MECHANICAL HARVESTER FOR PROCESS ORANGES

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ABSTRACT. *An experimental, direct-drive, double-spiked-drum canopy shaker was developed to harvest oranges from high density groves. Each drum was 2.44 m (8 ft) in diameter and had six horizontal whorls spaced 300 mm (12 in.) apart on a vertical shaft. Each whorl had 16 nylon rods, 32 mm (1.25 in.) in diameter, spaced at equal angles. Maximum rod penetration into the canopy was 1 m (39 in.), shaking frequency was 4 to 5 Hz, and maximum horizontal displacement of the rod tip was of 250 mm (10 in.). The shaker was towed by a tractor along a tree row at travel speeds ranging from 1.4 to 3.2 kph (0.9 to 2 mph). In the canopy space penetrated by the shaking rods, mature fruit removal averaged 71 to 91%. These promising results prompted the development of a prototype harvesting system. The shaker drums were enlarged to 3.66 m (12 ft) in diameter and increased in height to harvest trees up to 4 m (13 ft) high. Fruit catching and conveying components were added under the shaker mechanism to collect and transport the detached oranges to the rear, row-center of the shaker unit. A self-propelled bulk transport unit followed the harvest unit at a synchronized speed. The bulk transport unit had a conveying system that received the oranges from the harvester and transferred them to its rear hopper (6 t capacity). Both the harvester and the bulk transport unit had trash removal devices. Tests during the winter and spring of 1997 demonstrated potential of the system as an effective high-capacity harvesting alternative if compatible tree training and machine design parameters can be achieved. Fruit receiving grade at the processing plant was as good as hand-harvested fruit.* **Keywords.** *Mechanical harvester, Oranges, Shaker.*

Considerable research by private, public, and industry groups have explored many techniques to develop an effective mechanical harvesting system for processed oranges, but without commercial success. Whitney (1995) summarized many of these approaches, such as harvest aids, contact removal devices, limb shakers, trunk shakers, air shakers, and robots. Millier et al (1970) developed a continuous, vertically reciprocating, spiked-drum canopy shaker and tested the shaker on fresh market oranges without success. Tests conducted with a stop-and-go, vertical canopy shaker (Sumner, 1973; Whitney et al., 1975) required 10 to 20 s/clamp, averaged 7 min/tree, and generally resulted in less than 85% fruit removal.

However, selectivity ratios (number mature/number immature oranges removed) for 'Valencia' harvested in May 1971 ranged from 11 to 15 (Sumner, 1973). 'Valencia' is the only cultivar that has two crops on the tree at harvest time. Castillo et al. (1996) developed a vertical canopy shaker that could operate continuously, or stop and go. They obtained fruit removal near 90% when the unit was stopped, and shook for 20 s at 3 Hz, with a 220-mm vertical stroke. When operated continuously at 1.89 kph (1.2 mph) fruit removal was less than 60%. Two ideas (Clark, 1968; Baker, 1971) proposed penetrating tree canopy with a plurality of rods and laterally reciprocating the rods to effect fruit removal. No results have been reported on these concepts. Peterson and Kornecki (1989) developed a shaker consisting of panels of radially spaced rods that were oscillated by a positive direct-drive that gave nearly uniform displacement and acceleration along the length of the rod. This shaker was moved continuously along a fruiting canopy and was a key component in the development of a blackberry harvester (Peterson et al., 1992) and a blueberry harvester (Peterson et al., 1997). In Florida, one-third of the commercial acreage has been planted since 1989 with tree densities spaced as close as 3 m × 6 m (10 ft × 20 ft). With close in-row tree spacing, trees have potential to develop into a continuous hedgerow that might be harvested with a canopy shaker.

OBJECTIVES

The objective of this research was to develop an effective, continuous mechanical harvesting system for processed oranges, grown in high density groves, using a canopy shaker.

The research was conducted in two phases. The phase one objective was to design and test a double spiked-drum canopy shaker that would effectively remove oranges. If phase one was successful, phase two was to develop a prototype harvesting system that would remove, catch, and containerize oranges.

