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CITRUS FRUIT INJURY AS RELATED TO MECHANICAL HARVESTING WITH LIMB SHAKER-CATCH FRAME SYSTEMS[1]

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Abstract. **Studies were conducted for 2 seasons to investigate injury to mechanically harvested 'Hamlin', 'Pineapple', and 'Valencia' oranges and 'Marsh' grapefruit in comparison with hand harvesting. Fruit were harvested with 2 different limb shaker-catch frame machines and were evaluated for injury as related to suitability for the fresh market. In most cases, the machine harvested fruit sustained higher levels of injury than did the hand harvested fruit, although in some tests the difference was not very great. Holding studies on in-grade (non-eliminated) fruit showed consistently higher levels of decay for machine harvested fruit than for fruit that were harvested by hand. Treatment of fruit with Benlate (benomyl) fungicide reduced decay levels for both machine and hand harvested fruit. Results of this study indicate a good potential for mechanical harvesting of oranges and grapefruit for shipment on the fresh market, but fruit will require careful inspection and grading for injury.**

Introduction

Citrus production in Florida totaled 10.4 million tons during the 1974-75 season, of which 1.76 million tons were shipped fresh with the remainder processed (3). The volume of fresh fruit shipments in Florida might be looked upon as a relatively small part (16.8%) of the total for the state, yet it represents a very significant quantity and is roughly equal to the volume of fresh citrus shipments from California which totaled 1.82 million tons during the 1974-75 season (3).

Much of the research emphasis and commercial interest related to mechanical harvesting of citrus in Florida in past years has been for fruit to be used for processed products. More recently, there has been some interest in the use of mechanical harvesters for fruit to be shipped on the fresh market.

Previous studies conducted by others (4, 6) showed the effects of mechanical harvesting on the quality of citrus fruit harvested with mechanical shakers, air shakers, a spindle picking head, and a vacuum tube picker's aid. Although some fruit is damaged when harvested with a limb shaker-catch frame harvesting system, fruit harvested by this system has been found to incur lower levels of damage than with other mechanical harvesting systems. Results are reported here on studies, conducted over the past 2 seasons, for evaluating amounts and types of damage to relatively large volumes of fruit harvested with the latest designs of limb shaker-catch frame systems. This research was carried out in order to learn more about the feasibility of using such systems for the harvesting of fresh market fruit, and to provide background information for devising economical methods for sorting out damaged fruit.

Materials and Methods

Groves and Fruit

Experiments were conducted with 'Hamlin', 'Pineapple',

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and 'Valencia' oranges and 'Marsh' grapefruit. Fruit were harvested mechanically from trees in commercial groves in central Florida and from the Agricultural Research and Education Center groves at Lake Alfred. Large numbers of fruit were collected for evaluation—usually 1 or 2 pallet boxes for each experiment. In most tests, a hand picked control of 1 or 2 pallet boxes (with picking methods comparable to current industry hand harvesting practices) was taken from adjacent trees for comparison purposes. In addition, a small minimum handling sample was carefully clipped for use as a control sample in establishing the decay potential for the fruit in most tests. In one test with 'Hamlin' oranges, trees were given a preharvest spray of ethephon as an abscission treatment.

Harvesting Equipment

Fruit harvested with two machines were evaluated in this study. One machine was a limb shaker-catch frame system developed by personnel of the Florida Department of Citrus (FDOC). The machine was operated by means of the shaker clamping onto all major limbs on a tree and shaking the fruit off. The fruit fell into a catch frame which used a "catch-dump" concept. The catch frame was covered with a commercial artificial turf material over expanded metal. The machine also had a straight through fruit handling and cleaning system. This machine has been described in further detail elsewhere (1, 2).

The other machine was a commercially developed (COMM) limb shaker-catch frame harvesting system similar in many respects to the FDOC machine. One of the major differences was that the catch frame was covered with a stretched canvas type of frame rather than a solid backing. The canvas was wrapped around each tree to form an inverted umbrella catching surface with the apex at the trunk.

