EFFECT OF MECHANICAL HARVESTING ON SUITABILITY OF ORANGES AND GRAPEFRUIT FOR PACKINGHOUSE AND CANNERY USE

W. GRIERSON

Citrus Experiment Station
University of Florida, F.F.A.S.
Lake Alfred

ABSTRACT

‘Hamlin,’ ‘Pineapple,’ and ‘Valencia’ oranges and ‘Marsh’ grapefruit from mechanical harvesting trials have been evaluated for 4 seasons. Keeping quality of ‘Hamlin,’ ‘Valencia,’ and ‘Marsh’ harvested with current mechanical equipment is within the limits normally experienced with cannery fruit, losses consistently being no more than in hand-picked ‘Pineapple’ oranges. Except for this variety, there was little difference in damage between mechanical shaker and air-shaker harvesting, the latter being harder on ‘Pineapples.’ Most external damage occurred before the fruit left the tree and took the form of cuts and punctures which were seldom more numerous than the ‘plugs’ in hand-picked fruit. However, a high percentage of adhering stems affords an unsolved problem. Least damage was with the spindle harvester using a bank of rubber augers. A good yield of intact sections was obtained in a single experiment with ‘Duncan’ grapefruit. No relationship was discernible between internal quality and keeping-quality. If granted FDA approval, new fungicidal sprays may control decay well enough to permit field storing fruit in “windrows” for several days, but sunburn remains an unsolved problem.

INTRODUCTION

For the past 4 seasons, the engineering studies on mechanical harvesting of citrus fruits have been paralleled by post-harvest studies checking physical damage to, and keeping-quality of fruit from the mechanical harvesting plots, including the hand-picked controls. This work has been reported only in a series of contract reports to the U. S. Department of Agriculture (10) and in a very much condensed form in the Annual Reports of the Florida Agricultural Experiment Station (5). No attempt is made here to give a complete account, particularly as the equipment was being developed and improved throughout this 4-year period. Thus, the data offered here represent the “current state of the art,” together with a certain amount of admittedly subjective judgement as to practicability for commercial use.

MATERIALS AND METHODS

Grove Techniques

Mechanical harvesting equipment has been described elsewhere (3,4). The use of abscission sprays to facilitate mechanical harvesting and, indirectly, reduce fruit damage, has recently been reviewed by Wilson and Coppock (11).

Field Plot Studies: Fruit for evaluation has been available from field plots of 4 varieties: ‘Hamlin,’ ‘Pineapple,’ and ‘Valencia’ oranges and ‘Marsh’ grapefruit. Experimental design involved 4 tree plots replicated 8 times and picked 4 times per season for each variety. Thus, a given tree was subjected to a given harvesting method (shaker-catchframe, air-blast, or hand-picked control) for 4 successive seasons. For 3 of these seasons, 1 field box (approximately 90 lbs. of fruit) was obtained for evaluation of fruit damage and keeping-quality from each plot at each picking. Results of these systematic samplings are presented in terms of averages for each variety, each year. More elaborate analysis of data was not considered suitable due to the constant revisions in the harvesting equipment and procedures, and the season-to-season variability due to weather conditions.

Equipment Changes and Modifications: At the start of these experiments, the shaker-catchframe system was fairly well developed and modifications were comparatively minor involving, principally, the manner in which the fruit was collected for transfer from the catchframe.
to the highway truck (8). Considerable experimenting was done with the air-shaker method, checking out such variables as fan speeds, forward speed of the equipment, and rate of oscillation of the air blast. Eventually, this line of study was taken over by a commercial company (FMC Corporation). Thus, comparisons between the 2 major mechanical harvesting methods are made for individual years and the multiyear comparisons involve hand harvesting and the shaker-catchframe method only.

Spindle Harvesting: Development of the spindle harvester equipped with banks of rubber augers has been carried on intermittently, principally, with the thought that this might provide a mechanical method for picking fruit for the fresh fruit market (4). Thus, evaluations of fruit from this equipment have been quite limited.

