Reprinted from
Proc. Fla. State Hort. Soc. 99:40-44. 1986.

A FIVE-YEAR STUDY OF ORANGE REMOVAL WITH TRUNK SHAKERS

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Additional index words. abscission, harvesting, citrus.

Abstract. **'Hamlin' and 'Valencia' sweet oranges (*Citrus sinensis* (L.) Osb.) were removed with trunk shakers for 5 yr in replicated field experiments near LaBelle, FL. Four trunk shaking modes, 2 linear, and 2 multidirectional, were compared with handpick checks, with and without abscission chemicals. Fruit yields, removal efficiencies, and trunk circumferences were measured. 'Hamlin' yields were not affected by the shakers; 'Valencia' yields were significantly reduced by one of the multidirectional shaker modes. Abscission chemicals did not reduce the yields of either 'Hamlin' or 'Valencia.' Abscission chemicals increased shaker removal efficiencies from 64 to 90% in 'Hamlin' and from 74 to 91% in 'Valencia'. Trunk growth was not affected by shaking. The most vigorous linear shaking mode provided superior harvesting efficiency.**

Trunk shakers have been used commercially to remove various deciduous fruits and nuts (1). The use of trunk shakers has been limited in citrus because of poor fruit removal, bark damage in 'Valencia', and inadequate tree trunk height for shaker clamp attachment in a high percentage of Florida groves (4). Research in Florida has demonstrated orange removal efficiencies of 90% with trunk shakers and abscission chemicals (3, 4). However, subsequent 'Valencia' yields were reduced up to 20% by the shakers and abscission chemicals (3, 4). The potential for shaking a tree with a single attachment, the use of abscission chemicals for fruit loosening, and the increase in tree numbers of a size and shape adaptable for trunk shaking increased the feasibility of this method of fruit removal.

This paper reports on a 5-year completed study on the effects of trunk shaking, with and without abscission chemicals, on tree growth, fruit yields, fruit removal, and harvesting efficiency. The initial results of this study were reported by Hedden, et al. (2).

Methods and Equipment

Two experiments on trunk shaking were performed on 'Hamlin' and 'Valencia' sweet orange trees near LaBelle in south Florida. 'Hamlin' and 'Valencia' orange trees were 15- and 8-yr-old, respectively, uniform in size and density, with adequate trunk height for grasping with the shaker s clamps. These trees were representative of many younger plantings on flatwoods soils in south Florida. Each experiment was a randomized, split-plot design which included 60 trees and 6 replications.. One of the two 5-tree main plots in each replication was randomly assigned to be sprayed with abscission chemicals (C) before harvest while the other main plot was not sprayed (NC). Within each main plot, 4 shaker and 1 handpicked check treatment were randomly assigned to each tree. These assigments were maintained for the duration of the experiment.

The trunk shaker and check treatments were as follows:

1. Linear shaker with 133 lb. of unbalanced mass rotating at 6 revolutions/sec with 5.5 inches eccentricity and 1010 lb. of total mass (excluding the unbalanced mass).
2. Linear shaker with 200 lb. of unbalanced mass rotating at 5 revolutions/sec with 5.5 inches eccentricity and 600 lb. total mass (excluding the unbalanced mass).
3. Multidirectional shaker with two 68 lb. unbalanced masses rotating at 12 revolutions/sec with 4.5 inches eccentricity in opposite directions at a speed difference of 18%. Total shaker mass was 992 lb. (excluding the unbalanced masses).
4. Same shaker as 3 except both eccentric masses rotated in the same direction.
5. Handpicked (check).

Linear shaking in Treatments 1 and 2 had theoretical amplitudes of 0.7 and 1.8 inches, respectively, under no-load conditions (Fig. 1). Multidirectional shaking with a commercially available shaker in Treatments 3 and 4 had a theoretical amplitude of 0.6 inch (Fig. 1) (2).

Four to 5 days prior to harvest, main plots receiving abscission chemicals were treated with an amount dependent upon fruit and tree condition and cultivar. The normal abscission chemical mixture for 'Hamlin' oranges was 75 ppm of 5-chloro-3-methyl-4-nitro-pyrazole (Release), 1.5 ppm of cycloheximide (Acti-Aid), and 0.1% Ortho X-77 surfactant which was applied at the rate of 4 gal of mix per tree. For 'Valencia' oranges, the abscission chemical mixture was 250 ppm of Release and 0.1% Ortho X-77 surfactant which was applied at the rate of 4 gal of mix per tree.

