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# EFFECTS OF SELECTED PREHARVEST FACTORS ON POSTHARVEST PITTING OF WHITE GRAPEFRUIT


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*Abstract.* **The effects of harvest date, canopy position, and fruit size on postharvest pitting of white grapefruit were evaluated. Fruit were harvested every five to seven weeks (7 Dec. 1995, 18 Jan., 5 Mar., 12 Apr., and 20 May 1996) from six trees in a grove near Vero Beach, Fla. Fruit were washed, coated with a shellac-based wax, stored at 21.0°C, and evaluated visually during storage. The incidence of pitting was greater among fruit harvested in Jan. and May (about 40 and 25% incidence, respectively) than for fruit harvested in Dec., Mar., and Apr. (< 15% incidence). Canopy position (interior vs. exterior) did not affect pitting. Fruit orientation to the sun did not affect the distribution of clusters of collapsed oil glands. Pitting increased with fruit size: Pitting incidence (%) = (-0.97 fruit per box) + 51.3; $r^2$ = 0.70.**

## Introduction and Literature Review

Postharvest pitting is a peel disorder characterized by clusters of collapsed oil glands that develop during the early weeks of storage (Petracek et al., 1995). Wax application and high temperature storage trigger pitting while reducing internal $O_2$ levels and increasing internal $CO_2$ levels. Fruit stored in low $O_2$ (4%) develop pits (Petracek, unpublished), and thus pitting may be a symptom of hypoxia.

While the effects of postharvest stress on pitting are becoming apparent, the disorder remains unpredictable. The mercurial nature of pitting is indicated in part by the following observations. First, pitting incidence varies among groves and harvest dates. Packinghouse reports indicate that pitting incidences vary greatly among fruit from adjacent groves that are harvested simultaneously and handled similarly. Reports also suggest that pitting incidences for a grove may vary among harvests within a season and among seasons.

Second, pitting incidence varies among fruit from a harvest. Pitting typically affects < 50% of the fruit. The majority of the fruit show no symptoms of pitting.

Third, distribution of pits on the fruit surface is uneven. The number of pit clusters is greatest at the stylar end (Petracek et al., 1995). Perhaps more important is that about one-quarter of the surface of pitted fruit do not develop pits.

These observations not only indicate that pitting is an erratically occurring event, but also suggest that susceptibility to pitting may be variable and alterable. In order to determine methods for controlling susceptibility, the effects of preharvest as well as postharvest factors must be examined. Many preharvest factors have been suggested as playing a role in pitting including rootstock, tree age, irrigation method, and fertilization strategies. However, no common cultural practice has been found among groves that report pitting (Petracek et al. 1995). In this initial investigation on the effects of preharvest factors on postharvest pitting, we examined the effects of three preharvest factors: harvest date, canopy position, and fruit size.

## Materials and Methods

*Plant material.* Mature 'Marsh' white grapefruit *(Citrus paradisi* Macf.) were harvested from six 30-year-old trees (Swingle rootstock) in a grove near Vero Beach, FL between 1 1:30 A.M. and 2:00 P.M. Fruit were transported to the Citrus Research and Education Center (CREC) in Lake Alfred, FL and stored overnight at 21.0°C and 93% RH. On the morning after harvest, fruit were washed on roller brushes with Fruit Cleaner 395 (FMC Corporation, Lakeland, FL.) and waxed on roller brushes with a commercially-available shellac-based wax (FMC Corporation, Lakeland, FL.). Wax coatings were dried at 60C for about 1 min after wax application, and fruit were stored at 21.0°C and 93% RH. Fruit were not degreened and fungicides were not used.

*Morphology.* Scanning electron micrographs of pitted fruit were prepared by freeze drying the pitted tissue, freeze fracturing the tissue in liquid $N_2$, and mounting the tissue on aluminum stubs. Samples were coated with gold-palladium and examined with an S530 Hitachi SEM (Danbury, Conn.) at 20 kV accelerating voltage and photographed with Polaroid P/N 55 film. Stereo pairs were created by tilting the sample 10°.