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Design

Shaker — Phase 1

The positive displacement double spiked-drum shaking principle developed by Peterson and Kornecki (1989) for small fruits was scaled up for orange harvesting (fig. 1). All shaker components were mounted on a tractor-towed trailer. Each drum was 2.44 m (8 ft) in diameter and had six horizontal whorls spaced 300 mm (12 in.) on a vertical central shaft. Each central shaft was bearing supported by two support arms that were bearing supported to the shaker frame. Each pair of support arms were oscillated by connecting rods that were driven by ball bearing eccentrics to generate a horizontal shaking action by the shaker rods. The oscillating shaker rods engaged the canopy's branches to transfer the shaking energy to effect fruit removal. The front and rear drive eccentrics were driven by a common shaft, but keyed 180° apart. This arrangement permitted the front and rear spiked-drums to be synchronized in opposite directions for dynamic balance. Each whorl had 16 nylon (Nylon 66) rods, 1.14 m (45 in.) long × 32 mm (1.25 in.) diameter spaced at equal angles. Maximum rod penetration into the canopy was 1 m (39 in.), shaking frequency ranged from 4 to 5 Hz, and maximum potential horizontal displacement of the rod tip was 250 mm (10 in.). All whorls on the rear drum were offset 150 mm (6 in.) vertically with respect to the front drum giving an effective shaking range from 0.6 m (2 ft) to 2.4 m (8 ft) above the ground. A caliper disc brake, on the central shaft above the top whorl of each drum, could be adjusted through a pressure reducing valve to impart up to 225 N-m (166 lbf-ft) of drag torque to resist drum rotation. By resisting drum rotation, more of the shaking action could be transmitted to the canopy. The shaker was sized only to test the shaking principle in a representative volume of the canopy, not to remove fruit from the entire tree. Hydraulic power was supplied by a 150 L/m (40 g/min.), 17 000 kPa (2500 psi) pto pump.

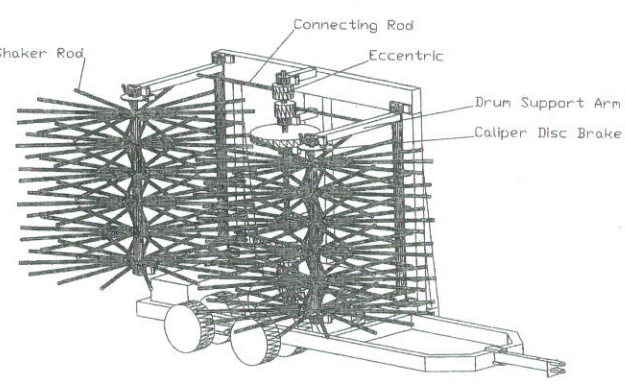

Figure 1–Schematic of orange shaker.

Prototype Harvester — Phase 2

The prototype harvesting system (fig. 2) consisted of a 70-kW (90 hp) tractor, the shaker unit, and a self-propelled fruit receiver and bulk storage container. The tractor towed the shaker unit and provided pto to power the shaker hydraulics.

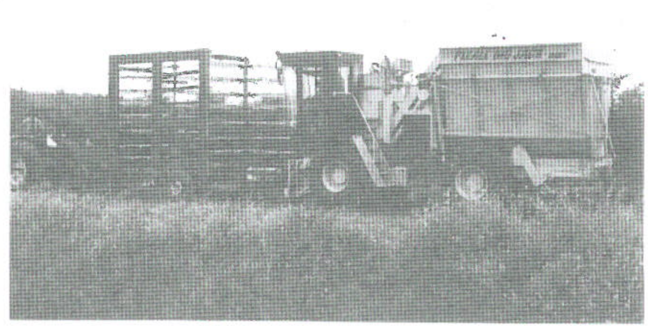

Figure 2–Prototype orange harvesting system.

