Mechanical harvesting has, of course, long been standard for many annual crops, the “combine harvester” for wheat being an early and successful example. In some instances (e.g., tomato, plant breeders have “tailor made” cultivars to adapt them to mechanical harvesting. Typically, such annuals are destroyed in harvesting. The plant must be preserved with perennial crops, although sometimes considerable injury to the plant can be acceptable when (as for grapes or raspberries) the plant is severely pruned annually. Substantial damage to the plant (tree) is not acceptable, in mechanical harvesting of tree crops, but leaf damage is of minor consequence for deciduous tree crops, and the fruit is biologically destined to abscise; if it is not harvested. Damage to the product is not a problem, it will soon fall naturally for some deciduous tree crops (particularly nuts of various kinds). In contrast, mechanical harvesting of citrus fruits involves quite extraordinary problems. The tree is evergreen and substantial leaf damage is not acceptable. The fruit has no clearly defined abscission period. The same grapefruit that might be picked in October can hang on the tree until May. Citrus fruits are extremely subject to decay. ‘Valencia’ (an important canny orange cultivar) takes 12 to 18 months from bloom to acceptable maturity to complicate matters further. Thus, there are 2 crops on the tree at harvest time; mature fruit that are to be harvested and immature fruit that must not be damaged or removed.

Fruit injuries. Some observations were quite consistent, e.g., most fruit damage occurred before the fruit fell. Those that came off first had the least damage. “Plugs” (fruit with torn peel at the stem end) were seldom encountered in mechanically harvested fruit, although these are a constant, and increasing, problem with commercial hand-harvesting. A particular problem, prior to the development of suitable abscission agents, was the high proportion of mechanically harvested fruit with short (10 to 20 cm) adhering stems. Inertia shakers (7, 25) and oscillating air shakers (12, 24, 25), with windrowing and pick-up machines (12, 21) for use when catch frames were not used. Collectively, the Florida citrus growers, chemical companies, private investors, University of Florida, and U.S. Department of Agriculture have spent many millions of dollars on research on mechanical harvesting, including abscission chemicals (3, 26, 27).

Several things were established clearly. ‘Hamlin’ (early) and ‘Pineapple’ (midseason) orange trees could be shaker-harvested in at least 5 successive years without significant effect upon yield (11). However, yields of ‘Valencia’ (late) decreased, due to losses of immature fruit of the next year’s crop, if harvesting was delayed until the small fruit was larger than 2 cm (3/4 inches) in diameter.

Fruit damage studies (1, 9, 10, 19, 20) involved: 1) sampling from experimental plots harvested regularly by hand and by various experimental machines over a period of 4 years; 2) simulated fresh fruit marketing studies; and 3) “prototype scale” studies with 3 large canneries. The latter showed that some apparent reduction of the difference between decay potential of mechanically harvested and hand-harvested fruit often was due to progressive degeneration of commercial hand-harvesting, rather than to any considerable improvement in mechanical methods.

No attempt is made here to review in detail the considerable worldwide research on mechanical harvesting of citrus. Only the more pertinent reports will be cited. In Florida, research up to 1977 was reviewed in a series of 5 papers, which are available bound as a single publication (5, 12, 21, 25, 27), and up to 1978 by Coppock (3). Meanwhile, similar research has been conducted in California, except that their program has had to be oriented toward the fresh fruit market. Florida has had a considerable advantage in that about 90% of its very large orange crop, the equivalent of 300 to 400 million bushels annually, is grown and harvested specifically for canny use.

The harvest mechanization program in Florida, as elsewhere, started modestly with fairly simple “picker’s aids” (6), none of which proved to be cost effective. More ambitious methods were tried when large sums were raised, through the Florida citrus commission, from a grower-voted tax on each box of citrus produced. Inertia shakers (7, 25) and oscillating air shakers (12, 24, 25), with and without catch frames (11, 12, 21), were developed, together with windrowing and pick-up machines (12, 21) for use when catch frames were not used. Collectively, the Florida citrus growers, chemical companies, private investors, University of Florida, and U.S. Department of Agriculture have spent many millions of dollars on research on mechanical harvesting, including abscission chemicals (3, 26, 27), of citrus.

Emphasis in the Florida mechanical-harvesting program increasingly has turned toward mechanical-plus chemical approaches, investigating such factors as those controlling the selective removal of mature (but not immature) ‘Valencia’ crops (2) and how more consistent abscission can be induced (26, 27).
Abscission research. Abscission research started modestly in 1964–1965 (13) and has been expanded consistently since then, with testing of about 5000 to 8000 candidate chemicals per year now being typical. Such program is complicated greatly by: 1) the need for abscission of mature fruit, but not of leaves or immature fruit; 2) variations in response due to weather and/or growth status of the trees; and the increasing time and expense involved in getting even limited legal clearance for any potentially promising chemicals. Wilson et al. (26) recently reviewed the current status of this program and pertinent extracts from that report are cited here.

Citrus fruits have been mechanically harvested successfully without abscission chemicals, but field experience has shown that chemical loosening is desirable because less tree-shaking time is required, resulting in less physical abuse to the machinery and trees. However, chemicals have not allowed the construction of less powerful shakers because chemically induced fruit loosening is not always uniform, resulting in about 10–15% still adhering strongly to the tree.

