Biophysical Properties of Citrus Fruit Related to Mechanical Harvesting

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IN 1967, Florida produced 195.9 million boxes (8.7 million tons) of citrus (2)*. The citrus industry has recently faced increased production coupled with increased harvesting costs and chronic labor problems. This situation has been eased by increased mechanization, and research efforts on mechanical harvesting have resulted in encouraging advances. Mechanized harvest methods gained limited industry acceptance in 1967 (3). Emphasis has been on harvesting fruit for processing since about 80 percent of Florida's citrus crop is utilized in this manner (2) and more fruit injury can be tolerated in fruit for processing than in fruit for the fresh market.

The two general concepts of mechanical fruit removal being considered are (a) mass removal such as that obtained with tree shakers, and (b) contact removal such as that obtained with spindles and strippers.

Oranges and grapefruit are the two main citrus fruits grown in Florida. The principal orange varieties are: Hamlin, an early season orange harvested between October and January; Pineapple, a midseason orange harvested between December and March; and Valencia, a late season orange harvested between April and June. Valencia oranges, being a late variety, normally have both a mature and a young crop on the tree during the harvest period. Marsh and Duncan are the main grapefruit varieties, harvested for processing between January and April.

Unlike apples, pears or bananas, citrus contains little or no starch and will not ripen after it is harvested (5). Thus, harvest date is a prime factor influencing the biological and physical properties of citrus.

With the refinement of fruit removal equipment, it became evident that engineers needed a better understanding of the biological and physical properties of citrus fruit in order to establish machine design parameters and explain the performance of harvest equipment. The purpose of this research was to obtain quantitative and correlative information on fruit maturity (Brix–acid ratio), detachment force, detachment type (plugged or unplugged fruit), detachment angle, fruit size and weight and percent fruit removed with a tree shaker for each principal variety. The scope of this research does not include an explanation of the biological processes that take place within the fruit but only covers the end results of these processes which have engineering value.

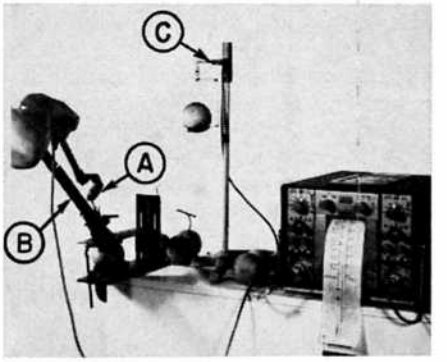

FIG. 1 Test equipment used to determine fruit detachment force, detachment mode and weight: (A) pull transducer, (B) detachment angle adjustment and (C) weight transducer.

EQUIPMENT AND METHODS

The research extended over one complete harvest season of each of the four principal varieties: Hamlin, Pineapple and Valencia oranges and Marsh grapefruit. It was conducted in conjunction with the development of a tree shaker harvest system. Plots of trees typical for each variety were selected. Four trees were harvested at each of four dates spaced over the harvest season for each variety. Before harvesting, three 40 fruit samples were taken at random around the trees at a 6-ft height. Each fruit was clipped off the tree leaving a stem 4-6 in. long and any leaves removed. These samples were used to determine the detachment force and type of detachment at 0, 45 and 90-deg angles and fruit weight and size. Brix-acid ratio was determined from a composite of these samples after the stems has been detached.

Special instrumentation was devised to determine the detachment force, detachment type and fruit weight (Fig. 1.). A two-channel oscillograph was used to record both the detachment force of the fruit and the fruit weight. A strain gage transducer designed with the sensing element stressed in bending (Fig. 1A) was used to detach the stems from the fruit. The signal from the pull transducer was amplified with a plug-in carrier amplifier on the two-channel oscillograph. Calibration was accomplished by adjusting the gain of the carrier amplifier for a 1 cm deflection of the oscillograph pen when a 10 lb weight was lifted with the pull transducer. The pull transducer support (Fig. 1B) could be adjusted for the desired detachment angles (with respect to the major axis of the fruit) of 0, 45 or 90 deg.