The shaker unit had drums that were 2.75 m (9 ft) in diameter with eight whorls spaced 400 mm (15.75 in.) apart. Each whorl had 16 nylon rods, 1.27 m (50 in.) long × 38 mm (1.5 in.) diameter spaced at equal angles. Maximum rod penetration into the canopy was 1.17 m (46 in.) and maximum potential horizontal displacement of the rod tip was of 250 mm (10 in.). In April 1997 the rods on the lowest four whorls of both the front and rear drums were changed to give a 3.66-m (12-ft) diameter drum. A 1.72-m (68-in.) long composite rod consisting of a 1.12-m (44-in.) long × 38-mm (1.5-in.) diameter nylon rod inserted 150 mm (6 in.) into a 44.5-mm (1.75-in.) outside diameter × 38-mm (1.5-in.) inside diameter steel pipe 750 mm (29.5 in.) long was used since its natural frequency was above the 5 Hz shaking frequency required. The top and bottom whorls were 3.8 m (12.5 ft) and 0.6 m (2 ft) above the ground, respectively. On the center axis of each drum, positioned above the fourth whorl, was a caliper disc brake as described above.

Conveyors (fig. 3) were added to the shaker unit in January 1997 to collect and transport the oranges to the rear-center of the row. Rod chains were used for the final conveyors design with 32 mm (1.25 in.) spacing between rods. A 1.22-m (4-ft) wide × 6.7-m long (22-ft) collection conveyor was positioned under the fruiting canopy to catch most of the fruit. Inclined plywood sheets covered the harvesters trailer frame and fed oranges into the collection conveyor. An inclined 400-mm (16-in.) wide × 10-mm (0.3875-in.) thick polyurthane belt was attached to the outside edge of the collection conveyor to act as a flexible extension of the catching surface. A 1-m (39-in.) wide

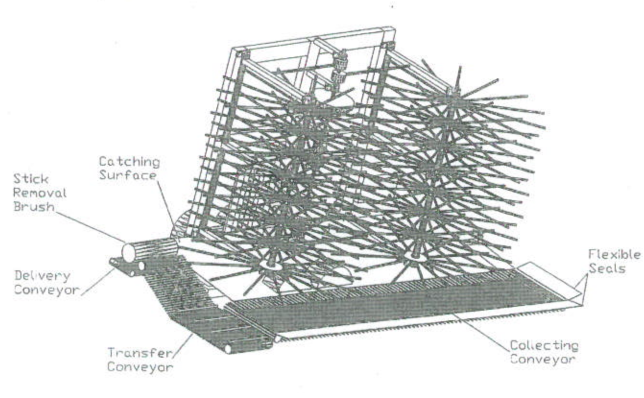

Figure 3–Schematic of prototype harvester.

transfer conveyor was used to transfer and elevate the oranges to a 500-mm (18-in.) wide delivery conveyor. Between the transfer and delivery conveyors was a 300-mm (12-in.) diameter stick brush that removed branches. The transfer conveyor deposited the oranges into the self-propelled bulk container unit. A hydraulic lift system for the outside pair of tires enabled the shaker unit to be tilted up to 12° to have the shaker match the tree profile (due to side hedging or uneven terrain).

The bulk container unit (Pixall, Clear Lake, Wis.) had a hydrostatic drive and high flotation tires. Two inclined flighted belts elevated the oranges into a 140-field box (6 t) bulk storage unit. Two belts were used to enable a transfer stage where high velocity air was introduced to remove trash. The container unit had a hydraulic lift system to elevate and dump the oranges into a highway service trailer.

Test Procedures

Shaker — Phase 1

The shaker unit was tested in commercial groves in Florida from February through May 1996. No special pruning or grove preparation was done. Preliminary tests were conducted to determine appropriate operating parameters. Prior to shaking, pull force measurements were taken on a representative fruit sample. After shaking, fruit on the ground were collected and weighed, and fruit in the shaken canopy volume were picked and weighed. A removal percentage was calculated. Ground speed ranged from 1.4 to 3.2 kph (0.9 to 2 mph).