Injury Evaluations

Harvested fruit were brought to the AREC Lake Alfred packinghouse for evaluation. Oranges were evaluated the day following harvesting, but grapefruit were evaluated 2 days after harvesting to allow time for the development of certain injury symptoms peculiar to grapefruit. Fruit were washed, dried and run over the grading line, at a rate much slower than in commercial packinghouses, for close inspection by 2 or 3 graders. Those with visible signs of injury were eliminated. The apparently sound fruit were then passed over the grading line a second time to remove injured fruit that were missed on the first inspection. In some tests, fruit were sprayed with blue dye (5) on the second pass to make minor injuries easier to detect.

Eliminated fruit were evaluated for the amount and distribution of the different types of damage occurring. Injured fruit were designated according to one of the following damage classifications:

SPLIT: Fruit split open due to impact.

CUT OR PUNCTURE: Skin cut where the albedo was slightly exposed, or a more major cut or large puncture.

PLUG: Injury to the fruit where a portion of the peel was removed at the stem end.

SUPERFICIAL INJURY: Minor scratches into the flavedo or slight indentation with skin not cut.

BRUISE: Impact damage as evidenced by soft skin near bruised area.

OLEOCELLOSIS: A light green or tan discoloration due to breakdown of the oil cells in the rind of the fruit; caused by impact.

Counts were also made of adhering stems and of non-harvest damage. Fruit were run over sizing equipment to get a size distribution on the total amount of fruit, and in some cases a separate size distribution was obtained on the damaged fruit.

Decay Evaluations

For each test, samples from the individual size categories of in-grade (non-eliminated) fruit were stored at 70°F. (21°C) for decay studies and evaluated at intervals up to 4 weeks. These samples totaled 200 to 400 oranges or 100 to 200 grapefruit from the machine harvested fruit. In all except the first two tests on 'Hamlin' oranges, an equal number of hand harvested fruit from the in-grade lots were also held. A carefully hand clipped control sample of 100 fruit for oranges or 50 fruit for grapefruit was usually included as a control sample in the decay studies. In most tests, additional samples were also treated with 600 ppm of Benlate fungicide to determine how much such treatment might reduce the decay potential in both the hand and the mechanically harvested fruit. In some tests, eliminated fruit with superficial injuries were also held to determine whether fruit with minor injuries from mechanical harvesting might be suitable for fresh shipment.

Results

Injury Evaluations

Results of the injury evaluations are summarized for each test in Table 1. Data were subjected to statistical analysis to compare differences in the various types of injury between machine and hand harvested fruit in each test. No attempt was made to compare different tests with each other on a statistical basis because of the potential variability in grove and weather conditions, etc

Comparisons can be made on the amount of injury between hand harvested and mechanically harvested fruit in 10 of the tests shown in Table 1. In 6 of these, total damage levels were significantly higher in mechanically harvested fruit, although in the 26 Jan, 1976 test on 'Pineapple' oranges the difference was not very great. In 3 of the tests, there was no significant difference in percent injury between hand or machine harvested fruit and in the 21 May, 1975 test on 'Valencia' oranges with the FDOC machine, the hand harvested fruit actually sustained significantly greater injury.

In the 3 Dec, 1974 test on 'Hamlin' oranges, there was no significant difference in total damage levels between fruit harvested mechanically from trees with the preharvest ethephon spray and those without the spray. There was also no difference between the level of adhering stems in this comparison. The trees sprayed with ethephon in this test suffered a severe leaf drop following the treatment so this practice was not repeated in subsequent experiments.

In the machine harvested fruit, generally higher total damage levels are shown for 'Marsh' grapefruit than for 'Hamlin' or 'Valencia' oranges. Total damage was very high in both the machine and hand harvested samples of 'Pineapple' oranges in the 10 Feb, 1976 test, probably due to the tender rind on this variety during this part of the season.

The level of split fruit for all varieties was small in the mechanically harvested fruit and almost non-existent in the hand harvested fruit. Cuts, punctures, superficial injuries, and bruising constituted the major injuries to mechanically harvested fruit and damage levels for these injuries were often higher than in hand harvesting. In contrast, plugged fruit were usually minimal in the mechanically harvested fruit but often contributed to a significant proportion of the damage in hand harvested fruit. Plugging is a considerable problem in commercial hand harvesting of citrus, and levels are generally higher

Table 1. Summary of damage to mechanically harvested and hand harvested citrus, 1974-75 and 1975-76 seasons.