The weight transducer also had a sensing element stressed in bending and instrumented with strain gages (Fig. 1C). This transducer was calibrated by adjusting the gain for a 2.5 cm deflection of the oscillograph pen when a 0.50 lb weight was placed on the platform. Samples with stems attached were brought into the laboratory, fruit and stem clamped and the detachment force measured by pulling the stem off with a smooth motion at the desired angle (either 0, 45, or 90 deg) resulting in a loading rate on the stem of approximately 10 lbs per sec. The circular clamp contacted the fruit at a ½-in. radius from the stem.

The fruit was then weighed. Both the detachment force and the weight were recorded on an oscillograph chart. The type of detachment was noted (plugged or not plugged). Fruit size was determined by measuring across its minor diameter with callipers.

Brix-acid ratio was determined according to procedures described by Soule *et al* (5). A tree shaker harvest system developed by Coppock and Hedden in 1966 (1) was used to harvest the fruit at various dates of harvest.

A definition of the factors measured are listed:

Date of harvest – date the harvest operation was performed.

Detachment angle – angle of application of detachment force with respect to the fruit's major axis (the axis passing through stem end).

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* Numbers in parentheses refer to the appended references.

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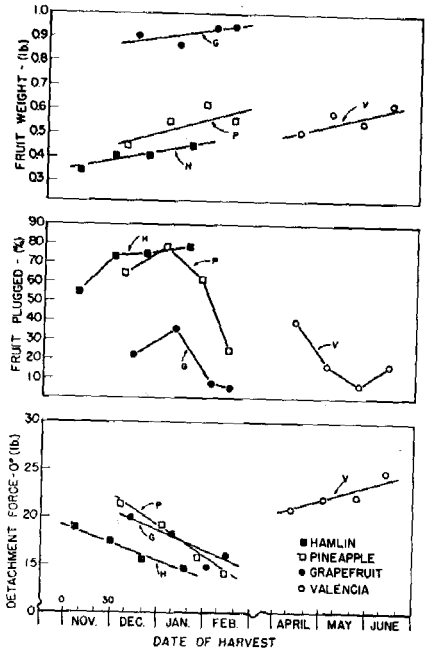

FIG. 2 Influence of the date of harvest on fruit detachment force, percentage of fruit plugged when stems were pulled at a 45 deg angle to major fruit axis and fruit weight.

Detachment force – force in lb required to detach the stem from the fruit.

Detachment type – type of fruit detachment (plugged or not plugged). Plugging resulted when a portion of the peel was torn out with the stem during detachment. It was measured as a percentage of the total number of fruit detached.

Fruit weight – weight of fruit measured in lb.

Force – weight ratio – detachment force divided by the fruit weight.

Fruit size – Diameter of fruit in in. measured across the minor axis.

Fruit removal – percentage of total fruit on the tree, removed during the harvesting operation.

Brix-acid ratio – a measure of legal maturity and internal quality of the fruit. Florida statutes set minimum standards to prevent the use of poor quality fruit. All determinations in this research were made after the minimum standards had been reached. Brix (measured in degrees) is an index of the total soluble solids in the juice and increases with the fruit maturity. The acid is the titratable acid found in the juice and decreases with the fruit maturity.

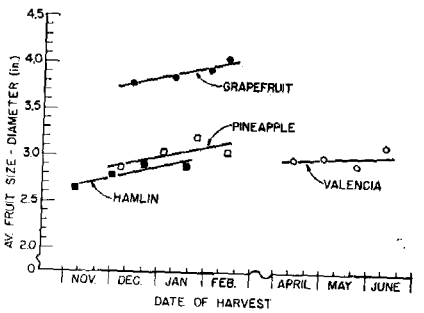

FIG. 3 Influence of date of harvest on fruit size.