The shaker treatment trees were shaken for 7 sec. Data were collected on fruit removal for 5 yr (1981 through 1985) and on fruit yield for 6 yr (1981 through 1986). A harvesting efficiency index (HEI) was calculated for each treatment as follows:

$$HEI = (1/6) \sum_{i=1}^{6} \frac{(TY_i)(TR_i)}{CY_i} \quad [1]$$

where TY_i = 1982-1986 average treatment yield in the (i)th replication, boxes/tree
TR_i = 1981-1985 average treatment removal efficiency in the (i)th replication, %

Florida Agricultural Experiment Station Journal Series No. 7732. Cooperative research by the University of Florida, U. S. Dept. of Agriculture, and the Florida Department of Citrus, Citrus Research and Education Center, Lake Alfred, FL. Trade names and company names are used in the publication solely for information purposes and do not constitute a guarantee or warranty of a product by the University of Florida, U. S. Department of Agriculture, or the Florida Department of Citrus.

CY_i = 1982-1986 average check yield of Treatment 5 (NC) in the (i)th replication, boxes/tree

Bark damage was observed after each tree was shaken. Trunk circumferences were measured as a tree growth indicator at 8 inches above ground level. The measurements were made for 5 yr (1982 through 1986) in Treatments 1-4 (C and NC) and only one yr (1986) in Treatment 5 (C and NC). All data were analyzed statistically and significant differences refer to the F values or Duncan's multiple range test at the 5% level.

Results

Tree Growth

'Hamlin'. Table 1 shows the trunk circumference measurements for 1982 and 1986 and the percentage increase or growth. There were no significant differences among the trunk circumferences in the initial shaker treatments. All shaker trees grew approximately 2 inches in circumference between 1982 and 1986. No significant differences in the 1986 and growth data indicated that shaking did not affect tree growth.

'Valencia'. Table 2 shows the trunk circumferences for 1982 and 1986 and the percentage increase or growth. In 1982, the trunks of shaker Treatment 1 (C) were significantly smaller than those of shaker Treatment 1 (NC) and shaker Treatment 3 (C). By 1986, all shaker treatment trunks had grown 2 inches or more. Again, the trunks of shaker Treatment 1 (C) were the smallest, and were significantly less than 4 of the shaker treatment trunks, but not less than the trunks of the handpick Treatment 5 (NC) trees. The percentage increases in circumference among shaker treatments were not significantly different.

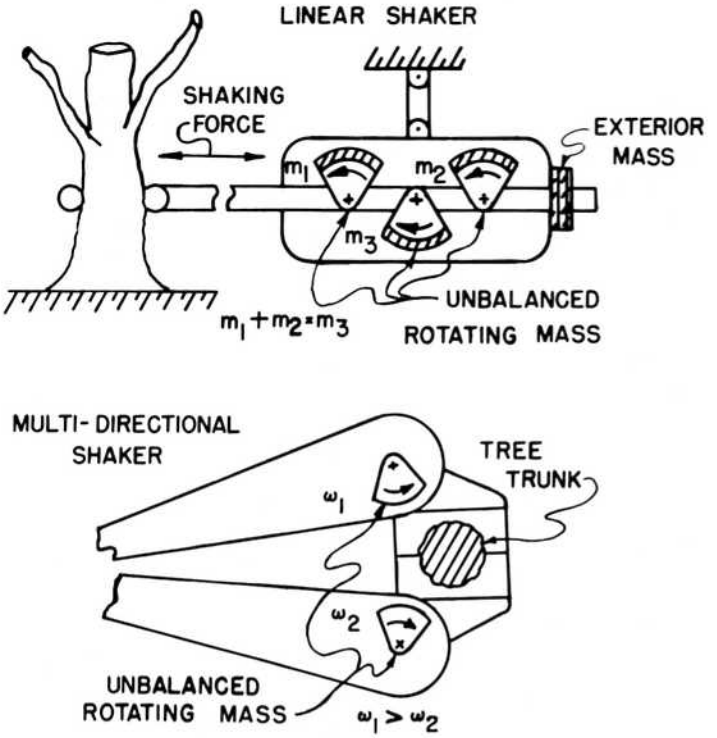

Fig. 1. Schematic diagram of the linear and multidirectional trunk shakers used in these experiments. Shown are the mass configurations for Treatments 1 (top) and 3 (bottom). Treatment 2 had added rotating mass and no exterior mass. Treatment 4 had both masses rotating in the same direction.

