Reprinted from *Proc. Int. Soc. Citriculture.* 91-93. 1978.

AIR SHAKERS FOR THE REMOVAL OF ORANGES IN FLORIDA[1,2]

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Additional index words. Mechanical harvesting, citrus.

Abstract. **Removal of oranges by means of a pulsating high velocity air stream has been under development in Florida for 2 decades. The air shaker offers considerable potential in Florida because it is readily adaptable to different shapes and sizes of trees up to 6 m high and has a high capacity to remove chemically-loosened fruit destined for processing. Its main disadvantages are high initial investment, high power requirement, and dependence on fruit loosening of a magnitude and uniformity not consistently available from existing abscission chemicals. Air shakers which have seen the greatest field use require 250 to 350 kw of power and weigh about 10000 kg. When abscission chemicals have reduced the orange bonding strength to an average of 20 to 25 N, removal capacities have ranged from 20000 to 40000 kg/hr. Fuel consumption was approximately 1 liter of diesel per 200 to 400 kg of fruit removed.**

The harvesting of oranges in Florida has been the subject of organized research for 2 decades because it usually accounts for over half the production cost and it is an arduous task. Initial efforts to assist the hand picker with mechanical aids were not successful because little potential gain was demonstrated. Mechanical means of harvesting have been investigated for the most part because they appear to offer a greater potential to reduce the human drudgery and costs associated with manual harvesting.

All harvest systems involve 2 distinct operations—fruit removal and fruit collection. Of the many problems to be solved in mechanical harvesting systems for Florida oranges, those associated with the fruit removal operation are the most difficult to solve. In recent years, Florida research in this area has dealt mainly with tree shakers because of their potential field capacity and the high percentage of Florida oranges going into processed products.

Trunk, limb, and foliage type mechanical tree shakers have been used with limited success in oranges. The main advantages of the air shaker concept over these are that: (a) no physical attachments are made to the tree, allowing continuous down-the-row operation, (b) a high percentage of fruit can be removed at a fast rate when the fruit bonding strength has been uniformly reduced to about 22 N (5 lb) by an abscission chemical, and (c) the operational reliability of the machine is inherently high (4). The main disadvantages of the air shaker concept are its high power requirement, large capital investment, and dependence on an abscission chemical for satisfactory performance. This paper summarizes the development and results of using air shakers as orange removal devices in Florida.

Air Shaker Development and Field Results

Air shakers develop a pulsating air blast that impinges on the tree canopy to shake the supporting structure and

[1]Florida Agricultural Experiment Stations Journal Series No. 1297.
[2]Cooperative research by the University of Florida, Agricultural Research and Education Center, U.S. Department of Agriculture, and State of Florida, Department of Citrus at Lake Alfred, Florida.

thus remove the fruit by shaking. The first machine investigated had a vertical air discharge opening 0.3 m (1 ft) wide and 2.1 m (7 ft) high (6). A set of parallel vanes in the discharge were pivoted on horizontal shafts. The trailing edge of the vanes moved up and down and the emanating air pattern alternately swept the tree up and down to provide the pulsating, shaking action at a frequency of 0.8 to 1.3 cps (50 to 80 cpm). Field trials with mature orange trees (without abscission chemicals) indicated a removal efficiency of about 70%, a capacity of 0.67 to 0.89 kg/s (5400 to 7200 lb/hr), and an energy input of 65000 J/kg (1 hp-hr per 90-lb boxes) of oranges removed. Subsequent yields were reduced 5% in early and midseason oranges and 12% in Valencia oranges.

Subsequent research and development to improve the performance of the air shaker dealt with larger machines (more air volume, Fig. 1), different means of manipulating the discharged air, and the aid of abscission chemicals to loosen the fruit. In the early 1970's, it was demonstrated