Picking Aid for Specialty Fruits: A “Selma” picking aid was imported from California by Minute Maid Corporation and used on the harvesting of ‘Dancy’ tangerines for the fresh fruit market. This consisted of a self-propelled vehicle with a hydraulically controlled picking stand in which the picker stood, controlling his position in the tree. A series of conveyors lowered the fruit to a box-filling position.

Special Experiments

A number of minor experiments were carried out independently of the broad design of the field work. Although not elaborate, several of these merit reporting.

Cannery Grapefruit for Sections: The grapefruit plots for mechanical harvesting have all been of the “Marsh” variety, which is not generally used for the production of canned grapefruit sections. Hence, a lack of external damage to mechanically-harvested grapefruit was no assurance that the integrity of the sections was preserved as is necessary in the canning of sections. Late in the 1964-65 season, half of the fruit on a single ‘Duncan’ (seedy) grapefruit tree was picked by hand. The remaining half was shaken to the ground with a mechanical shaker and picked up in field boxes. Samples from both lots were stained by scratching with a wire brush and dipping in dilute food color. These stained fruit were then run through the Sections Plant at the Florida Citrus Canners Cooperative, Lake Wales. Spotters picked off the stained fruit just prior to the mechanical peelers, and the 2 lots were peeled separately and then sectionized into cans by the professional sectionizers.

Internal Quality: Fruit samples from every picking of the mechanical harvesting plots were checked for standard maturity factors of juice content, Brix, acid, and ratio (8).

Staining: Initially, stain tests were done by the method of Long (7), using indigotin sulfate. Later, a reversible tannic acid method, developed by Sunkist, was used (9).

“Windrowing”: At the request of the Industry Harvesting Committee, we have tested the effect of accumulating fruit in “windrows” down the center of the row. For this, the usual procedure has been to have the fruit hand-picked, dropped onto canvases, and the canvases pulled to the center of the row, spilling the fruit in a ridge down the center of the row, convenient for a pick-up machine. Such “windrows,” left on the ground for several days, were sampled at intervals to determine the effect on the development of decay. In individual experiments, the effect of a pre-harvest fungicidal spray (1,2) and of position in the windrow have been checked.

RESULTS

Comparison of Mechanical Harvesting Methods.

Sample Variability: Although harvested from the same plots for several successive years, sample variability afforded a major problem in evaluation of data, even within a given season. Table 1 shows minimum and maximum losses from decay in individual samples, by varieties, in 1964-65, together with averages for the season. These are contrasted with the average decay levels in control samples in the Decay Control Project. (This latter affords as good a picture of the average decay level for the season as we have been able to find.) With such extreme range in decay potential, it becomes essential to evaluate data so that the consequent recommendations will minimize the chance of weak crops from weak varieties being handled with the roughest method, thus resulting in disastrous losses.

Mechanical Shaker v. Air-Shaker: Table 2 compares decay at 1 week from picking in 1964-65 in 3 varieties of oranges and one of grapefruit, harvested by 3 methods: hand-picking, mechanical shaking, and air-shaker. Note that results from each type of mechanical picking have to be compared with a separate control
Table 1. Variability in decay at 1 week from picking at 70°F (as per cent).

<table>
<thead>
<tr>
<th>Decay levels</th>
<th>Grapefruit</th>
<th>Orange varieties</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Marsh</td>
<td>Hamlin</td>
</tr>
<tr>
<td></td>
<td>Hand</td>
<td>Shaker</td>
</tr>
<tr>
<td>Min.</td>
<td>0.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Max.</td>
<td>15.0</td>
<td>35.0</td>
</tr>
<tr>
<td>Avg.</td>
<td>2.1</td>
<td>12.8</td>
</tr>
</tbody>
</table>

Project 1198*
Avg. 0.3   -    19.0  -   2.0  -   2.3  -

* Project 1198 is the Florida Citrus Commission's Decay Control Program. The values shown here are supplied by Mr. A. A. McCormack and represent the averages from control samples picked at approximately weekly intervals throughout the crop season for each variety.

Table 2. Post-harvest decay at 70°F in various varieties as related to method of picking (as per cent).