Results

The influence of the harvest date on fruit detachment force, percentage of fruit plugged and fruit weight for the four fruit varieties is shown graphically in Fig. 2. Each point is an average of four replications. Detachment force at 0-deg detachment angle decreased as the harvest season progressed for all varieties except Valencia oranges in which it increased. Detachment forces at 45 and 90-deg angles are not shown, but the reaction was similar. Generally, the percentage of the fruit plugged when detached decreased over the season for Pineapple and Valencia oranges and Marsh grapefruit, but not for Hamlin oranges. The sharp increase in percent fruit plugged during the first half of the harvest season for early and midseason oranges and grapefruit maybe the results of environmental factors, since it occurred at approximately the same data in all varieties. Fruit weight increased in all varieties, with Marsh grapefruit being the heaviest and Hamlin oranges the lightest.

The influence of harvest date on the average fruit size is shown in Fig. 3. Fruit size increased over the season for early and midseason fruit. There was only a slight indication that Valencia oranges increased.

The effect of the date of harvest on fruit removal with the tree shaker, Brix-acid ratio, and force (45-deg angle)-weight ratio is shown in Fig. 4. Detachment force at 45-deg angle was used in the force-to-weight ratio because it was believed that the major portion of the fruit is detached at this angle when harvested with a tree shaker. The percent of Hamlin, Pineapple, and Valencia oranges removed with the tree shaker did not materially increase during the harvest season. Percent removal of Marsh grapefruit increased from 92 to 97 percent over the harvest season. Typically, the Brix-acid ratio of all fruit varieties increased as the fruit season progressed. Force-weight ratio decreased sharply for Hamlin and Pineapple oranges, while it decreased only slightly for Marsh grapefruit and Valencia oranges.

Fig. 5 shows graphically how detachment force and percent of fruit plugged are related to detachment angle. Each point is a seasonal average. The detachment force decreased over 50 percent for all varieties as the detachment angle was increased from 0 to 90 deg. The percent of plugged fruit decreased with an increase in detachment angle

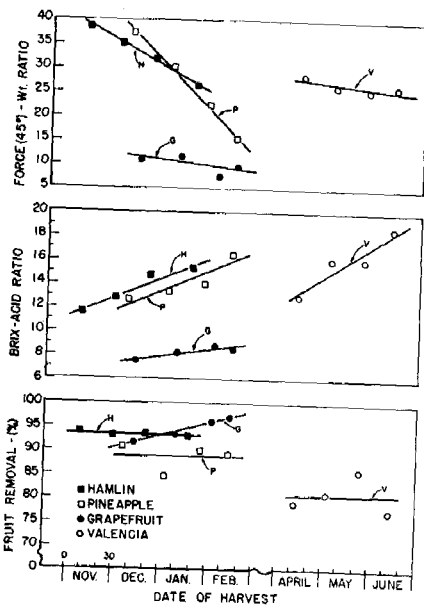

FIG. 4 The influence of date of harvest on fruit removal with tree shaker, Brix-acid ratio and force (45 deg angle)-weight ratio.

which can be explained in part by the lower detachment force at greater angles. Handpickers use this fact to reduce the detachment effort and fruit damage involved in hand harvesting.

Fig. 6 shows regression curves for the relationship between fruit size and detachment force. Their projection on the abscissa axis gives the size range. The detachment force increased with fruit size for all varieties.

Discussion of Results

Harvesting mechanisms such as the tree shaker depend on the inertia of

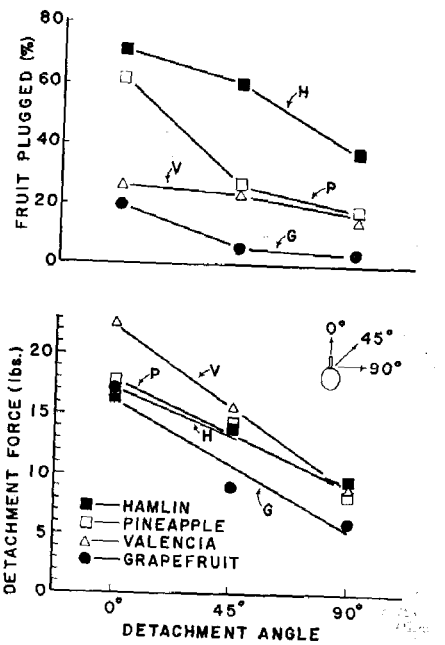

FIG. 5 The relationship between detachment angle, detachment force and percent of fruit plugged for four fruit types. Detachment force at 90 deg angle is less than one-half that at 0 deg angle