*Effect of canopy position, harvest date, and fruit size.* The effect of harvest date and canopy position was determined. Fruit were harvested on 7 Dec. 1995, 18 Jan., 5 Mar., 12 Apr., and

20 May 1996. Exterior canopy fruit were selected from fruit exposed to the sun in the eastern, southern, western quadrants of the trees and were marked according to their orientation to the trunk of the tree. Interior canopy fruit were selected from fruit not exposed to the sun. All fruit were harvested from the lower canopy (2 to 10 feet of about 20 feet trees). Clusters of sunken glands were circled with a marking pen on a weekly basis after packing (n = 3 boxes of 20 fruit per canopy position per harvest date). Pitting incidence was defined as the percent of fruit per box with four or more pits.

The effect of fruit orientation on cluster distribution was examined. Fruit were harvested on 20 May 1996 from the interior and exterior canopies of the southern quadrant and marked according to the orientation to the tree. Fruit were washed, waxed, and stored at 21.0°C and 93% RH. Randomly selected pitted fruit (n = 12 fruit per canopy position) were visually evaluated on a weekly basis over 49 days of storage. Fruit were divided into six regions of approximately equal area (stem end, stylar end, sun side, left of sun side, right of sun side, and shade side) and number of clusters were counted.

The effect of fruit size on pitting was examined for fruit harvested on 20 May 1996. Fruit were washed, sized, waxed, and stored at 21.0°C (n = 3 boxes of 20 fruit per fruit size). Fruit were visually inspected after 50 days. Pitting incidence was defined as the percent of fruit per box with four or more pits.

*Statistical analysis.* Data for the studies on effects of (1) harvest date and canopy position on pitting incidence and (2) canopy position and region of fruit on cluster distribution were organized in a completely randomized factorial design and analyzed by analysis of variance (PlotIT ver. 3.1, Scientific Programming Enterprises, Haslett, MI.). Cluster distribution for the four midsection regions of exterior fruit only was analyzed by analysis of variance. The effect of fruit size on pitting incidence was analyzed by linear regression analysis.

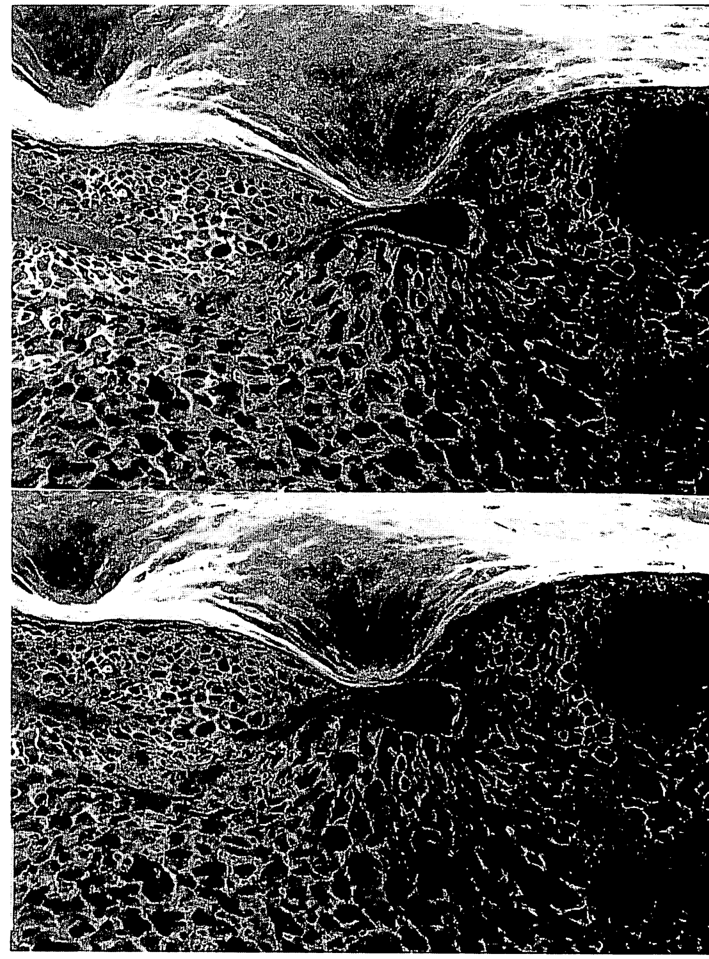

Figure 1. Stereo pair of an scanning electron micrograph of collapsed oil glands (left and center) and a healthy oil gland (right) of white grapefruit affected by postharvest pitting. Bar = 500 µm.