<table>
<thead>
<tr>
<th>Mechanical</th>
<th>Air-shaker</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variety</td>
<td>shaker-catchframe</td>
</tr>
<tr>
<td></td>
<td>Hand picked</td>
</tr>
<tr>
<td>Marsh G.F.</td>
<td>2.1</td>
</tr>
<tr>
<td>Hamlin</td>
<td>9.1</td>
</tr>
<tr>
<td>Pineapple</td>
<td>25.8</td>
</tr>
<tr>
<td>Valencia</td>
<td>1.5</td>
</tr>
<tr>
<td>Oranges avg.</td>
<td>12.1</td>
</tr>
</tbody>
</table>
because the control samples were hand-picked from each tree which was then mechanically harvested, thereby removing tree-to-tree variability in the comparison. Air-shaker harvesting was done with the Citrus Experiment Station machine at near optimum settings. Except for ‘Pineapples’ differences were not consistent; and if the higher decay in the air-shaker-harvested fruit is real, it is probably due to the fact that this fruit fell to the ground rather than into a catchframe, as with the mechanical-shaker system.

Air-shaking consistently resulted in more damage to ‘Pineapples’ than did mechanical shaking. In 1956-66, hand-picked controls for both types of mechanical harvesting averaged approximately 18% at 1 week, which mechanical shaking raised to 42%; but air-shaking increased to 62%. Air-shaking ‘Pineapple’ oranges involves definitely higher risks than with the other varieties tested.

Spindle Harvesting: Work on the spindle harvest machine had been very erratic until the 1967-68 season when this concept was revived because of the possibilities for harvesting fresh fruit, particularly ‘Valencia’ in which it is essential to take off the mature fruit while leaving the small, green fruit of the next crop. Because of the possibility of fresh fruit use, holding tests were duplicated with grove-run fruit and also fruit that was washed and waxed, as it would be for a packinghouse. Figure 1 shows decay curves for the average of 4 harvests of ‘Valencia’ oranges in the central Ridge district. There is surprisingly little difference between development of decay in the grove-run and washed-and-waxed oranges. There is definitely a consistent increase in decay due to mechanical harvesting, even in fruit which was caught immediately below the augers and not allowed to drop to the ground. However, it is possible that if FDA approval is obtained for the new fungicides discussed below, this increase in decay could be contained to the point where it would be no more than that experienced when harvesting with the inefficient labor that is becoming increasingly common. A particularly encouraging result was a single harvest of ‘Valencia’ oranges

**DECAY IN "SPINDLE-HARVESTED" VALENCIAS**

- △ MECHANICAL PICKED, FALL TO GROUND
- □ MECHANICAL PICKED INTO BAG
- ○ HAND PICKED INTO BAG

**GROVE RUN**

**WASHED AND WAXED**

![Graph showing decay in "spindle-harvested" Valencia oranges](image-url)

*Fig. 1.—Development of decay in ‘Valencia’ oranges from spindle harvesting experiments. Average of 4 picking dates.*
in the Indian River district in which keeping-quality of the sprinkle-harvested fruit was slightly better than that of the hand-picked control!

Picker's Aid: The 'Dancy' tangerines harvested with the "Selma" picking aid were used in simulated shipping tests reported elsewhere (6). Not only was the slight damage due to handling during the conveying equipment controllable with post-harvest fungicides, but a rainstorm during the hauling of one set of control samples proved more harmful than did use of the mechanical equipment, indicating that the method was working within the limits of natural hazards.

Variety Comparisons: Here results have been surprisingly consistent, as is shown in Figure 2. It will be noted that decay decreased for 3 successive seasons in 'Hamlin' and 'Pineapple' oranges, reflecting the drought conditions of successive years. In all 3 seasons, decay in mechanically-harvested 'Hamlin' was almost exactly equal to decay in hand-picked 'Pineapple' oranges, indicating that losses in mechanically-harvested 'Hamlin' were within a range normal to the citrus trade. It is obvious that 'Pineapples' are very subject to decay; and for this variety, successful mechanical harvesting will probably be dependent on extremely rapid handling between the tree and the cannery. With the exception of 1965-66, losses in mechanically-harvested 'Valencia' were less than those for hand-picked 'Hamlin.' Percentage-wise, the increase in decay for 'Marsh' grapefruit is most severe, but losses remain below those normally experienced with hand-picked 'Pineapples.'

