ORANGE REMOVAL WITH TRUNK SHAKERS AND ABSCISSION CHEMICALS

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ABSTRACT. *Trunk shake-catch systems have been used commercially to a limited extent to mechanically harvest Florida oranges for processing for the past four seasons. In most cases, oranges left on the trees by the shakers and those missing the catchframes must be gleaned by hand harvesters. The cost of gleaning reduces or may eliminate the profit for the mechanical harvesting operation. During the past two seasons, abscission chemicals to reduce the detachment force of oranges have been tested to determine to what extent they increase the fruit removal efficiency of the shakers. This article discusses orange removal results with various chemicals. In general, removal efficiencies were increased 10 to 15 percentage points when orange detachment forces were reduced 50 to 80%.*
Keywords. *Mechanical harvesting, Citrus, Harvest efficiency.*

Although research was conducted in Florida on mechanical harvesting of citrus from the late 1950s to the mid 1980s (Whitney, 1995), no mechanical harvesting system was commercially adopted. During the 1980s, the industry experienced a succession of devastating freezes which reduced total citrus production to about one-half of the record 1979-1980 crop of 11.6 Mt. High fruit prices coupled with low production and adequate harvesting labor minimized interest in mechanical harvesting until 1991, when new citrus plantings in south Florida rapidly increased production, and fruit prices dropped significantly.

Trunk shakers and abscission chemicals for citrus harvesting were first investigated in the 1960s. A five-year study (Hedden et al., 1988) found that abscission chemicals increased fruit removal (including preharvest fruit drop by abscission chemical) of trunk shakers by 17 to 26 percentage points over harvest without abscission chemicals with little apparent effect on yield and tree growth. In 1986, however, the experimental use permits and registration of abscission chemicals for citrus expired. Fruit Harvesters International, Inc. (Alva, Florida) initiated the development of a trunk shake-catch mechanical harvester in 1993 and has been keenly interested in developing an abscission chemical to improve harvester efficiency since then. In 1994, the Florida citrus industry initiated a harvesting research and development program administered by the Florida Department of Citrus to ensure that the harvesting of future crops would be done at a competitive cost. One of the mechanical fruit removal methods under development has been the trunk shaker (Whitney, 1999). In 1996, the industry once again became interested in abscission chemicals as an aid to mechanical harvesting.

In 1997 and 1998, harvesting tests were initiated to evaluate trunk shakers and new and previously tested abscission chemicals. The objectives of these tests were to determine how effectively the abscission chemicals loosened oranges and how they improved the fruit removal efficiency of trunk shakers.

MATERIALS AND METHODS

Four different trunk shakers with scissors-type clamps and three abscission chemicals were used in eight replicated field tests. In each test, abscission chemical treatments were applied to three replicate trees and an adjuvant (Kinetic, Setre Chemical Co., Memphis, Tennessee) was added at 0.1% to the abscission chemical and water mixture. The trees were shaken three to eight days post spray when fruit loosening was judged to be optimum and minimum preharvest fruit drop had occurred. Within each test, each tree was shaken for approximately the same length of time at the same frequency. Length of shaking time was set as the minimum which maximized fruit removal from the trees having the loosest fruit (defined as the lowest fruit detachment force and/or highest preharvest fruit drop), and thus maximize differences in fruit removal related to fruit looseness. To establish fruit looseness, fruit detachment forces were measured on 10 fruit per tree, and preharvest fruit drop was determined by weighing the fruit on the ground for each tree just prior to harvest. During the shaking operation, acceleration measurements in the x-y horizontal plane were

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recorded with a Daqbook (Iotech, Cleveland, Ohio) data acquisition system on two trees with representative trunks by attaching accelerometers to both the shaker head and trunk. The accelerometer signals were integrated using Dadisp (DSP, Cambridge, Massachusetts) software which quantified the displacement and frequency of the shake pattern. After shaking each tree, fruit removed by the shaker was weighed as was the fruit left on the tree. The height aboveground at which the shaker clamp pads contacted the trunk and the trunk circumference at that height were measured.

