresh grapefruit blocks in

a factorial design, or fruit were harvested from untreated trees in both the ‘Star Ruby’ and ‘Marsh’ blocks and exposed to different postharvest treatments. ‘Marsh’ fruit came from a different section of the block used for the MKP plots where fruit set was better and fruit size was smaller. Harvested fruit were transported to the IRREC and held at 70 °F with 30%, 55%, or 95% RH. Fruit under 95% RH were drenched with tap water and had wet rags placed over the top of each stack of four crates (reps) before being placed in the temperature- and RH-controlled room. After 3 or 4 d under these conditions, fruit were washed as before and some fruit were coated with carnauba wax (Sta-Fresh 2109, FMC Corporation) or carnauba wax plus either 2,000 ppm thiabendazole (TBZ; FMC Corporation) or 2,000 ppm Imazalil (FMC Corporation). Because some have reported increased peel breakdown after incomplete rinsing of detergent from the fruit (Petracek et al., 2006), one set of fruit was washed but not rinsed or waxed. Each treatment consisted of 4 replicates of 50 fruit each. As before, the fruit was then stored on the floor of the air-conditioned IRREC postharvest facility (~73 °F, 70% RH), and evaluated weekly for the development of peel breakdown and decay.

STATISTICAL ANALYSIS. Percentage data were transformed to arcsine values and all data was analyzed by analysis of variance using SAS (PROC GLM) for PC (SAS Institute Inc, Cary, N.C.). When differences were significant ($P \leq 0.05$), individual treatment means were separated using Duncan’s multiple range tests ($P = 0.05$). Means presented are untransformed values.

Results and Discussion

‘MARSH’ WHITE GRAPEFRUIT BLOCK. None of the foliar MKP treatments from the first two ‘Marsh’ grapefruit harvests, or water stress treatment from the second harvest, resulted in significant differences in marketable fruit, fruit decay, or peel disorders (data not shown). Although peel breakdown did occur, development was slow and not as severe in this block as in the previous year. A contributing factor may have been the relatively poor fruit set and large fruit sizes that occurred in the section of the block where the plots were located. Larger fruit are more susceptible to postharvest peel pitting (Petracek et al., 1995), but less susceptible to SERB (Grierson, 1965). SERB development in fruit from the first harvest was likely inhibited further by storing the fruit at 50 °F for almost a month (Dou et al., 2001). Fruit from all other harvests were never held below 70 °F.

A third harvest of fruit from control and water stress plots was possible 49 d after installing the plastic covers. Although the plants were still not visibly wilted, fruit from the water stress treatments developed significantly more peel pitting and overall peel breakdown after storage than control fruit, resulting in significantly less overall healthy fruit (Table 1). Interestingly, although SERB might be expected to be more severe in fruit from water-stressed trees (Grierson, 1965), such fruit did not develop significantly more SERB; only the pitting form of peel breakdown was significantly increased. While stem-end rot (SER; primarily *Lasiodiplodia theobromae*), green mold (*Penicillium digitatum*), and total decay tended to be more prevalent in fruit from water stressed trees, the differences were not significant.

‘STAR RUBY’ RED GRAPEFRUIT BLOCK. ‘Star Ruby’ red grapefruit harvested 2, 3, or 4 weeks after MKP application resulted in significantly less SERB and total peel breakdown and significantly more marketable fruit than the control after storage (Table 2). Relatively little peel pitting developed and treatment differences were nonsignificant. Postharvest decay was also not

Table 1. Percentage of fruit with visible symptoms of decay or peel breakdown when harvested 49 d after blocking irrigation and rain with large plastic sheets fastened to the ground under trees and drip emitters. Fruit were held at 70 °F with 55% RH for 3 d before washing (no wax or fungicides used), storing under air-conditioned room temperatures of ~73 °F and 70% RH, and evaluated on the indicated days.

Days after harvest	Treatment	Marketable (%)	Stem-end rot (%)	Penicillium (%)	Total decay (%)	Peel pitting (%)	Stem-end rind breakdown (%)	Total peel breakdown (%)
13	Control	91.33 a ²	3.33	1.33	3.33	2.67	3.33	6.00 a
	Water def.	78.67 b	5.33	4.67	5.33	10.00	6.00	16.00 b
	Significance	*	NS	NS	NS	NS	NS	*
25	Control	81.00 a	4.67	1.33	5.33	3.33 a	13.00	14.33
	Water def.	60.00 b	15.33	6.00	17.33	11.33 b	13.33	24.00
	Significance	*	NS	NS	NS	*	NS	NS

²Values within each column followed by unlike letters are significantly different by Duncan's multiple range test at $P \leq 0.05$.