Analysis of Damage

Staining Studies: Experiments in which fruit were stained to facilitate grading out mechanical damage concentrated on grapefruit in which losses were least (excluding 'Valencia,' for which shaker harvesting was not considered immediately feasible because of the 2-crop situation).

The percentage of sound fruit thus separated ranged from 45% to 69%. Thus, a high volume of fruit would have to be stained and graded in order to reclaim an economic proportion for fresh fruit merchandising. This would still be subject to the normal elimination of fruit with surface defects other than mechanical damage. An initial problem was that even the sound fruit had many tiny scratches and marks picked up by the indigotin sulfate blue dye, thus disfiguring them for fresh fruit merchandising. However, this problem is obviated with the switch to the Sunkist tannic acid stain which, although not so readily distinguishable, is easily reversible (9). Keeping-quality of this apparently sound fruit was still below that of the hand-picked controls.

Origin of Damage: On various occasions, samples were gathered at particular stages through the mechanical harvesting operation. For example: hand-picked check before shaker harvest; at conveyor leaving the catchframe; entering the hi-lift truck after discharge from the collecting bin; and entering the semi-trailer after discharge from the hi-lift truck. A typical example of such a sampling is shown in Table 3. It is apparent that most of the visible damage has been done by the time the fruit leaves the catchframe and starts its passage through the collecting system since the percentage of sound fruit remained virtually unchanged. However, susceptibility to decay increased with each stage of handling, even though there was no consistent increase in discernible damage (Table 4). Some of this handling (transfer from hi-lift to semi-trailer) is common to both mechanical and manual harvesting methods, but there was no prac-
Table 3. Hamlin oranges harvested with FCC-CES shaker-catchframe Hi-lift system.

<table>
<thead>
<tr>
<th>Sample location</th>
<th>% sound</th>
<th>% split</th>
<th>% punctures</th>
<th>% plug</th>
<th>% bruised</th>
<th>Total no. fruit</th>
<th>% stems</th>
<th>Avg. length of stems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cross convey. to elevator</td>
<td>88.0</td>
<td>0.2</td>
<td>8.7</td>
<td>0.7</td>
<td>2.5</td>
<td>439</td>
<td>45.4</td>
<td>1.9 in.</td>
</tr>
<tr>
<td>Hi-lift</td>
<td>84.3</td>
<td>0.8</td>
<td>6.4</td>
<td>4.0</td>
<td>4.7</td>
<td>376</td>
<td>37.5</td>
<td>2.7 in.</td>
</tr>
<tr>
<td>Semitrailer</td>
<td>87.4</td>
<td>2.3</td>
<td>6.5</td>
<td>1.3</td>
<td>2.5</td>
<td>383</td>
<td>40.9</td>
<td>2.0 in.</td>
</tr>
<tr>
<td>Handpicked</td>
<td>86.6</td>
<td>0</td>
<td>0.6</td>
<td>12.8</td>
<td>0</td>
<td>179</td>
<td>9.5</td>
<td>2.1 in.</td>
</tr>
</tbody>
</table>

*Note: Stem count over 1/2-inch in length made independent of other classifications.

tical way of applying such handling to the handpicked control samples.

A similar study used ‘Pineapple’ oranges and included a sampling of the fruit left on the tree after shaking. (Shaking operations seldom remove more than about 95% of the fruit.) This fruit that remained on the tree had nearly as high a percentage of damage as that which landed in the catchframe; moreover, damage was distributed between cuts and punctures, or between slight, medium, and severe damage in approximately the same proportion as for the fruit which had been shaken off. Thus, it appears that much of the injury in mechanical harvesting is done before the fruit leaves the tree. The fall through the branches and into the catchframe does surprisingly little damage.