Table 1. Trunk circumferences of 'Hamlin' in trunk shaker experiment.

Treatment		Trunk circumference at 8 inches above ground[z]		
Shaker	Chemical	1982	1986	Percent increase or growth
1—lin. 133 lb. unbal. mass	NC	25.6 a	27.8 a	8.6 a
1—lin. 133 lb. unbal. mass	C	24.1 a	26.0 a	7.9 a
2—lin. 200 lb. unbal. mass	NC	25.4 a	27.7 a	9.1 a
2—lin. 200 lb. unbal. mass	C	25.1 a	27.7 a	10.4 a
3—multi. opp. rotation	NC	26.2 a	28.3 a	8.0 a
3—multi. opp. rotation	C	24.6 a	27.0 a	9.8 a
4—multi. same rotation	NC	25.5 a	27.9 a	9.4 a
4—multi. same rotation	C	24.3 a	26.2 a	7.8 a
5—handpick	NC	—	27.5 a	
5—handpick	C	—	27.9 a	

[z]Mean separation in columns by Duncan's multiple range test, 5% level.

Table 2. Trunk circumferences of 'Valencia' in trunk shaker experiment.

Treatment		Trunk circumference at 8 inches above ground[z]		
Shaker	Chemical	1982	1986	Percent increase or growth
1—lin. 133 lb. unbal. mass	NC	20.3 a	23.0 a	13.3 a
1—lin. 133 lb. unbal. mass	C	18.2 b	20.5 b	12.6 a
2—lin. 200 lb. unbal. mass	NC	19.4 ab	22.0 ab	13.4 a
2—lin. 200 lb. unbal. mass	C	18.8 ab	21.8 ab	16.0 a
3—multi. opp. rotation	NC	19.9 ab	22.6 a	13.6 a
3—multi. opp. rotation	C	20.1 a	22.9 a	13.9 a
4—multi. same rotation	NC	19.5 ab	22.5 a	15.4 a
4—multi. same rotation	C	19.2 ab	22.1 ab	15.1 a
5—handpick	NC	—	21.3 ab	
5—handpick	C	—	21.7 ab	

[z]Mean separation in columns by Duncan's multiple range test, 5% level.

Fruit Yields

'Hamlin'. The fruit yields of all treatments are shown in Table 3. All trees were fairly uniform with no significant differences the first year (1981). The January 1982 freeze caused considerable defoliation prior to the 1982 harvest. Acti-Aid was not used in the abscission chesical mix because young flush and bloom buds were present at harvest time. The 1982 fruit yields were high and shaker Treatment 4 (NC) was significantly higher than handpick Treatment 5 (NC). The 1983 fruit yields were very low as a result of the 1982 freeze damage. Shaker Treatment 2 (C) had the highest fruit yields and was significantly higher than several of the other shaker treatments and the handpick Treatment 5 (NC). In the final 3 yr (1984-1986), the trees recovered from the freeze damage with the average fruit yields increasing each successive year. Significant differences in treatment yields were noted only in 1985, but the shaker Treatments (1-4) were not significantly different from the handpick Treatment 5 (NC).

The overall effects of shaker and/or chemicals on fruit yields are shown in the last column of Table 3. These yields are the averages for 1982-1986, subsequent to the initiation of shaking and abscission chemical application. There were no significant differences among all treatments.

Table 3. 'Hamlin' orange yields in trunk shaker experiment.