## Results and Discussion

The three-dimensional perspective of the anatomy of pitting is illustrated in Fig. 1. The damage caused by pitting was often targeted lo the oil glands. Adjacent oil glands were often not affected by this collapse.

Harvest date significantly affected pitting (Table 1). Pitting was highest on 18 Jan. (35 to 40% pitting incidence) or about four weeks prior to the beginning of anthesis. Pitting was also high at the end of the season (about 25%, 20 May). Pitting for the other harvests was <15% including for the harvest during anthesis (5 Mar.). Pitting incidence of fruit from this grove during one season was thus episodic, a characteristic seemingly common to the entire industry. Although complete and accurate records on pitting are not available, industry reports suggest that the pitting incidence was greatest from Mar. to June, 1994, Jan. to mid-Feb. 1995, and Dec. 1995 to Jan. 1996.

Canopy position did not affect the pitting incidence (Table 1). These results contradict a preliminary study (Apr. 1994) on canopy position. In that study, fruit were harvested from interior and exterior canopies from the eastern, southern, western, and northern quadrants of the trees. Although fruit from the exterior canopy of all quadrants pitted (< 20% incidence) no interior canopy fruit pitted (unpublished).

Distribution of oil gland clusters over the surface of the fruit was significantly affected by the region of fruit (Table 2). The pitting incidence near the stylar end was about twice that of any other region (cf. Petracek et al., 1995). The number of clusters in the four midsection regions of exterior canopy fruit were not significantly different. The lack of orientation effect from the 20 May harvest is corroborated by informal observations of pitted exterior canopy fruit of the previous (Dec., Jan., Mar., and Apr.) harvests.

Table 1. Effect of harvest date and canopy position on pitting of white grapefruit.

| | Pitting incidence (no. of pitted fruit/box)[z] | |
|---|---|---|
| | Canopy position | |
| Harvest date | Interior | Exterior |
| 7 Dec. 1995 | 1.3 ± 1.3 (6.5) | 2.7 ± 2.2 (13.5) |
| 18 Jan. 1996 | 7.0 ± 2.1 (35.0) | 8.3 ± 0.9 (41.5) |
| 5 Mar. 1996 | 0.3 ± 0.3 (1.5) | 2.0 ± 0.0 (10.0) |
| 12 Apr. 1996 | 2.0 ± 0.6 (10.0) | 0.7 ± 0.7 (13.5) |
| 20 May 1996 | 4.7 ± 0.3 (23.5) | 5.0 ± 0.6 (25.0) |
| l.s.d. (α=0.05): 2.9 | | |

[z]Fruit (n = 3 boxes of 20 fruit) were harvested from the interior and exterior canopies of six trees. Fruit were washed and waxed the day after harvest, and stored at 21.0°C and 93% RH. Pitting incidence is the mean number of pitted fruit (± SE) per box with 4 or more collapsed oil glands after 35 days of storage. Percentage of pitted fruit is in parentheses. The main treatment effect of harvest date was significant ($P < 0.001$).

Table 2. Effect of canopy position and region of fruit on cluster distribution pitting of white grapefruit.

| Region of fruit | Clusters/region[z] Canopy position Interior | Exterior |
|---|---|---|
| Stem end | 0.7 ± 0.3 | 0.5 ± 0.2 |
| Stylar end | 1.4 ± 0.5 | 3.8 ± 1.7 |
| Sun side | 0.8 ± 0.4 | 0.9 ± 0.5 |
| Left of sun side | 0.4 ± 0.2 | 0.5 ± 0.3 |
| Right of sun side | 0.6 ± 0.3 | 1.1 ± 0.5 |
| Shade side | 0.5 ± 1.2 | 1.2 ± 0.8 |
| l.s.d. (a=0.05): 1.8 | | |

[z]Fruit were harvested 20 May 1996 from the interior and exterior canopies of the southern quadrant of four trees and marked according to the orientation to the tree. Fruit were washed and waxed the day after harvest and stored at 21.0°C and 93% RH. Randomly selected pitted fruit (n = 12) were evaluated after 50 days in storage. Fruits were divided into six regions of approximately equal area and number of clusters were counted. The main treatment effect of region of fruit was significant ($P < 0.011$).