Comparison with Commercial Cannery Operations: A constant problem is that handpicked controls taken by laboratory assistants or Experiment Station grove workers are invariably handled more gently than fruit picked by typical cannery crews. For this reason, typical cannery loads were sampled at a cooperating cannery. Also, when mechanically-harvested loads were received at another cannery, incoming commercial trucks were sampled at the same time in order to compare the cullage between the two. Five trailer loads of ‘Pineapple’ oranges were sampled, each containing approximately 500 boxes of oranges. The average findings of the 5 loads are shown in Table 5. The outstanding difference between mechanically-harvested loads and commercially-picked cannery loads is the proportion of “plugged” fruit; that is to say,

Table 4. Decay in the same fruit as in Table 3.

<table>
<thead>
<tr>
<th>Sample location</th>
<th>Decay from all causes (mainly mold)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>At 3 days</td>
</tr>
<tr>
<td>Cross convey. to elevator</td>
<td>1.1</td>
</tr>
<tr>
<td>Hi-lift</td>
<td>2.9</td>
</tr>
<tr>
<td>Semitrailer</td>
<td>3.1</td>
</tr>
<tr>
<td>Handpicked</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 5. Percentage damage in "hand-harvested" Pineapple oranges arriving at processing plant.

<table>
<thead>
<tr>
<th>Sampling date</th>
<th>% sound</th>
<th>% split</th>
<th>% punctures</th>
<th>% plugged</th>
<th>% badly bruised</th>
<th>Total no. fruit</th>
<th>% fruit with stems 1/2-inch or longer*</th>
</tr>
</thead>
<tbody>
<tr>
<td>March 2, 1967</td>
<td>83.2</td>
<td>0.4</td>
<td>1.6</td>
<td>13.4</td>
<td>3.4</td>
<td>500</td>
<td>2.8</td>
</tr>
</tbody>
</table>

*Independent of percentage of damaged fruit.
fruit peel torn around the stem end. The staff of the second cooperating cannery checked 6 trailer loads of mechanically-harvested grapefruit; 4 harvested with the FMC air-blast machine; 1 with the CES shaker-catchframe system; and 1 with the Pounds shaker (a commercially-built shaker of Experiment Station design which shakes the fruit onto the ground for manual pickup). The cannery superintendent reported “no apparent difference” in the amount of culis graded out from the mechanically-harvested loads as compared with those from the conventional loads they were receiving. The high proportion of “plugs” in the conventionally-picked fruit tended to counterbalance the cuts and punctures in the mechanically-harvested fruit.

**The Stem Problem**: It will be noted in Table 3 that approximately 40% of the ‘Hamlin’ oranges sampled through the shaker-catchframe system had adhering stems; moreover, these stems averaged approximately 2 to 3 inches long. Long stems are not too hard for alert graders to catch. Short stems are hard to remove manually in the cannery receiving line and can cause grave difficulties, especially with FMC in-line extractors. The 6 cannery loads of grapefruit, noted above, were also sampled for adhering stems. The cannery staff considered that the air-blast harvested grapefruit had 10 to 14% of stems long enough to be troublesome and 8 to 9% for grapefruit harvested with the mechanical shakers. These figures corresponded very closely to our own records for adhering stems in the samples taken for examination at the Citrus Experiment Station. So far, removal of these stems is an unsolved problem.

**Windrows and Pick-up Machines**.

Considerable work has been done on methods by which the fruit goes to the ground, either by hand or by some form of mechanical picking, and is then oriented into windrows between the trees for mechanical pick-up. The first obvious problem is: what damage is done in falling to the ground? This has been a most unsatisfactory field in which to gather information as the damage varies with variety, height of tree, maturity and condition of the soil or other receiving surface. In repeated experiments with soft ‘Valencias’ in a drought period falling onto a canvas, fruit damage was noted from the act-falling to the ground is clearly discernible in ‘Valencias’ in Figure 1 and in another experiment, 7% of ‘Pineapples’ split when shaken from high trees onto ground packed by a recent rainfall. Some small-scale experiments indicated that dicing the soil prior to shaking would minimize splitting of turgid fruit.

