Proc. Fla. State Hort. Soc. 117:355-358. 2004.

POSTHARVEST PEEL PITTING IN CITRUS IS INDUCED BY CHANGES IN RELATIVE HUMIDITY

FERNANDO ALFEREZ[1] AND JACQUELINE K. BURNS
University of Florida, IFAS
Citrus Research and Education Center
Horticultural Sciences Department
700 Experiment Station Road
Lake Alfred, FL 33850

LORENZO ZACARIAS
Instituto de Agroquimica y Tecnologia de Alimentos (CSIC)
Valencia, Spain

Additional index words. water relations, grapefruit, tangerine, physiological disorder

Abstract. **Peel pitting at non-chilling temperatures remains an important problem during postharvest handling and storage of several citrus species, including Spanish 'Navelina' and 'Navelate' oranges and Florida 'Marsh' grapefruit and 'Fallglo' tangerines. The disorder is characterized by sunken areas on the flavedo and collapse of oil glands, followed by browning in advanced stages. Postharvest peel pitting results in decreased external quality and reduced value for fresh market fruit. Although the cause for this disorder is unknown, recent work demonstrated that altering peel water status through sudden changes in relative humidity during postharvest handling and storage can promote peel pitting. A period of low humidity followed by storage at high relative humidity triggered peel pitting. It was of interest to define threshold conditions necessary to promote peel pitting at harvest and during postharvest handling and storage. Studies were conducted to determine the effect of cumulative hours of dehydration before storage at high relative humidity on peel pitting, and to associate climatic conditions at the time of harvest with the incidence and severity of peel pitting. The results demonstrated that 3 hours of storage at low relative humidity induced peel pitting, and harvesting fruit when relative humidity was high greatly reduced the disorder.**

Postharvest peel pitting at non-chilling temperatures can be a severe disorder in several citrus varieties including Spanish varieties 'Navelina' (Lafuente and Sala, 2002) and 'Navelate' (Agusti et al., 2001) oranges, and Florida varieties 'Marsh' grapefruit (Petracek et al., 1995) and 'Fallglo' tangerines (Petracek et al., 1998). The disorder is characterized by the appearance of sunken areas of flavedo ('pits') that eventually spread and affect oil glands. In severe cases, pits may turn bronze in color and become necrotic. These symptoms diminish the commercial value of fruit for fresh market. In addition, the disorder is unpredictable, and its incidence and severity varies season-to-season or even during the same season.

Previous efforts have focused on the elucidation of the primary factor triggering this disorder. Petracek et al. (1998) related peel pitting with coating formulation and gas permeability, suggesting that the development of this disorder was caused by a reduction in internal O_2 and increase in CO_2. Yet, a low correlation was found between internal CO_2, O_2 and peel pitting, suggesting that other factors might be involved (Petracek et al., 1995). Some data suggested that alterations in peel water status might play a role in the origin of the disorder. Under field conditions in Spain, peel pitting was found in 'Navel' oranges after a few days of low relative humidity (RH) followed by a period of high RH (Agusti et al., 2001). Peel pitting in 'Navelina' orange was enhanced when RH increased after storage at 22 °C (Lafuente and Sala, 2002). Since then, increasing evidence indicated that variations in RH during postharvest handling and storage change the water status in fruit and lead to peel pitting in 'Navelina' and 'Navelate' oranges (Alferez et al., 2003) and in 'Marsh' grapefruit (Alferez and Burns, 2004).

The objective of this paper is to summarize results of peel pitting research obtained in Spain and Florida from studies conducted with 'Fallglo' tangerine and 'Marsh' grapefruit from 2002 to 2004.

Material and Methods

Plant material. Mature 'Marsh' grapefruit and 'Fallglo' tangerines were harvested at groves located in Lake Alfred and Haines City (Florida) during two consecutive seasons (2002-2003 and 2003-2004). In Valencia, Spain, mature 'Marsh' grapefruit were collected from commercial groves during the same seasons. Fruit of each variety were uniform in size and free from peel defects. Fruit were harvested and transported to each research facility and subjected to treatments indicated below. Fruit were placed in perforated plastic bins during storage.

Field-run fruit treatment. To study the effect of altering storage RH conditions at 20 ± 1 °C on the development of postharvest peel pitting in field-harvested fruit, 'Marsh' grapefruit were randomly divided into lots of 30 replicate fruit each. Four lots were stored up to 19 d at 30 ± 1% RH (VPD 1637 Pa) and another lot was kept at 90 ± 1% RH (VPD 233 Pa). After 3, 6 or 10 d of storage at 30% RH, a single lot of 30 fruit was transferred from 30% to 90% RH until the end of the experiment.