Date harvested	Fruit variety	Harvest[z] method	Total fruit	Damage levels as percent of total fruit							
				Split	Cut or punct.	Plug	Super. injury	Bruise	Oleo.	Total damage	Adhering stems
3 Dec. 74	Hamlin	FDOC	5500	0.5a	3.8a	0.1a	4.5a	0.0	0.0	8.9a	6.3a
	Hamlin	FDOC[y]	5500	0.9b	3.3a	0.4b	3.9a	0.0	0.0	8.5a	6.1a
6 Jan. 75	Hamlin	FDOC	4400	0.8	2.5	0.8	4.7	0.0	0.0	8.8	13.4
17 Dec. 75	Hamlin	FDOC	3474	0.7a	2.2a	0.5a	3.1a	5.2a	0.0	11.6a	23.2a
	Hamlin	HAND	2232	0.0b	0.0b	3.7b	0.3b	0.9b	0.0	5.0b	1.3b
24 Feb. 75	Pineapple	FDOC	4912	0.3a	2.1a	0.2a	2.9a	1.8a	0.0	7.3a	2.0a
	Pineapple	HAND	2559	0.0b	0.1b	0.7b	0.6b	2.0a	0.0	3.4b	0.0b
	Pineapple	COMM	2352	0.5a	5.6c	0.0c	6.7c	1.0b	0.0	13.8c	0.0b
26 Jan. 76	Pineapple	FDOC	3809	0.4a	2.5a	0.4a	1.2a	3.6a	0.0	8.2a	15.0a
	Pineapple	HAND	2547	0.0b	0.5b	1.5b	0.4b	3.8a	0.0	6.2b	1.6b
10 Feb. 76	Pineapple	COMM	2228	2.5a	4.0a	0.7a	6.6a	6.0a	0.0	19.6a	16.1a
	Pineapple	HAND	1844	0.0b	0.2b	11.4b	0.8b	5.3a	0.0	17.8a	2.0b
21 May 75[x]	Valencia	FDOC	4253	0.2a	0.2a	0.2a	0.3a	3.3a	0.0	4.2a	9.6a
	Valencia	HAND	2264	0.0a	0.0a	1.4b	0.0b	4.3a	0.0	5.7b	1.0b
21 May 75[x]	Valencia	COMM	2241	0.5a	0.3a	0.0a	0.1a	4.6a	0.0	5.5a	17.4a
	Valencia	HAND	2228	0.0b	0.0a	0.4b	0.0a	4.7a	0.0	5.2a	3.6b
5 May 76	Valencia	FDOC	1500	1.1a	1.3a	0.1a	1.5a	5.9a	0.0	9.9a	23.6a
	Valencia	HAND	1574	0.0b	0.0b	1.7b	0.5b	2.2b	0.0	4.4b	4.4b
3 Feb. 75	Marsh	FDOC	1014	0.0	3.6a	0.0	1.8a	6.1a	2.3a	13.8a	0.0
	Marsh	HAND	1014	0.0	2.8a	0.0	2.2a	5.8a	2.1a	12.8a	0.0
7 Apr. 75	Marsh	COMM	708	0.7a	4.7a	0.0a	3.7a	7.6a	2.5a	19.2a	0.0
	Marsh	HAND	832	0.0b	1.4b	0.1a	2.5a	3.8b	0.5b	8.4b	0.0

[z]Harvest method: FDOC = Florida Department of Citrus Mechanical Harvester; COMM = Commercial Mechanical Harvester; HAND = Hand Harvested.
[y]Preharvest ethephon spray.
[x]Fruit from different groves.
Values followed by the same letter do not differ significantly at the 5% level by Chi Square test with Yate's correction. Comparisons can be made vertically within tests separated by horizontal lines.

than shown for the hand harvested fruit in these tests. Oleocellosis occurred only in the tests with 'Marsh' grapefruit. There was no difference in the level of this injury between machine and hand harvested fruit in the first test, but oleocellosis was significantly greater in the machine harvested fruit in the second test on 'Marsh' grapefruit.

