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.

Literature Cited

Grierson, W. 1971. Chilling injury in tropical and subtropical fruit: IV. The role of packaging and waxing in minimizing chilling injury of grapefruit. Proc. Trop. Reg. Amer. Soc. Hort. Sci. 15:76-88.

Grierson, W. 1986. Physiological disorders. p. 361-378. In: W. F. Wardowski, S. Nagy and W. Grierson (eds.). Fresh Citrus Fruit. Van Nostrand Reinhold Company, Inc. New York.

Kawada, K., W. Grierson and J. Soule. 1978. Seasonal resistance to chilling injury of "Marsh" grapefruit as related to winter field temperature. Proc. Fl. St. Hort. Soc. 91:128-130.

Petracek, P. D. 1996. Stimulation of citrus pitting by wax application and high-temperature storage. HortScience. 31:604 (abstr.).

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

Purvis, A. C. 1980. Influence of canopy depth on susceptibility of 'Marsh' grapefruit to chilling injury. HortScience. 15:731-733.

Whiteside, J. O., S. M. Garnsey and L. W. Timmer. 1988. Compendium of citrus diseases. APS Press, St. Paul, Minn.

Proc. Fla. State Hort. Soc. 109:254-257. 1996.

TECHNIQUE FOR ABRASIVE DAMAGE ASSESSMENT OF CITRUS

W. M. Miller and W. L. Verba
University of Florida, IFAS
Citrus Research and Education Center
700 Experiment Station Road
Lake Alfred, FL 33850

Additional index words. Fruit quality, physical properties, tribology, washing.

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.

Florida Experiment Agricultural Station Journal Series No. N-01329.

Trade company names are included for benefit of the reader and imply no endorsement or preferential treatment of the product by the University of Florida. SI units are utilized, for rotational velocity conversion, 1 Hz = 60 rpm.

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 encountered in packingline brush washer treatments; 2) evaluate the technique for various brush washer variables, in particular material selection and rotational speed, under pilot plant conditions; and 3) extend the evaluations to commercial packingline evaluations.

Materials and Methods

A spherical rubber mold was made to cast the paraffin wax balls. The mold making process is a ten step procedure (Dow Corning, 1976). Plastic balls were used as the model and room temperature vulcanizing silicone rubber (Dow Corning 3110) was selected for the master mold. A fill port, approximately 1 cm, was integrated into the upper half of the mold and the mold was cut into two parts after a recommended 24 hr cure period at room conditions.

This rubber master mold was then used to form paraffin wax balls. The wax was heated to approximately 82°C in a double boiler. Inside rubber mold surfaces were treated with silicone mold release and the two parts of the mold clamped together. Using a pre-heated glass funnel, the mold was half filled and then shaken gently. After a time delay of 1-2 minutes, the remaining spherical void was filled and the entire mold again manually shaken. This shaking action eliminated any significant air pockets negating the requirement for a vacuum deaeration. The setup period at room temperature was established at 12 hr., after which time, the balls were removed and inspected for defects. The average diameter was 6.7 cm with a ± 0.05 cm standard deviation for all balls molded. Density for the balls was 0.89 ± 0.01 g/cm^3 which is in the range for fresh citrus (Miller, 1986a).

Various tests were conducted to assess if tribology characteristics of the paraffin balls would be indicative of the severity of brushing action. Tests were conducted under the following conditions:

a. controlled time exposure, test brush beds
b. long duration exposure, test brush bed
c. pilot plant tests at the CREC, Lake Alfred, FL
d. commercial citrus packingline tests

In both pilot plant and commercial tests, 3 replications were used and 3 wax balls tested in an individual run.

Results and Discussion

Initial controlled pilot plant tests provided information with respect to the variables usually considered important for existing brush washer operations. These factors are the exposure time of the fresh citrus to brushing action, brush bristle material and brush rotational speed. Two terms will be introduced to simplify the following discussion. First, the total mass loss of the paraffin ball for a given test will be designated TML and the rate of mass loss as RML.