Washed and waxed fruit treatment. Five additional lots of 30 uniform fruit were washed on conventional commercial brushes on a packingline. Four lots were stored for up to 19 d at 20 ± 1 °C and 30 ± 1% RH. The remaining lot was kept at 90 ± 1% RH at the same temperature. After 3, 6 and 10 d, one lot was coated with commercial shellac-based wax (Sta-Fresh 590 HS from FMC Food Tech) over conventional commercial brushes and air-dried prior to transfer to 90% RH and 20 ± 1 °C until the end of the experiment.

Cumulative hours of dehydration and incidence and severity of pitting. Eight duplicated lots of 30 uniform 'Fallglo' tangerine fruit harvested in Haines City (Fla.) were used. Seven duplicated lots were stored for up to 21 d at 20 ± 1 °C and 30 ± 1% RH. The remaining duplicated lot was washed and waxed on conventional commercial brushes on the packing line immediately after harvest and kept at 90 ± 1% RH at the same temperature. After 2, 4, 8, 16, 24, 48 or 72 h, a duplicated lot was

This research was supported by the Florida Agricultural Experiment Station and approved for publication as Journal Series No. N-02612.

[1]Corresponding author.

washed, waxed and then transferred from 30% to 90% RH. This experiment was repeated twice: on 28 Oct. and 13 Nov. 2003. The same experiment was performed with 'Marsh' grapefruit harvested at CREC groves, and fruit were washed and waxed after 3, 6, 9, 12, 24, 48, and 72 h at 30% RH, and then transferred to 90% RH.

RH at harvest and development and severity of peel pitting. Fruit of 'Fallglo' tangerines and 'Marsh' grapefruit were harvested at 42% and 89% RH, and 39% and 94% RH, respectively. Temperature at both 'Marsh' harvests was 21 °C, whereas for 'Fallglo' temperatures were 26 and 24 °C. Fruit were divided into 4 duplicated lots of 30 fruit. Three duplicated lots were stored for up to 21 d at 20 ± 1 °C and 30 ± 1% RH. The remaining duplicated lot was washed and waxed on conventional commercial brushes on the packing line and kept at 90 ± 1% RH at 20 ± 1 °C. After 24 h, 3 d or 6 d, a duplicated lot was washed and waxed and then transferred from 30% to 90% RH.

Estimation of peel pitting index and cumulative weight loss. At various times during experiments, fruit were inspected and peel pitting quantified using a peel pitting index (PPI) estimate as previously described (Alferez et al., 2003). Briefly, fruit were rated on a scale from 0 (no pits) to 3 (severe pitting). The PPI was calculated according to the following formula previously reported for chilling injury and peel pitting by Lafuente et al. (1997, 2002):

$$\frac{\Sigma(\text{Peel pitting scale (0-3)} \times \text{number of fruit in each class})}{\text{total number of fruit}}$$

Cumulative percent weight loss was monitored and daily % weight loss rate calculated.

Results and Discussion

In this paper we report results of parallel experiments conducted in Florida and Spain designed to gain information about factors that promote postharvest peel pitting at non-chilling temperatures. Although the experimental conditions used in this study are not standard postharvest practices for citrus fruit, they have proven useful to understand factors causing the disorder (Alferez et al., 2003; Alferez and Burns, 2004).

Changes in relative humidity promote peel pitting during postharvest storage of citrus fruit. Results reported in this study demonstrate that changes in RH from low to high during storage promote peel pitting in citrus fruit. Experiments in Florida consistently showed that field-run 'Marsh' grapefruit stored at 30% RH for an increasing period of time (3, 6, or 10 d) followed by transfer to 90% RH developed peel pitting (Fig. 1A). Similar results were observed in Spain (data not shown), suggesting that changes in peel water status induced by exposure to low RH conditions followed by high RH storage results in peel pitting. The effect of washing and waxing grapefruit after 0, 3, 6 or 10 d of low RH storage was determined. Waxing fruit immediately after harvest had little effect on peel pitting, but if wax was applied after 3, 6 or 10 d after low RH storage followed by high RH storage for 3 weeks, PPI increased in 0.8, 0.85 and 0.9 units respectively (Fig. 1B). Taken together, these results demonstrate that waxing exacerbates, but is not required, for the development of peel pitting under these conditions.