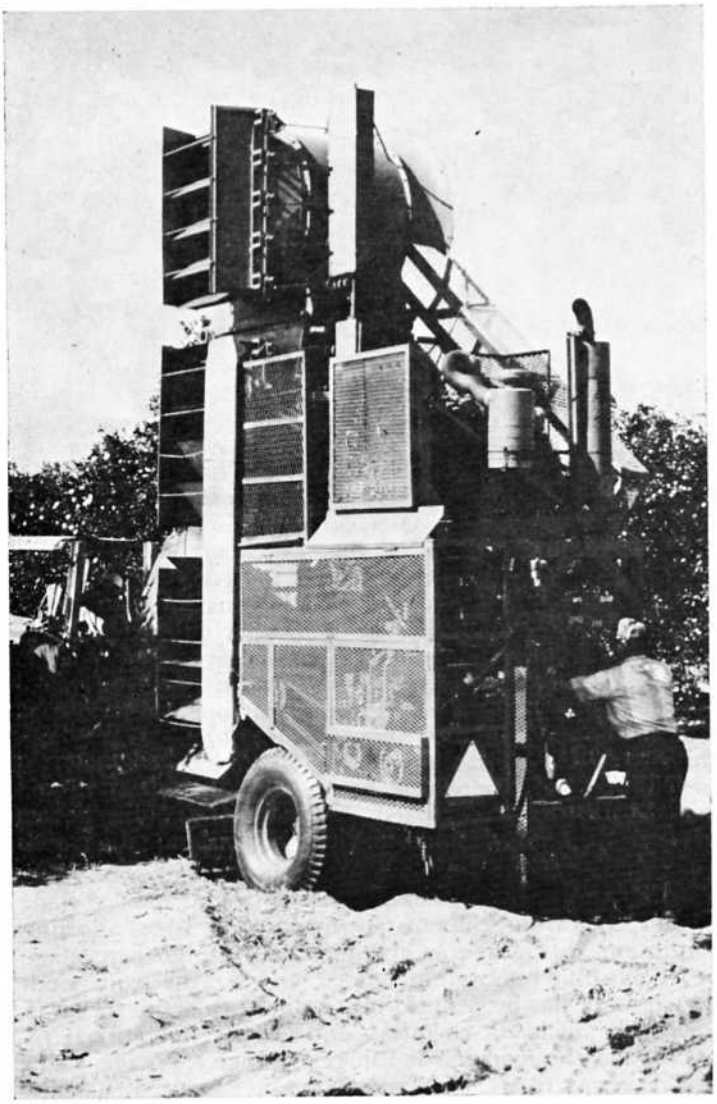

Fig. 1. Air shaker developed at AREC, Lake Alfred, is tractor-drawn, 5.5 m (18 ft) high, and weighs 9100 kg (20000 lb).

that the air shaker, with the fruit-loosening aid of abscission chemicals, could achieve fruit removal efficiencies greater than 90% at capacities of 5.3 kg/s (42000 lb/hr) in early and midseason oranges (6). No significant reductions in subsequent yields were found with the early and midseason varieties, whereas 15 to 40% reductions were measured in Valencia oranges when young fruit diameter exceeded 3 cm.

Tests in 1974-75 showed that when Valencia oranges were loosened with 250 ppm of abscission chemical Release® (5-chloro-3-methyl-4-nitro-1H-pyrazole, manufactured by Abbott Laboratories), an air shaker at 0.45 m/s (1 mph) ground speed achieved 86% mature fruit removal efficiency with an 18% subsequent yield reduction averaged over the season (2). This was equivalent to a harvest efficiency (mature fruit removal efficiency x subsequent yield potential) of 70% [0.86 x (100-18)]. Similar field tests (3) in 1975-76 showed that when the air shaker ground speed was increased (exposure time decreased) to 0.9 m/s (2 mph), harvest efficiency was increased to about 80%. Mature fruit loosening was good and mature fruit removal efficiency was 90% while yields were reduced about 11%.

The most recent work on air shakers has focused on semicommercial field harvest trials and developing more efficient methods of manipulating air to achieve fruit removal. Whitney and Schultz (7) discussed the different methods used to date for manipulating the air. Three of the methods which have seen the most use (wobble, upstream pivot, and center pivot plates) have been evaluated in the field and by air pressure (velocity) measurements (5). Based on the air pressure measurements, the center pivot plates delivered the most effective air shaking pattern because the air pulses developed were more distinct for a longer duration. These results were confirmed by field trials which indicated that the center pivot plates could remove equivalent percentages of oranges 30 to 50% faster than the other 2 types of plates. Also, the center pivot plates could generally achieve higher percentage fruit removal efficiencies at a given removal rate where fruit loosening was not satisfactory. When good fruit loosening resulted, the field trials indicated that a 242 kw (325 hp) air shaker could remove more than 90% of early and midseason oranges using an energy input of 22000 J/kg (1 hp-hr for three 90-lb boxes) of oranges removed (approximately 80000 lb/hr).

Attempts to mechanically harvest oranges with an abscission chemical-airshaker-mechanical pickup system have met with very limited success. The principal reason this system has not been successful is that the air shaker has rarely achieved the fruit removal efficiency and capacity of which it is capable under good fruit loosening conditions. Performance of the air shaker has not been acceptable because abscission chemicals have not consistently loosened the fruit to a satisfactory level. In early and midseason oranges, temperatures below 60°F (15.6°C) usually reduce the effectiveness of the abscission chemical. Rains associated with frequent cold fronts can wash a high percentage of the abscission chemical off the fruit, if the rains follow the chemical application within a few hours. The effectiveness of abscission chemicals has generally increased with fruit maturity, and has not been particularly effective on fruit harvested at minimum maturity early in the season. This phenomenon, as well as nonuniform deposition of chemical on the fruit, probably explains to some extent the nonuniform loosening among fruit on the tree. In Valencia or late season oranges, temperatures are usually favorable for abscission chemical activity, but timing the application to avoid rain within a few hours is a problem. Also, Valencias often exhibits a 2 to 3 week period during the harvest season when abscission chemicals are relatively ineffective (1). Uniform loosening of mature fruit is required to maximize harvesting efficiency of the air shaker in Valencias and this condition has been achieved only rarely.