Test 1

A new abscission chemical, prosulfuron (Peak, Novartis, Greensboro, North Carolina) was applied 20 February 1997 to 'Hamlin' orange trees spaced 7.3 m × 7.3 m and 4.5 m tall. The chemical, which was named Transfer by Wilcox and Taylor, 1996, was reported to have promise for loosening citrus. The four abscission chemical treatments [0 (control), 15, 30, and 45 ppm] were each applied using water at 2330 L/ha with a pto airblast sprayer. Each tree was shaken on 28 February with an FMC Model 729 shaker (FMC Corp., Madera, California) for 5 s. The shaker head, described by Whitney et al. (1988), had two 30.9-kg unbalanced masses rotating in the same direction with one mass rotating 15% faster than the other. Each mass had an eccentricity of 114 mm and was mounted on a separate vertical shaft.

Test 2

Another new abscission chemical, metsulfuron-methyl (Ally, DuPont Co., Wilmington, Delaware) was applied 6 January 1998 to Hamlin orange trees spaced 7.3 m × 7.3 m and 4.5 to 6 m tall. Twelve abscission chemical treatments were applied with a pto airblast sprayer. The treatments were 0 (control), 1, 2, and 4 ppm each applied using water at 467, 1870, and 4670 L/ha. Each tree was shaken on 16 January with a Fruit Harvesters International (FHI) trunk shaker for 12 to 15 s. The shaker used two sets of unbalanced masses and specifications were proprietary information.

Tests 3-5

These tests were conducted in 1998 using Hamlin orange trees spaced 6.1 m × 4.6 m and 4 m tall. Each test corresponded to a harvest date (Test 1, 16 January; Test 2, 30 January; Test 3, 13 February) for which abscission chemical treatments were applied with a handgun sprayer using water at 6800 L/ha on 6 January, 20 January, and 6 February, respectively. The three treatments were a control, metsulfuron-methyl at 2 ppm, and CMN-pyrazole (Release (previously tested, see Hedden et al., 1988), Abbott Laboratories, Chicago, Illinois) at 100 ppm. On the date of harvest, the trees were shaken for 5 s. In Test 3, a FHI shaker was used and in Tests 4 and 5, a Compton (Compton Enterprises, Inc., Chico, California) side-mount shaker was used. The Compton shaker, described by Whitney (1999), had two sets of unbalanced masses totaling 125 kg mounted on one vertical shaft. The masses (220 mm eccentricity) rotated in the same direction with one set rotating 15% faster than the other.

Tests 6-8

These tests were conducted in 1998 using 'Valencia' orange trees spaced 6.1 m × 4.6 m and 3 m tall. Each test corresponded to a harvest date (Test 6, 20 April; Test 7, 7 May; Test 8, 21 May) for which abscission chemical treatments were applied with a handgun sprayer using water at 6800 L/ha on 15 April, 1 May, and 18 May, respectively. The four treatments were a control, metsulfuron-methyl at 0.5 ppm, CMN-pyrazole at 50 ppm, and CMN-pyrazole at 100 ppm. On the date of harvest, the trees were shaken for 5 s with an experimental Compton (Compton Enterprises, Inc., Chico, California) monoboom-mounted shaker. This shaker, different than the one used in Tests 4 and 5, had two sets of unbalanced masses totaling 130 kg mounted on a single shaft to one side of the parallel clamp pads and centered on the length of the longitudinal axes of the pads. The masses (220 mm eccentricity) rotated in the same direction with one set rotating 15% faster than the other.

All data were statistically analyzed using the GLM procedure in SAS (SAS Institute, Cary, North Carolina). Duncan's Multiple Range Test was used to determine mean separation at the 5% level of significance.

Results

Shaker fruit removal is defined as the fruit removed by the shaker; whereas, total fruit removal is defined as preharvest fruit drop plus shaker fruit removal. All percentage calculations were referenced to the total fruit yield of the tree.