Adhering stems were usually significantly higher for mechanically harvested than for hand harvested oranges. There were no adhering stems in the tests on 'Marsh' grapefruit.

Data on the relationship between injury and fruit size on mechanically harvested oranges showed that the injury level was greater among the smaller sizes of 'Hamlin' and 'Valencia' oranges. The larger sizes of 'Pineapple' oranges, however, sustained more injury than the smaller sizes. The influence of fruit size on injury was not studied in the grapefruit tests.

Decay Evaluations

Results of the decay studies on fruit that were not eliminated during grading are shown in Table 2 for mechanically harvested, hand harvested, and carefully hand-clipped control samples. Decay evaluations were made on each sample at several intervals, usually weekly, during holding at 70° F. Because of space limitation, results are shown here for only one observation date for each test. A period of 14 days was chosen for oranges (10 days in one instance) because any differences would usually show up in this period of time and the 2-week period is approximately the length of time during which oranges might be expected to be in marketing channels for domestic shipments. A longer period, 21 days, was chosen for grapefruit because of a slower rate of decay development for grapefruit than for oranges. A high percentage of Florida grapefruit are now shipped overseas, which lends further justification for the longer observation period on grapefruit.

Again, for the decay data, the statistical analysis was done only within tests because of the potential uncontrolled variability between tests. In most tests, decay was much higher in the mechanically harvested fruit than in the hand harvested or hand clipped control samples. Differences in decay levels between mechanically harvested and hand harvested fruit were larger in most instances than might be anticipated by the differences in injury levels found in the damage evaluations. Benlate treatments reduced the decay levels in all tests for both mechanically harvested and hand harvested fruit, although in nearly half of the comparisons, the reduction was not statistically significant at the 5% level.

Decay levels were by far the highest in untreated 'Pineapple' oranges for both the machine harvested and hand harvested samples. Decay in the carefully hand clipped control sample of 'Pineapple' oranges n the 24 Feb, 1975 test was higher (14%) than for the control for any of the other varieties indicating a possible high decay potential for this variety. Previous studies (4, 6) have also confirmed that the 'Pineapple' variety is highly susceptible to mechanical damage due to its soft rind. In contrast, Benlate appeared to reduce the decay in 'Pineapple' much more significantly than for the other varieties studied.

As indicated previously, the decay results shown in Table 2 were based on samples taken from the fruit that were not detected as being injured (non-eliminated) during the grading. The significantly higher levels of decay in the mechanically harvested fruit indicate that these fruit apparently sustained injuries which were not easily detected

Table 2. Summary of decay on non-eliminated samples of mechanically harvested, hand harvested, and hand clipped control samples of citrus.

Date harvested	Fruit variety	Harvest[z] method	Days at 70° F.	Percent decay No Benlate	Percent decay Benlate
3 Dec. 74	Hamlin	FDOC	14	10.8a	—
		FDOC[y]	14	13.9a	—
		CONTROL	14	1.0b	—
6 Jan. 75	Hamlin	FDOC	14	31.0a	—
		CONTROL	14	9.0b	—
17 Dec. 75	Hamlin	FDOC	10	22.3a	14.7c
		HAND	10	4.0b	1.3b
24 Feb. 75	Pineapple	FDOC	14	58.0a	9.0c
		HAND	14	32.0b	2.3d
		CONTROL	14	14.0c	—
26 Jan. 76	Pineapple	FDOC	14	33.7a	3.0c
		HAND	14	10.3b	0.3d
10 Feb. 76	Pineapple	COMM	14	26.4a	1.1b
		HAND	14	23.6a	2.8b
21 May 75	Valencia	FDOC	14	23.9a	16.7a
		HAND	14	7.8bc	5.8cd
		CONTROL	14	5.0cd	1.0d
21 May 75	Valencia	COMM	14	18.3a	14.9a
		HAND	14	7.7b	6.8b
		CONTROL	14	1.0c	1.0c
5 May 76	Valencia	FDOC	14	6.3a	5.9a
		HAND	14	6.3a	1.9b
3 Feb. 75	Marsh	FDOC	21	14.8a	6.0b
		HAND	21	7.0b	2.0bc
		CONTROL	21	0.0c	0.0c
7 Apr. 75	Marsh	COMM	21	18.0a	16.5a
		HAND	21	8.0b	4.5b
		CONTROL	21	0.0b	—