These controlled rotational velocity tests were conducted using a soft applicator bristle which was a 50/50 mix of horsehair, approximately 0.010 in. (0.025 cm) dia., and polystar-E (0.018 in., 0.046 cm dia. polypropylene) bristles (Industrial Brush, 1988). Brush rotational speed was not significant at the levels of 1.3, 2.0 and 2.7 Hz (Table 1, Figs. 1, 2). These data followed the expected trend of increased TML with respect to time. Also, the RML values were observed to be inversely related to exposure time. At least two factors may have lead to this result. First, the initial transition period from zero to a fixed rotational speed for the ball or fruit may provide significant abrading action and hence is a more predominate factor in short time exposures. Secondly, minor wax buildup from the balls was observed on the brushes in extended tests. This buildup may reduce the abrasiveness of the brushes, thereby reducing RML.

Another set of tests was conducted with a pilot plant brush bed to assess brush type (0.018 in., 0.046 cm Polystar E and 0.022 in., 0.056 cm Black Pex) at a fixed rotational speed of 1.6 Hz. These brushes were quite rigid for use in citrus fruit washing. These brushes had a single ridge cut to induce more scrubbing action in cleaning (personal communication, OMT Engineering). In this test, TML was affected significant-

Table 1. Summary of statistical significance from brush test program for TML-total mass loss and RML-rate loss with * denoting significant difference at 5% level.

	Variable		
Test condition	Brush speed[y]	Time	Interaction
Short-time[z]			
TML	—	*↑	—
RML	—	*↓	—
Short-time	Brush type[x]		
TML	* (G > B)	*↑	—
RML	* (G > B)	—	—
Long-time[w]	Brush type[v]		
TML	* (W > BL > G)		
RML	* (W > BL > G)		
Commercial	Wash process[u]		
TML	—		
RML	* (HP > conv)		

[z]30, 60, 120 s with 50/50 horse-hair/polypropylene brush.
[y]1.3, 2.0, 2.7 Hz.
[x]G-polystar-E, B-black pex @ 1.6 Hz.
[w]60, 120, 180 min.
[v]W-polystar-O, BL-polyethylene, G-polystar-E.
[u]HP-high pressure, conv-conventional.

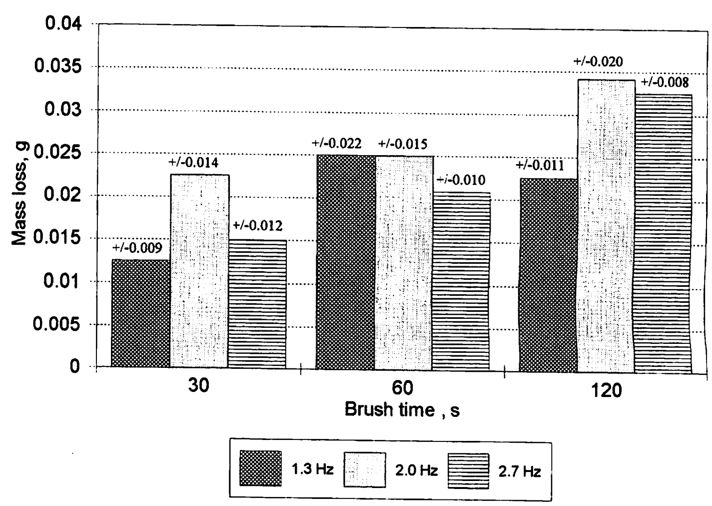

Figure 1. Wax ball mass loss (TML) as a function of brush rotational speed (nos. above bars represent ± 1 std. deviation).