Test 1

The results are summarized in table 1. Eight days after application, all prosulfuron treatments significantly reduced the detachment force of Hamlin oranges about 30% compared with the control. Even though there were trends in the other dependent variables listed in table 1, the differences were not statistically significant at the 5% level. Preharvest fruit drop with the prosulfuron treatments averaged 16.7%. Shaker and total fruit removal increased with prosulfuron concentration, averaging 67 and 83.7%, respectively (9.8 and 22.7 percentage points higher than the control). These results were similar to those reported in Hamlin oranges by Hedden et al. (1988). The FMC 729 shaker head developed a maximum displacement of 30 to 35 mm at 15 to 18 Hz on a trunk of 570 mm circumference.

Table 1. Harvest results with treatments prosulfuron and FMC 729 shaker head (5 s shake) in 'Hamlin' oranges, Test 1

Prosulfuron Treatment (ppm)	Fruit Detachment Force (N)	Preharvest Fruit Drop (%)	Shaker Fruit Removal (%)	Total Fruit Removal (%)	Trunk Circumference (mm)	Shaker Clamp Pad Height (mm)	Tree Fruit Yield (kg)
0 (control)	73a*	3.8a	57.2a	61.0a	600a	500a	357a
15	50b	16.6a	61.9a	78.5a	570a	460a	313a
30	46b	17.5a	68.0a	85.5a	590a	460a	295a
45	51b	16.1a	71.2a	87.2a	480a	450a	217a

* Means in each column followed by same letter are not significantly different at the 5% level with Duncan's Multiple Range Test.

Table 2. Harvest results with metsulfuron-methyl treatments and FHI trunk shaker (12-15 s shake) in 'Hamlin' oranges, Test 2

Metsulfuron Methyl Prosulfuron Treatment (ppm)	Fruit Detachment Force (N)	Preharvest Fruit Drop (%)	Shaker Fruit Removal (%)	Total Fruit Removal (%)	Trunk Circumference (mm)	Shaker Clamp Pad Height (mm)	Tree Fruit Yield (kg)
0 (control)	73a*	1.1a	71.2a	72.3a	650a	370a	443a
1	43b	3.4a	79.5a	82.9b	740ab	360a	562ab
2	43b	10.0ab	76.4a	86.4b	710ab	350a	521ab
4	38b	16.2b	70.6a	86.8b	820b	350a	652b

* Means in each column followed by same letter are not significantly different at the 5% level with Duncan's Multiple Range Test.

Test 2

Table 2 summarizes the harvest results for each metsulfuron-methyl concentration averaged over L/ha. All concentrations of metsulfuron-methyl significantly reduced fruit detachment forces and significantly increased total fruit removal. In general, these effects were related to metsulfuron-methyl concentration. Preharvest fruit drop was significantly increased only by metsulfuron-methyl at 4 ppm. Shaker fruit removal was not significantly affected by any of the metsulfuron-methyl treatments. Although the values are not shown, increasing the L/ha had a similar effect as increasing metsulfuron-methyl concentration (Kender et al., 1999). Compared to all other tests, tree sizes and fruit yields were considerably greater and more variable. Accelerometer measurements indicated the FHI shaker head operated at 6 Hz while the displacement was 50 mm on a trunk with an 860 mm circumference and 80 mm on a trunk with a 560 mm circumference.

Test 3-5

The results are summarized in table 3. Compared with the control in Test 3, metsulfuron-methyl and CMN-pyrazole significantly reduced fruit detachment forces, and significantly increased the percentage of shaker and total fruit removals. Further, fruit removals with metsulfuron-methyl were significantly greater than those obtained with CMN-pyrazole. The FHI shaker operated at 6 Hz and 80 mm displacement on a trunk of 450 mm circumference.