Pitting increased significantly with fruit size (Table 3, 20 May 1996 harvest): Pitting incidence (%) = (-0.97 fruit per box) + 51.3; $r^2 = 0.70$. The range of pitting incidence determined by this linear model was 12.5 to 25.1% for size 40 to size 27 fruit, respectively).

The relationship between size and pitting is confirmed by shipping reports. Fruit were harvested on 25 Nov. 1995, 2 Dec. 1995, and 10 Feb. 1996 from a grove near Fort Pierce, FL, commercially packed, shipped in containers at 10.0 to 15.5°C, and evaluated about 23 days after packing. Pitting increased with size for all three harvest dates (Table 3). Although the data for these harvest dates were collected by inspectors who were untrained in distinguishing postharvest pitting from similar peel disorders, their data are consistent and corroborate the results of our study.

One perspective to consider in examining the relationship between fruit size and pitting is that pitting increases with the ratio of volume:surface area (Table 3). Volume:surface area ratios represent the relationship between amount of respiring fruit pulp to area available for gas exchange. Higher volume:surface area ratios could result in higher internal $CO_2$ and lower internal $O_2$. Internal gas levels may affect the probability that a fruit will pit since pitting may be triggered by storage in high $CO_2$ and low $O_2$ (Petracek, 1996). Controlled atmosphere studies could be used to determine whether increased pitting among larger fruit is caused by gas level.

Although the fruit harvested for commercial shipping were taken from the same grove, the rate of pitting was substantially different among harvest dates. The difference in pitting from the 25 Nov. and 2 Dec. harvests (Table 3) is particularly interesting since thc times of harvest, weather conditions, and handling procedures and time course were reportedly similar. One explanation offered for the higher incidence of pitting for the 2 Dec. harvest was that the rain received before this date ended a dry period that extended through the 25 Nov. harvest.

Postharvest pitting and chilling injury (CI) are two distinct peel disorders that are conveniently compared and contrasted. The two disorders are similar in that both postharvest pitting (Petracek et al., 1995) and CI (Grierson, 1986; Whiteside et al., 1988) result in the scattered collapse of the peel, but they are distinguished by their responses to postharvest stress. Postharvest pitting is stimulated by high temperature (≥15.5°C) storage of fruit coated with shellac-based waxes (Petracek et al,. 1995). Conversely, CI is stimulated by low temperature storage (<12C) and is reduced by wax application (Grierson, 1971).

The preharvest effects of the two disorders may also be compared. Harvest date and canopy position affect CI, a postharvest peel disorder that resembles postharvest pitting. Kawada et al. (1978) noted that although CI incidence varied among seasons, the incidence consistently decreased during the winter harvest which coincides with anthesis. Postharvest pitting is affected by harvest date, but no apparent trend was observed (Table 1). Purvis (1980) found that CI is greater for fruit harvested from the exterior canopy of the tree. Postharvest pitting is not affected by canopy position (Table 1). However, pitting is affected by fruit size (Table 3), where the effect of fruit size on CI has not been documented previously.

Further studies on the effects of preharvest factors on postharvest pitting are necessary to develop a better understanding of the basic physiology of pitting and a means of predicting or controlling the incidence of pitting. The elusiveness of postharvest pitting as manifested in the changes in susceptibility during the growing season suggest that cultural practices may be changed to reduce or eliminate the

Table 3. Effect of fruit size on pitting of white grapefruit.[z]

| Size (no. per box) | Average radius (cm) | Volume:surface area (cm) | Harvest date 25 Nov. 1995 | 2 Dec. 1995 | 10 Feb. 1996 | 20 May 1996 |
|---|---|---|---|---|---|---|
| | | | Pitting incidence (%) | | | |
| 27 | 5.95 | 1.98 | — | — | — | 25.0 |
| 32 | 5.72 | 1.91 | 14.7 (13) | 38.5 (17) | 16.4 (20) | 18.3 |
| 36 | 5.40 | 1.80 | 11.4 (27) | 32.9 (26) | 11.4 (29) | 21.7 |
| 40 | 5.16 | 1.72 | 11.6 (26) | 26.4 (27) | 9.8 (25) | 10.0 |
| 48 | 4.92 | 1.64 | 9.1 (25) | 20.4 (22) | 8.2 (26) | — |
| 56 | 4.60 | 1.53 | 4.1 (10) | 21.6 (8) | — | — |
| Coefficients | | a | 26.4 | 50.8 | 30.5 | 45.5 |
| | | b | -35.2 | -59.3 | -42.5 | -64.8 |
| | | $r^2$ | 0.91 | 0.89 | 0.95 | 0.65 |