Other problems associated with the abscission chemical-air shaker combination are defoliation and peel damage (chemical burn). High rates of chemical are generally

applied for the air shaker and the amount of defoliation and peel damage is generally correlated with the rate of applied chemical. Peel damage and defoliation should be minimized commensurate with satisfactory fruit loosening, since they are undesirable side effects that can reduce fruit quality and subsequent fruit yields. Little or no safety margin exists with available abscission chemicals when used with air shakers.

Air shaker performance has also been related to the size and structure of the tree. Poor fruit removal efficiencies in the tops of trees have resulted with the air shaker when tree height was too great in relation to the air discharge height of the machine. To effectively shake a tree by air, the tree should not be quite as high as the air discharge. Because of the greater densities of fruit and tree structure generally found in the tree tops, the air pattern must deliver effective shaking forces to the center of the tree top to realize high removal efficiencies. It has generally been found that to achieve uniform fruit removal over the tree, the air shaking intensity should be minimum and maximum at the bottom and top of the tree, respectively. When the foliage and fruit of tree tops are slightly below the top of the air discharge, peak air pressures (or forces) can be delivered to the tree tops. Trees with round tops (normal canopy shape) can be shaken by air when the tree height equals or slightly exceeds the air discharge height. However, any tree height above the air discharge is air shaken by that portion of the air shaking pattern which is not most effective. Hedging and topping efforts to confine tree size on large mature trees usually result in large limbs near the canopy surface and can be difficult to shake by air.

Two semi-commercial mechanical harvesting operations which have used a system of abscission chemicals and an air shaker to remove fruit to the ground for mechanical pickup, have demonstrated that the system is not feasible at the present stage of development under the existing economic conditions of adequate and reasonably-priced labor.

Future Outlook for Air Shakers

What potential does the air shaker have as a citrus removal device if and when mechanical harvesting becomes a reality in Florida? This will depend to a great extent on developments in abscission chemicals and smaller, productive trees. Fruit loosening must be more dependable with less undesirable side effects than that provided by existing abscission chemicals if high harvest efficiencies and capacities are to be expected. The performance of air shakers would generally be improved if the mature tree size could be limited to heights of 5 to 6 m and widths (diameters) of 3 to 4 m. It has not been demonstrated that mature trees can be maintained in a long-lived, productive state within these limits on existing scion-rootstock combinations. It is hoped, however, that future rootstock and interstock developments will be helpful in producing high fruit yields on smaller trees with a reasonably long productive life. Uniformly fruited hedge rows, as opposed to individual trees, facilitates the use of the air shaker because they provide a continuous wall of fruit and should generally maximize its capacity. However, the air shaker can have problems adequately shaking limbs of adjacent trees, depending on the extent to which the limbs overlap (entangle) in the row.

In summary, air shakers are best suited for trees less than 6 m high and 4 m wide, with fruit supported on heavily foliated, relatively flexible limbs which are not particularly well suited for limb or trunk shakers. Such trees would be characterized by those which develop normally and have undergone no severe hedging and topping. When fruit are uniformly loosened to a bonding strength of 22 N (5 lb) or less, an air shaker can remove more than 90% of the fruit with an energy input of 22000 J/kg (1 hp-hr for three 90-lb boxes) of fruit removed.

Literature Cited

1. Holm, R. E., and W. C. Wilson. 1976. Loss in the capacity of 'Valencia' oranges treated with abscission chemicals to produce ethylene and fruit loosening during the regreening period. *Proc. Fla. State Hort. Soc.* 89:35-38.
2. Whitney, J. D. 1975. Orange yield and removal studies with air and trunk shakers using two abscission chemicals. *Proc. Fla. State Hort. Soc.* 88:120-124.
3. ————. 1976. Air shaker harvest trials in 'Valencia' oranges with two rates of abscission chemical. *Proc. Fla. State Hort. Soc.* 89:41-43.
4. ————. 1977. Design and performance of an air shaker for citrus fruit removal. *Trans. ASAE* 20(1):52-56.
5. ————. 1978. Performance of three air shaker patterns in citrus. *Trans. ASAE.* 21(3) :435-437, 441.
6. ————, and J. M. Patterson. 1972. Development of a citrus removal device using oscillating forced air. *Trans. ASAE* 15(5):849-855, 860.
7. ————, and D. R. Schultz. 1975. Analysis of air shaker principles to remove citrus fruit. *Trans. ASAE* 18(6):1061-1064, 1069.