³Irrigation and rain withheld for 49 days prior to harvest.

NS, *Nonsignificant or significant at $P \leq 0.05$, respectively.

Table 2. Percentage of 'Star Ruby' red grapefruit with visible symptoms of decay or peel breakdown following harvest 2, 3, or 4 weeks after MKP application in the field. Harvested fruit were exposed to different postharvest treatments and then stored for the indicated days under air-conditioned room temperatures ~73 °F with 70% RH.

Harvest ² (weeks)	Days after harvest ³	Treatment	Marketable (%)	Total decay (%)	Pitting (%)	Stem-end rind breakdown (%)	Total peel breakdown (%)
2	25	Control	70.50 a ⁴	1.00	1.00	27.50 a	27.50 a
		MKP	86.50 b	1.00	1.50	11.00 b	11.00 b
		Significance	**	NS	NS	**	**
3	27	Control	82.58	10.25	1.67	7.67 a	9.33 a
		MKP	85.70	9.66	0.67	2.64 b	2.97 b
		Significance	NS	NS	NS	*	*
4	12	Control	64.32 b	2.52	6.87	25.32 a	32.10 a
		MKP	72.89 a	3.19	4.61	18.89 b	23.50 b
		Significance	***	NS	NS	***	***

²Weeks after MKP application.

³Fruit evaluated after storage for the indicated number of days.

⁴Values within each column followed by unlike letters are significantly different by Duncan's multiple range test at $P \leq 0.05$.

NS, *, **, ***Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively.

significantly affected by the preharvest MKP treatments. The current data supports Grierson's (1965) suggestion that higher K levels in citrus fruit reduces development of SERB after harvest. Because fruit from the 3rd and 4th week harvests were given different postharvest treatments (see postharvest tests section), differences in peel breakdown and decay between harvests are not directly comparable.

While nutrient analysis of leaf and fruit peel tissues were taken of both the 'Marsh' and 'Star Ruby' treatments, no significant differences were detected (data not shown). In particular, fruit peel K levels were quite variable from fruit to fruit and the source of the variability is not clear. Further tests are needed to clarify how MKP applications affect K content of both leaves and fruit, especially during the first 2 months after application.

POSTHARVEST TESTS. Holding fruit under high (95%) RH conditions for 3 d after harvest significantly reduced peel breakdown compared to storage at 30% RH (Tables 3 and 4). In 'Star Ruby' grapefruit, peel pitting was significantly increased but SERB only tended to increase after storage for 3 d at 30% RH (Table 3). However, in 'Marsh' grapefruit SERB significantly increased by the 30% RH treatment, with peel pitting only tending to be increased (Table 4). Peel breakdown of 'Star Ruby' grapefruit held at 55% RH was not significantly different from fruit held at 30% RH (Table 3), whereas in 'Marsh' grapefruit it was not significantly different from fruit held at 95% RH (Table 4). Spraying the fruit with tap water (no sanitizer added) and keeping the fruit

under very high RH conditions did not increase decay compared to holding fruit at 30% or 55% RH (Tables 3 and 4). On the contrary, in 'Star Ruby' grapefruit, total decay was significantly reduced (Table 3).

Wax treatments with fungicide were added because of anecdotal reports suggesting that inclusion of a fungicide, such as thiabendazole (TBZ) or Imazalil, may reduce postharvest peel breakdown of citrus. As expected, inclusion of TBZ significantly reduced the development of postharvest decay in both tests (Tables 3 and 4). However, it is unclear why Imazalil did not have a similar effect. On the other hand, while peel pitting and SERB are considered physiological disorders and not likely to be reduced by fungicides, Imazalil did significantly reduce peel breakdown from SERB in 'Star Ruby' grapefruit (Table 3), but gave no benefit in 'Marsh' grapefruit (Table 4).

Waxing by itself did not significantly influence the development of peel breakdown in either test (Tables 3 and 4). This is surprising given the long-standing recommendation to quickly wax fruit after washing to reduce the occurrence of SERB (McCornack and Grierson, 1965; Ritenour and Dou, 2003). Waxing usually had no significant effect on decay, except for total decay of 'Star Ruby' grapefruit, where it was significantly increased (Tables 3 and 4). Even more surprising is that, except for a slight increase in green mold in one test, removing fruit from the packingline immediately after washing, so that detergent residue (visible foam) was left on the fruit, did not affect subsequent de-

Table 3. Percentage of 'Star Ruby' red grapefruit with visible symptoms of decay or peel breakdown following harvest, storage for 3 d at 70 °F under different RH conditions, and exposure to different packingline treatments. Fruit were then stored under air-conditioned room temperatures of ~73 °F with 70% RH and evaluated 49 d after harvest.