In Test 4, both metsulfuron-methyl and CMN-pyrazole provided a significant reduction (80%) in fruit detachment force and significantly increased preharvest fruit drop. Both abscission chemical treatments significantly increased total fruit removal by 14 percentage points, and shaker fruit removals were less, but not significant. In Test 5, both metsulfuron-methyl and CMN-pyrazole significantly reduced fruit detachment forces (60%) and significantly increased total fruit removals about 14 percentage points. Only metsulfuron-methyl significantly increased shaker fruit removal. The Compton shaker operated at 10 Hz and a displacement of 50 mm on a trunk of 540 mm circumference in both tests.

Table 3. Harvest results with metsulfuron-methyl and CMN-pyrazole treatments with FHI (Test 3) and Compton (Tests 4 and 5) shakers (5 s shake) in 'Hamlin' oranges, Test 3-5

Abscission Chemical Treatment (ppm)	Fruit Detachment Force (N)	Preharvest Fruit Drop (%)	Shaker Fruit Removal (%)	Total Fruit Removal (%)	Trunk Circumference (mm)	Shaker Clamp Pad Height (mm)	Tree Fruit Yield (kg)
Test 3							
Control	76a*	1a	78.2a	79.2a	450a	280a	207a
Metsul.	27b	4.8a	93.0b	97.8b	450a	280a	186a
CMN-P 50	43b	4.8a	83.4c	88.2c	480a	290a	238a
Test 4							
Control	85a	4.9a	79.0a	83.9a	530a	310a	246a
Metsul.	18b	25.9b	73.2a	99.1b	550a	330a	273a
CMN-P 50	13b	31.7b	66.3a	98.0b	530a	310a	274a
Test 5							
Control	61a	0.8a	80.7a	81.5a	540a	290a	269a
Metsul.	26b	1.1a	94.9b	96.0b	500a	280a	237a
CMN-P 50	24b	3.4b	94.2ab	97.6b	570a	210b	271a

* Means in each column within each test followed by same letter are not significantly different at the 5% level with Duncan's Multiple Range Test.

Table 4. Harvest results with metsulfuron-methyl and CMN-pyrazole treatments and experimental Compton trunk shaker (5 s shake) in 'Valencia' oranges, Tests 6-8

Abscission Chemical Treatment (ppm)	Fruit Detachment Force (N)	Preharvest Fruit Drop (%)	Shaker Fruit Removal (%)	Total Fruit Removal (%)	Trunk Circumference (mm)	Shaker Clamp Pad Height (mm)	Tree Fruit Yield (kg)
Test 6							
Control	99a*	0a	85.6ab	85.6a	380a	270a	130a
Metsul.	83a	10.2a	85.6ab	95.8b	410a	260a	127a
CMN-P 50	49b	2.6a	91.2a	93.8ab	380a	290a	134a
CMN-P 100	21c	24.5b	74.2b	98.7b	420a	260a	101a
Test 7							
Control	101a	0a	87.8a	87.8a	340a	240a	156ab
Metsul.	100a	0a	83.3a	83.3a	350a	230ab	171a
CMN-P 50	92a	0a	87.5a	87.5a	470a	200b	173a
CMN-P 100	76b	0a	95.3b	95.3b	410a	270c	129b
Test 8							
Control	101a	0a	79.7a	79.7a	480a	260a	202a
Metsul.	78ab	0a	88.2ab	88.2ab	440a	320a	180a
CMN-P 50	66b	0a	92.4b	92.4b	450a	250a	190a
CMN-P 100	28c	3.2b	92.3b	95.5b	440a	280a	191a

* Means in each column within each test followed by same letter are not significantly different at the 5% level with Duncan's Multiple Range Test.

Tests 6-8

Table 4 summarizes the results. In Test 6, only the CMN-pyrazole treatments significantly reduced fruit detachment force, and only metsulfuron-methyl and CMN-pyrazole at 100 ppm significantly increased total fruit removal by 10 to 13 percentage points. Shaker fruit removal was not significantly changed by any of the abscission chemical treatments. CMN-pyrazole at 100 ppm was superior to CMN-pyrazole at 50 ppm in decreasing detachment force and increasing preharvest drop. The shaker was operated at 8 Hz and had a maximum displacement of 80 mm on a trunk of 480 mm circumference.