Treatment		Yield, boxes/tree[z]						
Shaker	Chemical	1981	1982	1983	1984	1985	1986	1982-1986 avg
1—lin. 133 lb. unbal. mass	NC	3.82 a	5.34 ab	2.10 ab	3.31 a	6.22 a	6.96 a	4.79 a
1—lin. 133 lb. unbal. mass	C	3.79 a	5.41 ab	2.77 a	3.71 a	5.62 abc	5.61 a	4.62 a
2—lin. 200 lb. unbal. mass	NC	3.64 a	5.32ab	1.80 b	3.50 a	4.80 bc	6.84 a	4.45 a
2—lin. 200 lb. unbal. mass	C	3.58 a	5.31 ab	2.00 ab	3.86 a	6.03 ab	6.36 a	4.71 a
3—multi. opp. rotation	NC	3.66 a	5.72 ab	1.49 b	3.82 a	4.80 bc	6.04 a	4.38 a
3—multi. opp. rotation	C	3.62 a	5.60 ab	1.77 b	4.06 a	4.76 bc	5.29 a	4.30 a
4—multi. same rotation	NC	3.62 a	6.32 a	1.31 b	4.24 a	4.43 c	6.39 a	4.54 a
4—multi. same rotation	C	3.92 a	5.73 ab	1.83 b	3.92 a	5.34 abc	6.15 a	4.59 a
5—handpick	NC	3.44 a	5.11 b	1.74 b	4.21 a	5.58 abc	6.55 a	4.44 a
5—handpick	C	3.82 a	5.96 ab	2.08 ab	3.68 a	4.99 abc	6.91 a	4.72 a

[z]Mean separation in columns by Duncan's multiple range test, 5% level.

'Valencia'. Table 4 shows the yield data for 'Valencia' oranges. All harvest tests occurred between late March and late April prior to the time when the young fruit were 0.5 inch in diameter. Initial yields in 1981 were not as uniform as those of the 'Hamlin' experiment, but no significant differences were indicated. As with 'Hamlin', 'Valencia' was harvested in 1982 after the freeze which resulted in considerable defoliation. The only significant difference was between shaker Treatment 1 (NC) and shaker Treatment 4 (C). No significant differences occurred in 1983 and 1985. In 1984, shaker Treatment 4 (C) was significantly less than 2 other shaker treatments and the handpick treatments. In 1986, handpick Treatment 5 (NC) was significantly less than the 2 shaker treatments and the handpick Treatment 5 (C). Overall for 1982 through 1986, only shaker Treatment 4 (C) was significantly less than handpick Treatment 5 (NC). This significant reduction may have resulted for 2 reasons. First, Treatment 4 provided the most aggressive shaking action between the 2 multidirectional shaker treatments as evidenced by its higher removal efficiencies (Tables 3). Second, shaking with abscission chemicals removed mature 'Valencias' faster and more completely than without abscission chemicals, thus subjecting the young fruit or next year's crop to more shaking energy and damage during latter portion of the 7 sec shake period. The abscission chemicals did not affect yields.

Fruit Removal and Harvesting Efficiency

'Hamlin'. The left hand portion of Table 5 shows the fruit removal efficiency data for the shaker treatments. Significant differences resulted each year between shaker Treatments 1 through 4. Abscission chemicals significantly increased the removal efficiency of the shaker treatments each year. Overall, abscission chemicals increased removal efficiency significantly from 64.5% to 90.3%. With abscission chemicals, there was no significant difference in the removal efficiencies of the two types of shakers. However, without abscission chemicals, the removal efficiencies of shaker Treatments 2 and 4 were significantly higher than that of shaker Treatment 3, which in turn was significantly higher than that of shaker Treatment 1.

The harvesting efficiency index (HEI) as defined in Eq. [1] was a measure of the percentage of the crop which could be harvested by each treatment when compared to conventional hand harvesting without abscission chemicals (Treatment 5 NC). The HEI values are shown in the last column of Table 5. The HEI of Treatment 5 (NC) would be 100. Treatment 5 (C) had a HEI of 114.4, which indicated the yields of the chemically treated handpick trees averaged 14.4% more than the Treatment 5 (NC) trees. However, this difference was not statistically significant. There was also no statistical difference among Treatment 5 (NC) and shaker Treatments 1 through 4 with abscission chemicals (C) and Treatment 2 (C) had the highest value at 107.0. Shaker Treatments 1 through 4 without abscission chemicals (NC) were significantly less than Treatment 5 (NC), but differences among shaker tretaments were not significant. Abscission chemicals increased the average HEI of shaker Treatments 1 through 4 from 65.4 to 100.3.

'Valencia'. The left-hand portion of Table 6 shows the removal efficiencies of the shaker treatments. As with

Table 4. 'Valencia' orange yields in trunk shaker experiment.