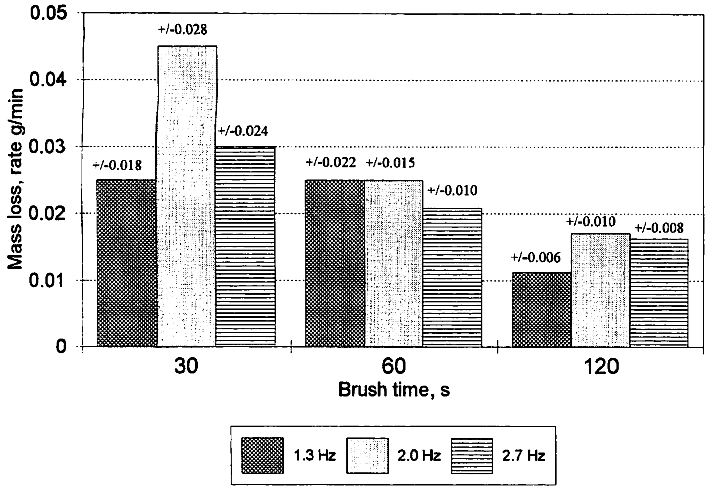

Figure 2. Wax ball rate loss (RML) as a function of brush rotational speed (nos. above bars represent ± 1 std. deviation).

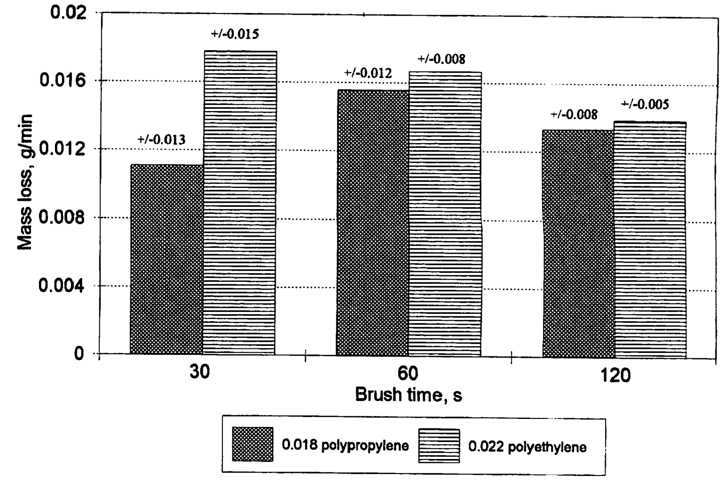

Figure 4. Wax ball rate loss (RML) as a function of brush material and time (nos. above bars represent ± 1 std. deviation).

ly by exposure time but time did not significantly affect RML (Table 1, Figs. 3, 4). This may indicate that these brushes were not as conducive to the wax buildup observed for softer applicator brushes.

The next series of tests consisted of very long-term exposure of the balls to dry brushing action of 60, 120 and 180 min (Fig. 5). Although this time period is much more extensive than conventional packingline operations, an assessment of the paraffin ball's weight loss characteristics in extended use was established. Additionally, it was of interest to observe if extended times could be utilized for brush material assessment as the total mass loss from the ball would be larger and more accurately measured. Brush materials selected were 0.018 in. (0.047 cm) polypropylene, 0.022 in. (0.056 cm) polyethylene and 0.012 in. (0.030 cm) polystar-O. The latter was considered the most abrasive but installed commercially for initial washing of Florida fresh citrus. The effect of brush type was significant for both the TML and RML. Additionally, both time and material and their interaction were significant factors for the TML. For RML, only brush material was significant. RML for the polypropylene averaged 0.004 g/min, the polyethylene 0.006 g/min and the polystar-O 0.018 g/min (Fig. 6).

Another evaluation phase was undertaken in a commercial citrus packinghouse in central Florida. In one season, the packinghouse was using conventual stationary bed rotary washers for washing and dewatering. The washer unit consisted of 40 brushes (polystar-O) and the dewatering unit had 28 brushes (polypropylene). In the following season, a high pressure water nozzle system had been installed. This unit consisted of multiple banks of 5 nozzles across a 1.6 m span operating at 1700 kPa. This nozzle bank was positioned over a portion of the brush washer bed of approximately 2 m in length. As noted in Table 1, the TML from conventional fruit washing was not significantly different from the high pressure treatment. However, RML were significantly greater for the high pressure washing (Fig. 7). These statistical results indicate a more effective washing in a shorter distance and time for the high pressure concept.