Pre-run storage RH (%)	Packingline treatment	Marketable (%)	Stem-end rot (%)	Penicillium (%)	Total decay (%)	Pitting (%)	Stem-end rind breakdown (%)	Total peel breakdown (%)
30	Wax	24.51 d ^z	43.01 a	2.29 ab	51.16 a	16.23 a	13.44 a	23.90 a
55	Wax	35.29 d	46.25 a	4.62 ab	49.82 a	8.72 b	7.74 ab	14.89 ab
95	Wax	62.89 bc	26.41 abc	3.41 ab	29.75 b	0.50 de	6.85 ab	6.85 c
95	Wax + TBZ ^y	88.20 a	5.30 d	2.16 b	7.03 d	0.00 e	4.77 b	4.77 cd
95	Wax + Imazalil ^y	74.68 abc	20.48 bc	5.75 ab	22.94 bc	0.48 de	0.47 c	0.95 d
95	No Wax	76.51 ab	12.92 cd	0.95 b	12.98 cd	4.33 bc	6.22 ab	9.59 bc
95	No Rinse or Wax ^x	55.27 c	32.03 ab	12.94 ab	33.47 ab	1.92 cd	6.87 ab	8.79 bc
	Significance	***	***	NS	***	***	**	***

^zValues within each column followed by unlike letters are significantly different by Duncan's multiple range test at $P \leq 0.05$.

^yFungicides incorporated into the wax at 2000 ppm.

^xFruit removed from packingline immediately after washing without rinsing of the fruit cleaning detergent.

NS, **, ***Nonsignificant or significant at $P \leq 0.01$ or 0.001 , respectively.

Table 4. Percentage of 'Marsh' white grapefruit with visible symptoms of decay or peel breakdown following harvest, storage for 3 d at 70 °F under different RH conditions, and exposure to different packingline treatments. Fruit were then stored under air-conditioned room temperatures of ~73 °F with 70% RH and evaluated 43 d after harvest.

Pre-run storage RH (%)	Packingline treatment	Marketable (%)	Stem-end rot (%)	Penicillium (%)	Total decay (%)	Pitting (%)	Stem-end rind breakdown (%)	Total peel breakdown (%)
30	Wax	58.50 c ^z	25.00 a	1.50 bc	28.00 a	2.50 ab	12.50 a	14.00 a
55	Wax	75.00 bc	20.50 ab	2.50 bc	21.00 ab	1.00 ab	2.50 c	3.50 c
95	Wax	73.50 bc	19.00 ab	1.50 bc	19.50 ab	1.00 ab	6.00 ab	7.00 abc
95	Wax + TBZ ^y	95.50 a	1.00 c	0.00 c	1.00 c	0.50 b	3.00 bc	3.50 bc
95	Wax + Imazalil ^y	79.00 b	10.00 b	0.00 c	10.50 b	3.50 ab	6.50 ab	9.50 ab
95	No Wax	61.50 bc	25.00 a	3.50 ab	26.50 a	5.00 a	7.00 ab	12.00 a
95	No Rinse or Wax ^x	66.50 bc	22.50 ab	7.00 a	23.50 ab	3.00 ab	7.50 ab	10.00 ab
	Significance	***	***	**	***	**	*	*

^zValues within each column followed by unlike letters are significantly different by Duncan's multiple range test at $P \leq 0.05$.

^yFungicides incorporated into the wax at 2000 ppm.

^xFruit removed from packingline immediately after washing without rinsing of the fruit cleaning detergent.

NS, **, ***Nonsignificant or significant at $P \leq 0.05$, 0.01 or 0.001 , respectively.

cay or peel breakdown. Further investigation is needed to clarify the relationship between natural and applied waxes and SERB development and peel breakdown.

The current results demonstrate that peel breakdown can be reduced by preharvest foliar MKP application, preventing tree water stress, and keeping harvested fruit under high RH conditions. However, it is unclear how long a preharvest foliar MKP application will benefit the fruit. For example, one reason why MKP treatments might have failed on the 'Marsh' grapefruit is that fruit were harvested 2 months after application, whereas 'Star Ruby' grapefruit were harvested less than a month after application. Further evaluation is also needed to determine how peel nutrient (i.e., K and N) levels respond to MKP applications.

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