Changing storage RH from low to high has been shown to alter fruit peel water condition (Alferez et al., 2003). We propose that symptom development is related to peel water status. When fruit is subjected to low RH, water is driven from

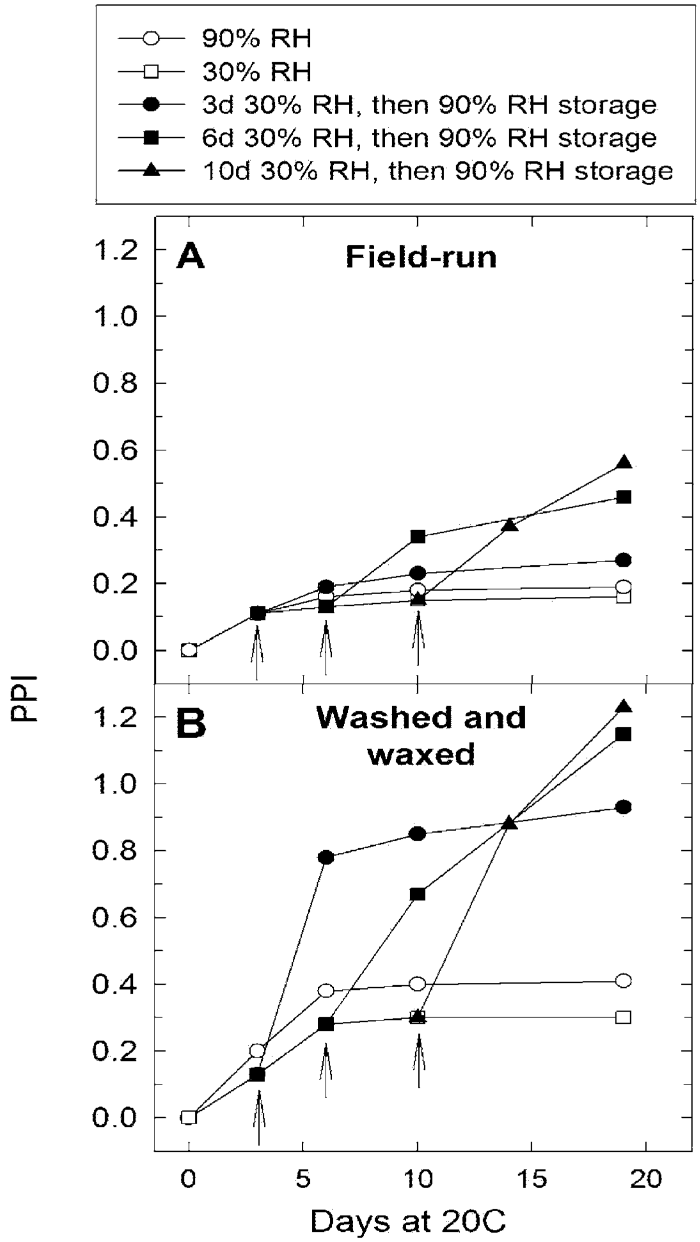

Fig. 1. Peel pitting index (PPI) in Marsh grapefruit stored at 20 ± 1 °C. Fruit were stored at 30% RH or 90% RH for 19 d, or stored for 3, 6 and 10 d at 30% RH before transfer to 90% RH for the remainder of the experiment. (A) Field-run fruit. (B) Washed and waxed fruit. Arrows depict the time of transfer from low to high RH storage.

flavedo epidermal cells to the atmosphere, reducing flavedo and later albedo water potential. Transfer of fruit to high RH reduces water pressure deficit and promotes water movement into internal flavedo and external albedo layers from the surrounding external atmosphere. Flavedo is rehydrated more quickly than albedo. Flavedo is the predominant source of water for dehydrated albedo (Kaufmann, 1970). As a result, tensions generated by the water-withdrawing force of albedo can cause collapse of the tissue (Agusti et al., 2001; Shomer and Erner, 1989) and peel pitting appears as depressed areas on the fruit surface.

Coating gas permeability, coating formulation and permeability of peel after coating have been related to peel pitting origin and development in some cultivars including

Table 1. Peel pitting index in 'Marsh' grapefruit and Fallglo' tangerine stored at 90% RH and 20 °C for 3 weeks after washing and waxing. Fruit were previously dehydrated for 0 to 10 d ('Marsh') or for 0 to 72 h by storage at 30% RH and 20 °C.[a]

Time of 30% RH storage	PPI after waxing and 3 weeks at 90% RH
'Marsh' grapefruit	
0 h	0.1 a
3 h	0.1 a
6 h	0.31 b
9 h	0.34 b
12 h	0.5 c
24 h	0.74 d
48 h	0.79 de
72 h	0.93 ef
6 d	1.15 f
10 d	1.2 f
'Fallglo' tangerine	
0 h	0.15 a
2 h	1.10 b
4 h	1.13 b
8 h	1.80 c
16 h	2.10 d
24 h	2.16 d
48 h	2.23 d
72 h	2.52 e

[a]For each cultivar, treatments with the same letter are not significantly different (Duncan's Multiple Range Test, $P < 0.01$).

'Marsh' grapefruit and 'Fallglo' tangerines (Petracek et al., 1995, 1998). The authors suggested that pitting was caused by reduction in fruit internal O_2 and increase in CO_2 levels, and the use of more permeable coatings and storage at lower temperature reduced postharvest peel pitting. However, low correlation was found between internal CO_2, O_2 and peel pitting (Petracek et al., 1995). We stored grapefruit at 5% CO_2 and 14% O_2, but were unable to produce peel pitting if there was no previous low RH storage treatment. These results demonstrate that peel water status, and not altered O_2 and CO_2 concentration, promoted peel pitting under these conditions.