Conclusions

It has been difficult to assess the abrasive phenomena associated with fruit washing. It is widely accepted for Florida

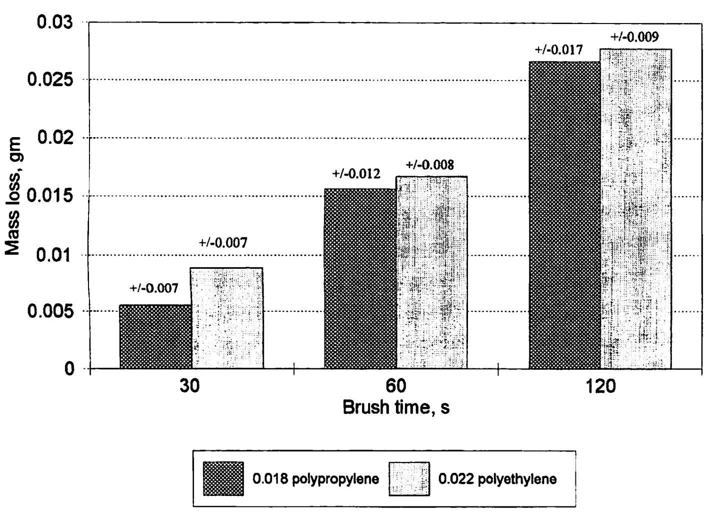

Figure 3. Wax ball mass loss (TML) as a function of brush material and time with brush speed = 1.6 Hz (nos. above bars represent ± 1 std. deviation).

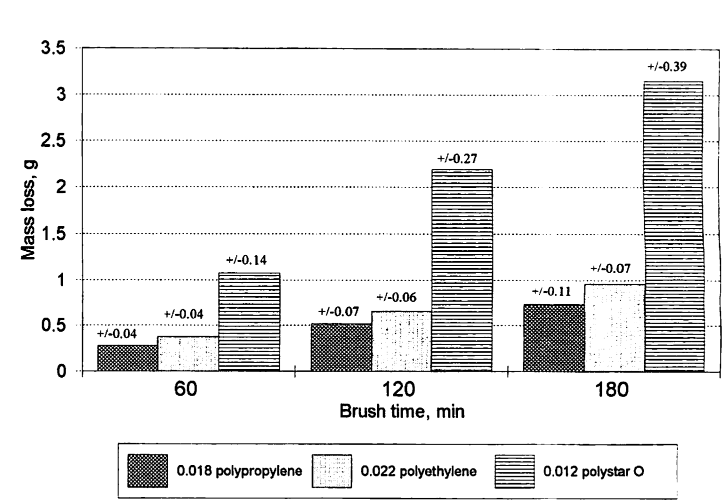

Figure 5. Wax ball mass loss (TML) over extended time periods for three brush materials (nos. above bars represent ± 1 std. deviation).

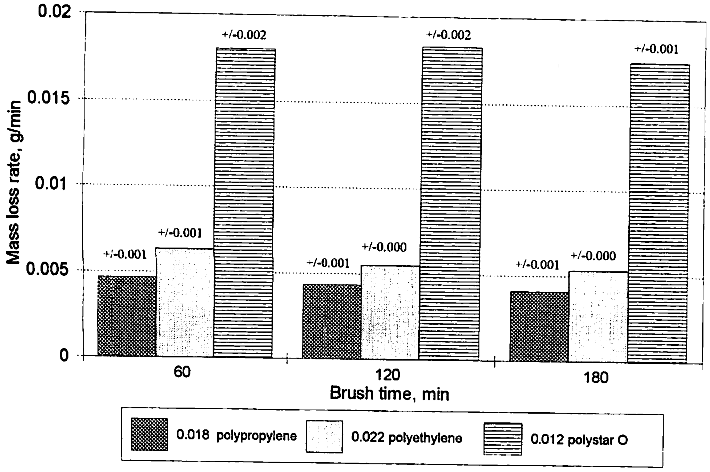

Figure 6. Wax ball rate loss (RML) over extended time periods for three brush materials (nos. above bars represent ± 1 std. deviation).