Prototype Harvester — Phase 2

All tests were conducted in commercial groves. Groves were selected with tree size that best fit the size of the harvester. However, since the harvester was not designed for a particular grove, no grove was an ideal match for the harvester. An ideal match would be a hedgerow whose width and height were such that the shaker's rods would penetrate to the tree center and top, and would place the outer edge of the catching surface along the trunk-line. Trees were skirted to 0.6 m (2 ft). Fruit removal data were collected before mid-January 1997. Removal was determined on a whole tree basis, even though the shaker's rods did not always penetrate the entire canopy or reach the tops of some trees. After mid-January 1997, both fruit removal and recovery data were collected. Prior to harvest, pull force measurements were taken on a representative fruit sample. The selectivity ratio was also determined in 'Valencia'.

Table 1. Canopy shaker removal results for 1996

Date	Fruit Type	Ground Speed (kph)	Shaker Frequency (Hz)	Canopy Width (m)	Pull Force (N)	Removal* (%)
2/8/96	'Hamlin'-orange	1.4	5	3-3.7		84
2/8/96	'Hamlin'-orange	1.9	5	3-3.7		79
3/21/96	Grapefruit	1.6	4	4.2	93	80
3/21/96	Grapefruit	3.2	4	4.2	93	83
4/11/96	'Valencia'-orange	1.9	5	4.0	120	91
4/11/96	'Valencia'-orange	3.2	5	4.0	120	71
4/11/96	'Valencia'-orange	1.9	5	4.9	138	80
4/11/96	'Valencia'-orange	3.2	5	4.9	138	89

* Of fruit on tree before harvest in the shaker rods penetration area, amount removed by shaking.

For both phases of shaker and harvester development, tests were conducted by personnel from the University of Florida, Citrus Research and Education Center under Contract to the Florida Department of Citrus. Each treatment was replicated at least three times with two to six half tree canopies per replication. The fruit removal efficiency data was provided by them.

Results and Discussion

Shaker — Phase 1

The double-drum shaker was very stable and reliable. Fingers penetrated into and out of the canopy easily and tree damage was minimal. The shaker unit showed good potential for fruit removal (table 1). Removal ranged from 71 to 91% at ground speeds from 1.4 to 3.2 kph (0.9 to 2 mph). It was difficult to determine exactly where the shaker rods had penetrated the canopy, but it was felt that the removal data accurately reflected the potential of the shaking technique.

Prototype Harvester — Phase 2

Increasing the diameter of the shaker drum proved difficult, since lengthening the nylon rods lowered their natural frequency. When the rods operated near their natural frequency they became unstable, produced wild fluctuations, and soon broke. Nylon rods 1.27 m (50 in.) long × 38 mm (1.5 in.) diameter could be shaken up to 5 Hz, but became unstable at higher frequencies. The longer composite shaker rod (1.72 m long) (68 in.) used to achieve the 3.66-m (12-ft) diameter drum was very stable up to 5.4 Hz. However, increasing the drum diameter to 3.66 m (12 ft) exceeded the design limits of the shaker support and drive members, resulting in frequent breakdowns. Even with the 3.66-m (12-ft) diameter drum, rod movement into and out of the canopy was satisfactory.

Table 2. Canopy harvester results for oranges 1996/1997

Date	Fruit Type	Ground Speed (kph)	Shaking Freq. (Hz)	Canopy Width (m)	Canopy Height (m)	Pull Force (N)	Removal* (%)	Recovery† (%)	Selectivity‡ (M/I)
12/28/96	'Hamlin'	1.9	5	3.7	1.8-3	64	95	n.a.§	n.a.
12/28/96	'Hamlin'	1.9	4.5	3.7	1.8-3	64	73	n.a.	n.a.
1/8/97	'Pineapple'	1.9	5	4.7-4.9	3.7-4.6	93	80	n.a.	n.a.
1/28/97	'Pineapple'	1.9	4.5	2.6	2.4	26	80	73	n.a.
4/17/97	'Valencia'	1.9	5	4	4	103	83	73	5
4/17/97	'Valencia'	1.9	4.7	4	4	103	80	78	8

* Of fruit on tree before harvest, amount removed by shaking.
† Of fruit removed by shaking, amount collected by the catching surfaces and deposited in bulk transport unit.
‡ Ratio of number of mature to number of immature oranges removed by shaking.
§ Data not taken or not applicable.