Cumulative hours of dehydration affect severity of postharvest peel pitting. We found a significant correlation between duration of the dehydration period before transfer of fruit to high RH and PPI (Alferez and Burns, 2003). This result led us to examine the cumulative time of low RH storage necessary to develop peel pitting. For this purpose, 'Marsh' grapefruit and 'Fallglo' tangerine were stored at 30% RH for increasing periods of time and then washed, waxed and stored at 90% RH for 3 weeks. Our results showed that the longer the low RH storage period before transfer to high RH, the higher the PPI after the 3-week high RH storage period (Table 1). A significant linear correlation during the first 72 h of dehydration before waxing and storage at high RH in both cultivars was measured, but in 'Marsh' grapefruit, linearity was lost after 72 h, suggesting that other factors, such as albedo thickness or the rate of water loss from flavedo and albedo under longer-term dehydration conditions may be involved in the development of peel pitting (Alferez et al., 2004).

Preharvest RH affects susceptibility of fruit to peel pitting. Peel pitting in Spain has been related with periods of high evapotranspiration followed by sharp increases in field RH. The disorder has been observed in 'Navelate' fruit on the tree when periods of rain are followed by seasonal dry winds (Agusti et al., 2001), suggesting the involvement of preharvest RH. We harvested 'Fallglo' and 'Marsh' when RH was either low or high, but at similar temperatures. Fruit were transported to the packinghouse and subjected to conditions that promote peel pitting as described above. Harvesting fruit after a period of rainfall or at high RH reduced peel pitting incidence (Table 2). Fruit harvested at low RH developed severe peel pitting (PPI = 2.5) when transferred to high RH after a period of dehydration.

Table 2. Field RH at harvest affects development of peel pitting. Influence of RH in the field at harvest on peel pitting in 'Fallglo' tangerines and 'Marsh' grapefruit kept for 3 d ('Fallglo') or 6 d ('Marsh') at 30% RH and then washed, waxed, and transferred to 90% RH for 3 wk.

	RH field conditions			
Date of harvest	At harvest	Previous 2 d	Hours at 30% RH after harvest	PPI after 3 wk at 90% RH
'Fallglo' tangerines				
Date 1 28 Oct 2003	89%	70 to 96% rainy	0	0
			1	0
			3	0
Date 2 13 Nov 2003	42%	46 to 97% sunny	0	0.15 ± 0.02
			1	2.16 ± 0.20
			3	2.52 ± 0.30
'Marsh' grapefruit				
Date 1 11 March 2004	39%	30 to 90% sunny	0	0
			1	0.50 ± 0.03
			3	0.55 ± 0.04
			6	0.67 ± 0.02
Date 2 16 March 2004	94%	66 to 95% rainy	0	0
			1	0
			3	0
			6	0

PPI are shown as means ± SE.

Literature Cited

Agusti, M., V. Almela, M. Juan, F. Alferez, F. R. Tadeo, and L. Zacarias. 2001. Histological and physiological characterization of rind breakdown of Navelate sweet orange. Ann. Bot. 88:422-451.

Alferez, F., M. Agusti, and L. Zacarias. 2003. Postharvest rind staining in Navel oranges is aggravated by changes in storage relative humidity: effect on respiration, ethylene production and water potential. Postharvest Biol. Technol. 28:143-152.

Alferez, F. and J. Burns. 2004. Postharvest peel pitting at non-chilling temperatures in grapefruit is promoted by changes from low to high relative humidity during storage. Postharvest Biol. Technol. 32:79-87.

Alferez, F., L. Zacarias, and J. Burns. 2004. Cumulative hours of low relative humidity before storage at high relative humidity and relative humidity at harvest modulate the severity of postharvest peel pitting in citrus. J. Amer. Soc. Hort. Sci. (In press).

Lafuente, M. T. and J. M. Sala. 2002. Abscisic acid and the influence of ethylene, humidity and temperature on the incidence of postharvest rindstaining of Navelina oranges (*Citrus sinensis* L. Osbeck) fruits. Postharvest Biol. Technol. 25:49-57.

Petracek, P. D., L. Montalvo, H. Dou, and C. Davis. 1998. Postharvest pitting of 'Fallglo' tangerine. J. Amer. Soc. Hort. Sci. 123: 130-135.

Petracek, P. D., W. F. Wardowsky, and G. E. Brown. 1995. Pitting of grapefruit that resembles chilling injury. HortScience 30:1422-1426.

Shomer, I. and Y. Erner. 1989. The nature of oleocellosis in citrus fruits. Bot. Gazette 50:281-288.