Treatment		Yield, boxes/tree[z]						
Shaker	Chemical	1981	1982	1983	1984	1985	1986	1982-1986 avg
1—lin. 133 lb. unbal. mass	NC	3.68 a	5.27 a	3.12 a	3.11 a	4.71 a	6.36 a	4.51 a
1—lin. 133 lb. unbal. mass	C	2.94 a	3.90 b	2.57 a	2.26 bcd	4.05 a	5.58 ab	3.67 cd
2—lin. 200 lb. unbal. mass	NC	3.68 a	4.56 ab	2.79 a	2.21 bcd	4.49 a	5.39 ab	3.89 bcd
2—lin. 200 lb. unbal. mass	C	3.79 a	4.66 ab	2.21 a	2.84 ab	4.64 a	6.40 a	4.15 abcd
3—multi. opp. rotation	NC	3.65 a	4.36 ab	2.69 a	2.37 bcd	3.58 a	5.53 ab	3.64 cd
3—multi. opp. rotation	C	3.90 a	4.66 ab	3.05 a	2.09 cd	4.01 a	6.26 ab	4.01 abcd
4—multi. same rotation	NC	3.16 a	4.26 ab	2.47 a	2.31 bcd	4.12 a	5.85 ab	3.80 bcd
4—multi. same rotation	C	3.34 a	3.82 b	2.38 a	1.68 d	3.88 a	6.09 ab	3.57 d
5—handpick	NC	3.45 a	4.46 ab	3.52 a	2.71 abc	5.01	5.18 b	4.18 abc
5—handpick	C	3.72 a	4.69 ab	2.95 a	2.72 abc	5.05 a	6.43 a	4.37 ab

[z]Mean separation in columns by Duncan's multiple range test, 5% level.

Table 5. 'Hamlin' orange removal efficiencies and harvesting efficiency indexes in trunk shaker experiment.

Treatment		Percentage fruit removal efficiencies[z]						
Shaker	Chemical	1981	1982	1983	1984	1985	1981-1985 avg	Harvesting efficiency index[z]
1—lin. 133 lb. unbal. mass	NC	58.4 c	64.2 c	43.1 d	54.4 c	58.0 c	55.6 d	63.7 c
1—lin. 133 lb. unbal. mass	C	99.8 a	91.9 a	78.7 ab	78.7 a	98.1 a	89.4 a	100.4 a
2—lin. 200 lb. unbal. mass	NC	75.8 b	78.7 b	67.3 bc	64.5 bc	65.4 b	70.3 b	74.0 bc
2—lin. 200 lb. unbal. mass	C	99.7 a	93.3 a	84.4 a	78.4 a	99.4 a	91.1 a	107.0 a
3—multi. opp. rotation	NC	67.9 b	73.9 b	43.7 d	57.5 c	63.2 bc	61.2 c	60.4 c
3—multi. opp. rotation	C	98.3 a	91.2 A	81.3 ab	79.6 a	99.2 a	89.9 a	94.1 ab
4—multi. same rotation	NC	73.2 b	74.5 b	62.5 c	73.7 ab	70.1 b	70.8 b	75.7 bc
4—multi. same rotation	C	99.8 a	93.1 a	81.4 ab	81.1 a	98.3 a	90.7 a	99.7 a
5—handpick[y]	NC	—	—	—	—	—	—	100.0 a
5—handpick[y]	C	—	—	—	—	—	—	114.4 a

[z]Mean separation in columns by Duncan's multiple range test, 5% level.
[y]Percentage fruit removal assumed to be 100%.

Table 6. 'Valencia' orange removal efficiencies and harvesting efficiency indexes in trunk shaker experiment.