In Test 7, only CMN-pyrazole at 100 ppm significantly decreased fruit detachment force and significantly increased shaker and total fruit removal. This date of application corresponded to the time when the 'Valencia' orange was less responsive to abscission chemicals (Hartmond et al., 1999). Shaker frequency and displacement results were similar to those in Test 6.

The results in Test 8 showed that only the CMN-pyrazole treatments significantly reduced fruit detachment force and significantly increased shaker and total fruit removal. Overall, CMN-pyrazole provided superior results by increasing fruit removals by 12 to 15 percentage points. Shaker frequency and displacement results were similar to those in Test 6.

Discussion

In assessing the significance of these results, one must consider how trunk shakers and abscission chemicals would be used in commercial citrus harvesting operations. Currently, shake-catch systems are being used without abscission chemicals. In most cases, fruit missing the catchframe and fruit left in the tree are gleaned by manual laborers. Thus far, gleaning has been necessary to satisfy the grower mindset that all fruit be harvested, just as the manual harvesters do. More importantly, gleaning eliminates the penalty to the shake-catch system for leaving too much fruit in the grove, which can make the economic feasibility of the system unacceptable. For example, consider an orange grove with a 50 t/ha yield and a delivered in price, less grove to plant hauling costs, of \$140/t. The fruit value is \$7,000/ha (50 × 140) less manual harvesting costs. If a mechanical harvester leaves 15% of the fruit in the grove, the penalty is \$1,050/ha (0.15 × \$7,000). If manual harvesting costs \$1,800/ha, then the mechanical harvester must operate at \$750/ha (\$1,800-\$1,050) to break even. As long as manual harvesters are available, the acceptance of mechanical citrus harvesters will be limited until the grower net profit using the mechanical system is equal to or greater than the net profit using manual harvesters. The goal with a mechanical harvesting system is to maximize mechanical fruit recovery so that the system would be economically feasible without using manual laborers for gleaning.

If an abscission chemical is to be used with a shake-catch system, then provisions must be considered for handling preharvest fruit drop. Ideally, to minimize or eliminate the need for manual labor with a shake-catch system, preharvest fruit drop should be kept to a minimum to minimize the quantity of fruit drop to be picked up from the ground and to maximize total mechanical fruit recovery without gleaning. If preharvest fruit drop is substantial, then shaking all fruit to the ground and picking it up mechanically or manually is an alternative harvesting system. Although shaking fruit to the ground may maximize fruit recovery from the trees with loose fruit and substantial preharvest drop, losses associated with mechanical pickup systems may reduce total fruit recovery to marginal or unacceptable levels.

The results in Tests 1 and 2 indicate the effect of shake displacement and frequency on fruit removal. In the control trees, the FMC shaker (not being used commercially in citrus) in Test 1 removed about 57% of the fruit with 30 mm displacement at 15 to 18 Hz for 5 s; whereas, in Test 2, the FHI shaker (which is being used commercially) removed 71% with 50+ mm displacement at 6 Hz for 12 to 15 s. In addition, the trees in Test 2 had somewhat larger trunk circumferences, higher fruit yields, and lower clamp pad heights, all of which tend to lower fruit removal with the trunk shaker (discussed below). Although the shake time was 5 s in Test 1 as compared to 12 to 15 s in Test 2, longer shake times in Test 1would not have significantly increased fruit removals to 71%. As might be expected, higher shaker and total fruit removals with the smaller displacement, higher frequency shake (Test 1) were more dependent on the effectiveness of the fruit loosening chemicals than were the larger displacement, lower frequency shake systems (Tests 2-8). Achieving adequate total fruit removal with the smaller displacement, higher frequency shake systems used in other tree fruit and nut crops will probably require chemical fruit loosening, which may result in substantial preharvest fruit drop. All of the trunk shakers under development in Florida produce the larger displacement, lower frequency shake because of superior fruit removal capabilities.