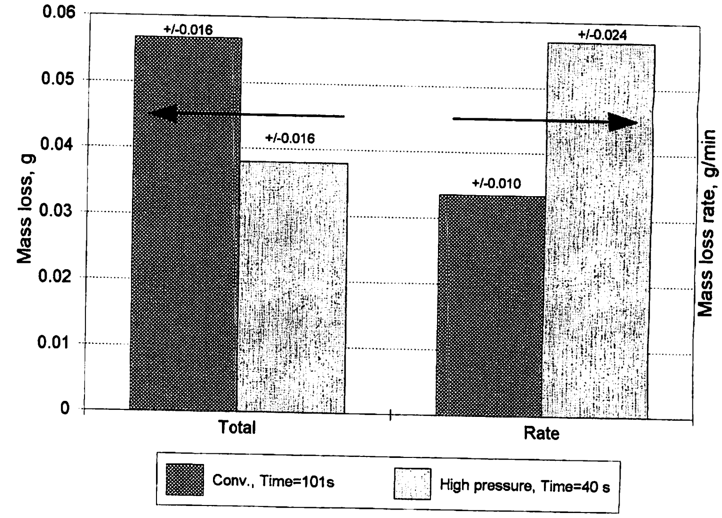

Figure 7. Both wax ball mass and rate loss (TML, RML) between conventional and high pressure washing (nos. above bars represent ± 1 std. deviation).

citrus that a thorough washing is required to remove surface dirt, chemical residues, insect deposits, etc. However, over-washing on rotary brushes can cause mechanical damages through the rupturing of oil cells as the fruit tends to rotate on a fixed axis.

Balls of paraffin wax were molded and subjected to brush washer treatments. In concept, the wax material would be abraded away and the weight loss of the ball would be a function of time and severity of the brush treatment. To evaluate this technique, standard size balls were molded and subjected to various treatments in pilot plant and commercial packing-line tests.

Specific conclusions from this initial study were:

1. Fabrication procedures to mold uniform paraffin wax balls of size similar to fresh citrus was possible. The balls were durable and could be used for multiple tests.
2. The degree of abrasive action the balls encountered in fruit washing could be established by the amount of the ball abraded away although the overall mass losses were relatively small, < 0.035 g in short-term tests of 120 s or less.
3. The more rigid brush material, polystar-O, caused a RML three to four times greater than more pliable brushes.
4. Long-term testing, > 60 min, had the effect of reducing the RML due to wax buildup on the brushes themselves.
5. Commercial packinghouse studies indicated that the balls would hold up under industrial conditions for conventional and high-pressure applications. The high-pressure washing, representing an intense short-term treatment, yielded higher RML levels.

Literature Cited

1. Brown, G. E. 1980. Fruit handling and decay control techniques affecting quality. In ACS Symposium Series, No. 143, Citrus Nutrition and Quality, eds. S. Nagy and J. A. Attaway, 197-224. American Chemical Society.
2. Dow Corning. 1976. How to make a mold with Silastic RTV silicone rubber. Bulletin 61-192a. Midland, MI.
3. Eaks, I. 1961. Techniques to evaluate injury to citrus fruit from handling practices. Proc. Amer. Soc. Hort. Sci. 78:190-196.
4. Industrial Brush. 1988. Cylinder brushes and rollers for processing produce. Bulletin IB 20B2. Lakeland, FL.
5. Ismail, M. A. and W. M. Miller. 1988. Evaluation of mechanical damage to citrus. In Fresh Citrus Quality Short Course. IFAS-Univ. of Florida. 10 p.
6. Miller, W. M. 1986a. Mechanical and physical properties for postharvest handling of Florida citrus. Proc. Fla. State Hort. Soc. 99:122-127.
7. Miller, W. M. 1986b. Mechanical dewatering techniques for fresh citrus. Energy in Agriculture 5:225-238.
8. Miller, W. M. and C. J. Wagner. 1991. Impact studies in Florida citrus packinghouses using an instrumented sphere. Proc. Fla. State Hort. Soc. 104:125-127.
9. OMT Engineering. 1995. Personal communication, Mr. Harold Thomas, Dunedin, FL.