[z]20 May 1996 fruit were harvested near Vero Beach, packed at the CREC (n = 3 boxes of 20 fruit per size), stored at 21.0°C, and evaluated after 50 days. 25 Nov. 1995, 2 Dec. 1995, and 10 Feb. 1996 fruit were harvested near Fort Pierce, commercially packed, shipped in containers at 10.0 to 15.5°C and evaluated about 23 days after packing. Total number of boxes examined for Nov., Dec., and Feb. harvests were 2530, 2543, and 1260, respectively (percent of boxes per fruit size is in parentheses). Regression coefficients were determined for the equation: Pitting (%) = (a · Volume:surface area) + b.

disorder. In particular, factors that may change during the season such nutrition, water relations, and respiration rates may play a key role in determining susceptibility to postharvest pitting.

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# TECHNIQUE FOR ABRASIVE DAMAGE ASSESSMENT OF CITRUS


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*Abstract.* **Abrasive injury to citrus fruit in packinghouses can cause physiological breakdown of the fruit, such as oleocellosis about the equator, or create damaged sites vulnerable to fungal invasion. To assess the abrasiveness of brush washing citrus fruit, paraffin wax balls, approximately 6.7 cm in diameter, were molded and abrasive action was measured by weight loss of these balls when subjected to various brush treatments. Both total mass loss (TML) and a mass loss rate (RML) were used to compare packingline brush treatments. More rigid brush material, specifically polystar-O, produced the highest mass rate loss of 0.018 g/min in long duration tests. That rate was 3× above the rates of polypropylene or polyethylene brushes. Testing of conventional brush washing versus high pressure washing indicated greater rate of mass loss for the high pressure application, but overall mass loss was less due to a shorter exposure time for washing. Wax balls were readily moldable and could be used in repeated tests in a citrus packinghouse environment for measuring potential abrasive damage in brush washing.**

Physical damage to citrus is encountered in various forms. Impact damage may occur in both field and postharvest handling and has been measured with an instrumented sphere (IS) (Miller and Wagner, 1991). Also, severe fruit deformation may occur when overfilled cartons are palletized.

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Another type of damage predominate in citrus is abrasive damage. Minor cuts of the flavedo are a potential site for fungal invasion (Brown, 1980). This type of abrasive damage can occur in pallet bins due to friction with rough material such as sand residue or splintered wooden pallet bin surfaces. Such damage also may occur in packing operations.

The washing unit operation is perhaps the most obvious site where fruit typically progress over rotary brushes for 0.3 to 2 minutes. The conventional brush bristles are fabricated from plastics such as polypropylene of approximate length of 2.5 cm and wrapped on a center metal core. The brushes are chain-sprocket driven at 1 to 3 Hz. Further rotary brushing may be imparted to the fruit in dewatering (Miller, 1986b), fungicide application and polisher drying. Abrasive damage on the packingline also may occur via contact with sand, adhering stems or rough metal surfaces in transferring fruit.

The most common technique to assess abrasive damage to citrus is by application of a TTC-dye to wounded and nonwounded flavedo and albedo tissue (Eaks, 1961; Ismail and Miller, 1988). Freshly wounded tissue readily absorbs the dye and becomes pink to red in color within 24 hr. One major difficulty with this technique is in subjective evaluation of damage through visual scoring. Control fruit taken before a unit operation are typically compared to fruit subjected to a given unit operation. Also, the time delay of 24 hr before dye color changes are detectable makes testing of parameters such as brush speed very lengthy.

In this study, a new technique was proposed and developed to assess abrasive damage by measuring the amount of material abraded from relatively soft control material. A procedure was developed to cast paraffin balls of similar size to citrus fruit. Such balls exhibited a measurable weight loss when exposed to typical brush washing conditions in a packingline. Therefore, it was reasoned that this weight loss would be an indicator of the degree of abrasive action of the washing process. A testing methodology and results obtained in pilot plant and commercial situations are described herein.

Specific objectives of this study were to: 1) develop a test method to assess the potential for abrasive injury encoun-