the fruit as one factor affecting removal. Thus, fruit weight and detachment force are important properties affecting performance. It could be expected that the percent of fruit removed by a shaker would increase over the harvest season in early and midseason fruit since the ratio of the detachment force the fruit weight decreased. Fig. 4 indicates that even though the force-to-weight ratio decreases considerably as the season progresses, the percent fruit removed increases only slightly. This would imply that other factors such as tree shape and structure have an overriding influence on fruit removal. However, it should be noted that the removal for early and midseason fruit was above 85 percent.

When compared with tree shakers, contact removal mechanisms depend less on fruit weight and more on fruit size and location in the tree to affect removal. Their performance could be expected to improve as the season progressed with early and midseason fruit since fruit size increases and detachment force decreases (Fig. 2 and 3).

Early and midseason varieties have similar harvesting characteristics. They are harvested during the winter months when the trees are in a semi-dormant stage and before a new crop has been set. Both fruit weight and size gradually increase over the harvest season with Marsh grapefruit being the heavier and larger and Hamlin oranges being the lighter and smaller (Fig. 2 and 3).

Late season fruit (Valencia oranges) are harvested after the new crop has been set and while the trees are in an active growing condition. Unlike the early and midseason fruit, the detachment force progressively increased with the harvest season. The young fruit on the trees at harvest time is a factor peculiar to this variety that must be considered when harvesting. The mature crop has to be removed with little removal of or damage to the young crop. Additional research is needed to determine the properties of the fruit in developing harvesting mechanisms which will distinguish between the two crops.

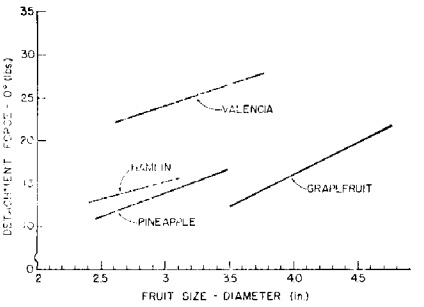

FIG. 6 Relationship between fruit size and detachment force. The equations for the regression curves are: Y = 2.95 + 4.08 xY = −2.83 + 5.57, Y = 8.99 + 5.03X and Y = −13.16 + 7.42X, respectively for Hamlin, Pineapple, and Valencia oranged and Marsh grapefruit. Y = detachment force and X = fruit diameter.

Plugged fruit are undesirable even for processing because they pick up dirt and bacteria during the handling operations which contaminates the processed product. The percentage of plugged fruit decreased with the harvest season for all varieties except Hamlin oranges and decreased with an increase in the detachment angle for all varieties (Fig. 2 and 5). This is an important consideration in the design of a harvest mechanism. A mechanism which detaches fruit at an angle as close to 90 deg as possible should plug a minimum number of fruit.

Summary

Research was conducted to obtain for each principal citrus variety at four different dates of harvest information on fruit maturity, detachment force, detachment type, detachment angle, fruit size and weight, and percent fruit removed with a tree shaker. Special instrumentation was devised to measure the fruit detachment force.

Detachment force decreased over the harvest season for early and midseason oranges and grapefruit but increased for Valencia oranges, a late season variety. The detachment force decreased to less than one-half when the detachment angle was increased from 0 to 90 deg.

Fruit removal with a tree shaker increased only slightly, and the detachment force-to-fruit weight ratio decreased for all varieties as the season progressed. Fruit size, weight and fruit quality tended to increase over the harvest season. Percent of plugged fruit decreased with an increase in the detachment angle.

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