Treatment		Percentage fruit removal efficiencies[z]						
Shaker	Chemical	1981	1982	1983	1984	1985	1981-1985 avg	Harvesting efficiency index[z]
1—lin. 133 lb. unbal. mass	NC	74.0 d	70.5 d	79.4 c	51.3 d	48.2 d	647 d	70.6 de
1—lin. 133 lb. unbal. mass	C	91.9 ab	87.3 a	95.0 a	80.2 ab	97.7 a	90.4 a	79.3 cde
2—lin. 200 lb. unbal. mass	C	85.0 bc	83.6 ab	92.1 ab	68.0 bc	74.2 b	80.6 ab	76.3 cde
2—lin. 200 lb. unbal. mass	C	94.0 a	90.1 a	95.1 a	84.2 a	97.0 a	92.1 a	91.2 abc
3—multi. opp. rotation	NC	80.1 cd	73.5 cd	85.4 bc	64.1 cd	61.4 c	72.9 c	65.0 e
3—multi. opp. rotation	C	93.9 a	83.8 ab	96.8 a	83.5 a	95.1 a	90.6 a	87.2 bcd
4—multi. same rotation	NC	81.9 cd	79.0 bc	79.1 c	70.5 abc	72.7 bc	76.7 bc	69.8 e
4—multi. same rotation	C	92.5 ab	90.8 a	95.9 a	81.8 ab	96.3 a	91.5 a	78.4 cde
5—handpick[y]	NC	—	—	—	—	—	—	100.0 ab
5—handpick[y]	C	—	—	—	—	—	—	105.7 a

[z]Mean separation in columns by Duncan's multiple range test, 5% level.
[y]Percentage fruit removal assumed to be 100%.

'Hamlin', significant differences resulted each year between shaker Treatments 1-4. Abscission chemicals significantly increased removal efficiency of the shaker treatments each year. The 5-yr averages (1981-1985) are shown in column 6. Abscission chaicals increased removal efficiencies from 73.7 to 91.2%. With abscission chemicals (C), there were no significant differences in removal efficiencies among shaker treatments. Without abscission chemicals (NC), the removal efficiency of shaker Treatment 2 was significantly greater than Treatment 3 and shaker Treatment 3 was significantly greater than Treatment 1. Treatment 2 developed the greatest amplitude among the shakers and generally provided superior fruit removal efficiencies. The amplitudes of Treatments 1 and 3 were similar, but Treatment 3 provided superior fruit removal efficiencies because it operated at approximately twice the frequency as Treatment 1, thus twice the shake cycles in 7 sec.

The harvesting efficiency index (HEI) of handpick Treatment 5 (C) was the highest at 105.7. The HEI's of all shaker Treatments except 2 (C) and 3 (C) were statistically less that Treatment 5 (NC). The low HEI of Treatment 1 (C) may have been due in part to the lower fruit yielding potential of its trees (see 1981 yields in Table 4). The low HEI of Treatment 4 (C) resulted because it reduced fruit yields as discussed earlier. As with Hamlin, Treatment 2 (C) had the highest HEI at 91.2 among shaker treatments. There were no significant differences in the HEI's among shaker Treatments 1 through 4 when considered eithe without abscission chemicals (NC) or with abscission chen icals (C). Abscission chemicals significantly increased th HEI of Treatment 3 only. On the average, abscissio chemicals increased the HEI of the shaker treatments fro 70.4 to 84.0.

Discussion

Tree growth of 'Hamlin' or 'Valencia' oranges was n affected by the shaker treatments or abscission chemical Bark damage was not an apparent problem with any of th shakers, even in 'Valencia'. Most trees had relative smooth trunks with sufficient height for the shaker clam pads.

'Hamlin' yields were not affected by shakers or absci sion chemicals. In 'Valencia', abscission chemicals did n affect yields, but one shaker treatment (multidirection shaker, same direction mass rotation) with abscission chen icals did reduce yields. The high frequency movement the multidirectional shaker appeared to remove more the young 'Valencias' (next year's crop) than did the lo frequency movement of the linear shaker. 'Valencias' we shaken before May and prior to the time when the youn fruit had reached a diameter of 0.5 inch. Shaking whe the young fruit is larger may reduce yield more than w measured in this study.

The fruit removal efficiencies of the shakers were increased by abscission chemicals an average of 26 and 17 percentage points in 'Hamlin' and 'Valencia', respectively. The harvesting efficiency index (HEI) of the shakers, a measure of the percentage of the crop which could be harvested when compared to conventional hand harvesting, was increased by abscission cheicals an average of 31 points in 'Hamlin' and 13 points in 'Valencia'. The most vigorous linear shaking treatment (No. 2) gave the best HEI among shakers, with or without abscission chemicals. Its HEI with abscission chemicals was 107 in 'Hamlin' and 91 in 'Valencia'. The HEI of all shaker treatments with abscission chemicals in 'Valencia' could probably be increased if the shaking time was less than 7 sec as used in this study, since most of the mature fruit was removed in the first few seconds of shaking.

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