**Pick-up Machines**: Repeated checks were made sampling before and after pick-up, by the Continental-Moss-Gordin pick-up machine. No consistent differences in fruit damage or keeping-quality were found, even with ‘Pineapple’ oranges. Rather than a deleterious effect, a benefit was found in that the number of adhering stems were usually sharply reduced, sometimes by 50%.

**The Decay Problem**: The whole operation of shake or air-blast, windrow for indeterminate periods and then pick-up mechanically and convey to a highway truck, obviously involves considerable decay hazards. A series of truckloads of ‘Valencia’ oranges were sampled in which the period between tree and unloading at the cannery varied from 1 to 6 days, this time being spent either in windrows in the grove or on the trucks waiting for unloading. The results are presented in Figure 3 in which losses from stem-end rot and from *Penicillium* mold are separated. This is because these 2 forms of decay respond quite differently to weather conditions. Weather during this period was dry and extremely hot, noon temperatures reaching at least 95°F. This encourages stem-end rot but sharply inactivates *Penicillium* mold. These 2 factors virtually cancelled each other out for the first 4 days. Had the weather been damp and cool with noon temperatures at approximately 75°F, stem-end rot would have been slightly slowed up and *Penicillium* would have developed extremely rapidly. In such circumstances, the effects could be additive and losses could be excessive. No brown rot (*Phytophthora citrophthora* Leonian) was encountered. This soil-borne organism occurs infrequently in damp locations and could mean complete loss of a windrowed crop.

**Pre-harvest Sprays**.

Two forms of pre-harvest sprays have been used in connection with these mechanical harvesting studies. Considerable work has been done on abscission sprays (11), and fruit from
the fruit windrowed for various periods in very hot weather. As can be seen in Figure 4, Benlate gave remarkable control of decay even under windrow conditions. This chemical does not yet have F.D.A. approval.

Sunburn: A real hazard involved in the windrow operation is sunburning of the surface fruit. Intense sunlight is capable of killing the surface of detached fruit, producing a scalded appearance. Juice samples were prepared from sunburned and non-sunburned fruit from the same windrow and all panelists reported off-flavor in sunburned fruit. Such fruit is very rapidly attacked by decay organisms.

Internal Fruit Quality, Maturity, and Fruit Damage.

Grapefruit Sections: The single experiment in making grapefruit sections from hand-harvested and mechanically-harvested 'Duncan' grapefruit indicated that the mechanically-harvested grapefruit were suitable for making sections. A somewhat higher (but obviously not significant) count of perfect sections was achieved with the mechanically-harvested fruit.

Internal Quality: For 3 years, all fruit from all plots was checked for the standard internal quality factors of juice content, Brix, acid content and ratio, but absolutely no indication of correlation between these factors and keeping-quality was ever found.

CONCLUSIONS

Mechanically-harvested 'Hamlin' oranges and 'Marsh' and 'Duncan' grapefruit can be delivered to the cannery with no more damage than is usually tolerated with hand-picked 'Pineapple' oranges under current cannery harvesting conditions. Damage to mechanically-harvested 'Pineapple' oranges is higher, but economic losses are not apt to be excessive if time between the tree and the cannery extractors does not exceed 48 hours (a not unreasonable stricture since 'Pineapple' oranges are harvested at a slack season for the canneries). Mechanically-harvested 'Valencia' oranges were at least as sound as 'Hamlin' receiving similar treatment, but attention is drawn to the problem (not dealt with here) of damage to the new crop. The spindle harvester shows some promise for 'Valencia' oranges for fresh fruit use.

Adhering stems pose an unsolved problem (particularly with fruit going to FMC in-line
extractors) but the Continental-Moss-Gordin pick-up machine proved beneficial in that it (quite fortuitously) removed a high proportion of these stems.

"Windrowing" appears practical for mechanical fruit pick-up purposes, but protracted field storage in the windrows is too hazardous to be advised at present.

LITERATURE CITED

3. Copsock, G. E. 1967. Harvesting early and midsea-