Fruit removal continued to look promising (table 2). Due to variability between groves, no test conditions presented a perfect match between the machine setup and tree training. In the first test on 'Hamlin' on 28 December 1996, the fruiting canopy was too wide for the 2.75-m (9-ft) diameter drum, but the operator angled the shaker unit to better fit the canopy and pressed the shaker into the canopy. This resulted in 95% removal (whole tree basis) but also caused considerable canopy damage and some fruit splitting (2.5%). Removal was reduced to only 73% when the shaker was not pressed into the tree as much as possible and the frequency reduced to 4.5 Hz. Canopy damage and fruit splitting (1%) was also reduced. On 8 January 1997, the canopy was too wide and too high for the shaker, yet fruit removal averaged 80%. After this test, the catching/conveying components were added. On 28 January 1997, the catching surface extended too far out from the ends of the rods for the narrow canopy tested, which prevented effective rod penetration into the canopy. Removal was 80%, but nearly complete fruit removal resulted where the rods penetrated the canopy (expected since fruit removal force was low due to a hard freeze on 15 January 1997). Recovery of the removed fruit averaged 73%. Many of the removed oranges bounced across to the opposite side of the tree. The flexible seal along the trunk line was not effective. Observation of ground loss suggests that two harvester units will need to operate opposite each other as a pair moving in unison along the tree row. The tests conducted on 17 April 1997 represent the best match between tree and machine characteristics. The 3.66-m (12-ft) diameter whorls had been added as the lowest four whorls front and back. Some tree damage occurred when the tips of the lowest rods penetrated near the trunk line and skinned some major scaffold limbs. Shortening the length of the rods on the lowest whorl on the front drum would eliminate this problem. Fruit removal force was in the range normally expected and immature fruit ranged from 6.4 to 15 mm (0.25 to 0.6 in.) in diameter. Fruit removal averaged 83% for a 5-Hz shaking frequency and 80% for a 4.7 Hz frequency. The upper half of the fruiting canopy was slightly too high and wide for the smaller whorls. Observations suggested that a closer vertical whorl spacing (increased rod density) would improve removal results. Selectivity ratios were 5 and 8 for 5- and 4.7-Hz shaking frequencies respectfully (selectivity ratio of 3 to 5 are typical with trunk shakers (Whitney, 1997)).

The rod type conveyors and detrashing systems were effective in collecting, conveying and detrashing the harvested fruit. Fruit receiving grade at the processing plant was as good as hand-harvested fruit. Operating the harvester and bulk container unit in unison was satisfactory. The capacity of the bulk container was enough to handle all the fruit harvested in any row we harvested. However, we anticipate situations will occur where other handling systems may need to be explored.

The potential capacity of this harvesting technique is very high. At 1.9 kph (1.2 mph) ground speed and at 3 m (10 ft) in-the-row tree spacing, nearly 10 trees/min. will be harvested when parallel harvesters are moving down the tree row. Two to three trees per minute is a high harvesting rate for conventional shake-catch harvesting systems.

Summary

The canopy shaker/harvester developed in this research demonstrated potential for harvesting process oranges. Tree training and grove conditions will have to be compatible with harvester design details. Trees need to be trained to a hedgerow whose width and height are such that the shaker's rods penetrate to the tree center and top. Reliability of drive and support components need to be improved. Additional research is needed to determine optimum configuration and operating parameters of the harvester. A shaking frequency of 5 Hz seems to effect the best fruit removal without excessive tree damage. Refinements in collecting and conveying components will be necessary to reduce fruit ground losses.

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