[z]Harvest method: FDOC = Florida Department of Citrus Mechanical Harvester; COMM = Commercial Mechanical Harvester; HAND = Hand Harvested; CONTROL = Hand Clipped Control Samples with Minimum Handling.
[y]Preharvest ethephon spray.
Values followed by the same letter do not differ significantly at the 5% level by Chi Square test with Yate's correction. Comparisons can be made in any direction within tests separated by horizontal lines.

by visual observation, but which made the fruit more susceptible to decay.

Since a fairly large proportion of the eliminated fruit in most tests were those with superficial injuries, it would be beneficial if mechanically harvested fruit with these injuries (minor cuts, scratches, indentations with skin not broken) would be suitable for fresh shipment. Limited decay studies were conducted on fruit with superficial injuries. In the two tests with 'Hamlins' where fruit were not treated with Benlate, decay in fruit with superficial scars was much higher than in the non-eliminated samples. Tests on 'Pineapple' oranges and 'Marsh' grapefruit where fruit were treated with Benlate, indicated less decay in the fruit with superficial injuries than in the Benlate treated non-eliminated samples.

Data on the influence of fruit size on decay in the in-grade fruit indicated that smaller sizes tended to have more decay in the case of 'Marsh' grapefruit and 'Pineapple' oranges; whereas there tended to be a trend toward more decay among the larger sizes of 'Hamlin' and 'Valencia' oranges.

Conclusions and Discussion

Damage levels were significantly higher in mechanically harvested fruit than for hand harvested fruit in 6 out of 10 tests where such comparisons were made, but the other 4 tests showed little difference between damage to machine and hand harvested fruit. One difficulty in comparing damage in machine and hand harvested fruit in tests such as those conducted here is that the damage to the hand picked samples taken by laboratory technicians may not be representative of that sustained in commercial hand picking practice. If anything, the damage to commercial hand picked samples might be expected to be greater than found in the hand picked fruit reported on here. Limited observations on 'Hamlin' oranges graded and packed for shipment by commercial packinghouses showed higher levels of visible injury than did either the machine harvested or hand harvested 'Hamlins' in this study. Most of the superficial injuries to fruit harvested with the DOC machine occurred when fruit made impact with stems which tended to build up on the artificial turf surface of the catch frame. The catch frame on this machine is currently being modified by covering the artificial turf surface with foam padding material and a vinyl outer cover.

Decay levels were substantially higher among in-grade samples of machine harvested fruit in comparison with those harvested by hand. These fruit were inspected more closely in the grading than might be expected in commercial practice. This indicates that some method of chemically treating the fruit to show up minor injuries prior to grading may be needed. Several of these methods have been used with citrus but not on a commercial basis, and this approach is obviously limited by regulations on food additives. An alternative solution might be to develop optical techniques for detecting major or minor fruit injury, which could be incorporated into automatic optical grading equipment. Research is currently underway on this, and initial results have been quite favorable.

The use of Benlate reduced decay levels in mechanically harvested fruit for all varieties studied. In the case of 'Pineapple', fungicide treatment could make the difference between mechanical harvesting being feasible or out of the question, unless better methods are developed to detect fruit injury. Complete dependence should not be placed on specific fungicides as they are continually subject to approval by regulatory agencies.

A factor which was not studied here, but which needs investigation, is the amount of scarring which may occur to the small green fruit of the subsequent crop during mechanical shaking of 'Valencia' oranges. It is apparent that adhering stems continue to be a problem with mechanically harvested citrus. Stem removal equipment must be improved or additional labor will be needed at the packinghouse to clip stems.

The overall results of this study indicate a good potential for mechanical harvesting of fresh market oranges and grapefruit with the limb shaker-catch frame system, particularly if methods are developed to more easily detect minor fruit injury.

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