The trees used in Tests 2-8 varied considerably in trunk circumference and fruit yield. In Test 2, trunk circumferences varied from 530 to 1020 mm and fruit yields varied from 212 to 888 kg/tree. In Tests 3-5, the range of trunk circumferences and fruit yields were 410 to 610 mm and 145 to 320 kg/tree, respectively; whereas, in Tests 6-8 they were 360 to 530 mm and 82 to 238 kg/tree. In the combined data from Tests 2-8, Pearson correlation coefficients (SAS Institute, Cary, North Carolina) were calculated between the variables. The coefficient was positive between total fruit removal and preharvest fruit drop ($r = 0.45$, $p = 0.0001$). They were negative between total fruit removal and fruit detachment force ($r = -0.43$, $p = 0.0001$), trunk circumference ($r = -0.37$, $p = 0.0002$), fruit yield ($r = -0.37$, $p = 0.0001$), and shaker clamp pad height ($r = -0.23$, $p = 0.02$). The negative coefficient with shaker clamp pad height was not expected. One explanation might be that the greater heights were associated with the trees in Test 2, which had larger trunk circumferences and fruit yields (negative coefficients with total fruit removal), and generally had lower total fruit removals than for Tests 3-8. Note that for the control treatment, the average total fruit removal (and similarly shaker fruit removal) increased from Test 2 to Tests 3-5 to Tests 6-8 as the trunk circumferences and fruit yields got smaller. Many of the mature citrus trees in the Florida citrus industry are similar or slightly larger than the trees in Tests 3-5 and have similar fruit yields.

Except for Test 2 in which the trunk circumferences and fruit yields were much larger, total fruit removals achieved with fruit loosening in Tests 3-8 were in the low to upper 90% range. In some cases, preharvest fruit drop was substantial and may not be considered suitable for shake-catch operations. How did the abscission chemical treatments affect shaker fruit removal? The Pearson correlation coefficient between shaker fruit removal and preharvest fruit drop was negative ($r = -0.57$, $p = 0.0001$), indicating that lower drop was associated with increased shaker fruit removal. This trend can be seen by examining the figures in the tables. Thus, if manual fruit gleaning is to be minimized or eliminated in a shake-catch operation, preharvest fruit drop as a result of fruit loosening should be kept to a minimum to maximize shaker fruit removal.

All three abscission chemicals used in these tests usually reduced the detachment force of oranges. Prosulfuron and metasulfuron-methyl provided orange loosening at low concentrations, and are cleared for other uses. However, they were phytotoxic to the trees. Whitney (1998) and Kender et al. (1999) reported twig dieback and injury to young Valencia fruit. On the other hand, CMN-pyrazole required higher concentrations to be effective, but has been field tested over several seasons (Hedden et al., 1988) and has shown no significant phytotoxic effects on orange trees. Its potential for clearance by the EPA is unclear at this time.

CONCLUSIONS

1. Abscission chemicals usually loosened Hamlin and Valencia oranges and increased shaker and total (preharvest fruit drop + shaker fruit removal) fruit removals up to 14 and 30 percentage points, respectively. Maximum shaker and total fruit removals were 95 and 99%, respectively.
2. Without abscission chemicals, orange removal by trunk shakers with 50 mm displacement at 6 to 10 Hz was 10 to 15 percentage points higher than with 30 mm displacement at 15 to 18 Hz.
3. As a result of fruit loosening by abscission chemicals, increased preharvest fruit drop increased shaker fruit removal with the smaller displacement shaker and generally decreased shaker fruit removal with the larger displacement shaker.
4. Total fruit removals were positively correlated with preharvest fruit drop and negatively correlated with trunk circumference, fruit yield, and fruit detachment force.

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