Abscission chemicals for citrus are classified as growth regulators, a good definition being: “substances capable of controlling key points in a living plant system so that the natural course of development is modified.” Most of the currently used abscission compounds function by producing superficial peel burn followed by production of wound ethylene. The latter moves in some manner through the fruit tissue and affects the abscission zone. The only commercially available chemical that appears to function through absorption by the tree and fruit, followed by conversion of the chemical into ethylene, is (2-chloroethyl) phosphonic acid (ethephon). In this sense, therefore, it appears to function more in the classic “growth regulator” sense than the others.

Available abscission chemicals. Four chemicals currently are available but their use is limited in each case by either natural factors (for example, the erratic response with ethephon) or by limitations set by their Environmental Protection Agency (EPA) approved labels:

1. Ethephon (Ethrel) is a product of Union Carbide Agricultural Products Co., Inc., Research Triangle Park, N.C., and is distributed worldwide. It is cleared by the EPA for use in Florida on lemons, tangerine hybrids, and tangerines only.

2. Acti-Aid (cycloheximide), a product of the Upjohn Company, Kalamazoo, Mich., is cleared by EPA for use in Florida on oranges intended for processing. This chemical generally has produced good loosening of early and midseason oranges when applied as dilute sprays. Unfortunately, its performance on ‘Valencia,’ or other late season oranges, has been unacceptable.

3. Release (S-chloro-3-methyl-4-nitro-1H-pyrazole) was originally developed by Abbott Laboratories, North Chicago, Ill., but all rights to use the compound as an abscission agent for citrus have been purchased by the Florida Department of Citrus, which also is financing toxicity studies for full EPA clearance. Currently, Release is available in Florida for use under experimental permit on oranges destined for processing. The chemical was the first to show the ability to loosen mature ‘Valencia’ oranges while causing virtually no injury to bloom, young fruit, or foliage when used as recommended.

4. Pik-Off (glyoxal dioxime), a product of CIBA-GEIGY Corporation, Greensboro, NC., is a chemical very similar in action to Release, but is no longer available for use under an EPA experimental use permit. It does not usually produce as good abscission as do some other chemicals, but it is satisfactory for many uses. It is in an advantageous position from both cost and residue standpoints and is compatible with ‘Valencia.’

5. Chemical combination. Combinations of Release and Acti-Aid applied with surfactant as dilute sprays have given better fruit loosening than either chemical used alone.

Thus, gains have been made in this expensive and time-consuming research but, so far, these have provided no major impetus for commercial use of mechanical harvesting. Florida is not alone in this. A recent review summarizing abscission research in California (15) says, “A decade ago, it looked as if mechanical harvest of citrus would soon be common.”

Flavor effects. The use of some abscission chemicals can cause detectable effects on both juice flavor (18) and essential oil components (16, 17). The effect is enough to be detected by a trained taste panel, particularly when the oranges are barely mature (18).

Prospects: canny vs. fresh fruit crops

We see little prospects for mechanical harvesting of citrus for the fresh fruit market, particularly as today’s food additive regulations preclude the use of stains to detect injuries, such as Sunkist’s ingenious patent using ferric chloride (22). We cooperated in December 1976 with a Florida packer (Lake Garfield Citrus Co-op., Bartow. An abscission chemical could not be used as none was approved specifically for oranges for the fresh fruit market.) The cooperators used a Roberts commerical harvesting machine (including catch frame) in a serious attempt to handle mechanically harvested ‘Hamlin’ oranges, but had to desist because damaged fruit could not be graded out adequately.

Decayed fresh fruit represent a very serious economic loss. By the time they show up on a distant market, their loss represents not only the original cost of the fruit at the packinghouse, but also the cost of handling through the packinghouse, plus the cost of the container, plus the cost of transportation to the market, plus wholesale and retail marketing costs. Additionally, the economic loss due to damage to the shipper’s reputation is intangible but real.

Currently, the most that fresh fruit packers expect from mechanical harvesting is that it will, in time, release pickers who would otherwise be working for the cannery.

The prospect for mechanical harvesting of fruit for processing is far more promising. The amount of fruit to be harvested is very much greater; the harvested fruit has to last only 1 to 3 days, not weeks; and monetary losses for decayed fruit are minor compared with the fresh fruit trade. Therefore the value on arrival at the cannery involved. However, interest and cooperation from the processing segment of the citrus industry typically reflect the availability of picking labor. Pickers are scarce when the economy is booming and far more available in times of recession.

Successful mechanical harvesting for the canneries must involve far more careful scheduling between the tree and the extractor than is now customary. This is because abscission chemicals, which cause superficial peel injury, can increase fruit spoilage. The safe time between harvesting and processing may be limited to 36 hours or less in warm weather with well-matured fruit. Therefore, mechanical-harvesting operations should be coordinated with processing operations so that fruit can be moved into the processing plant immediately upon arrival.

Mechanical harvesting for the cannery would probably be in general practice today if the shortage of pickers (a real problem before the current prolonged recession) had continued. It is notable that interest in mechanical harvesting of citrus seems most acute in Australia, where agricultural wages and benefits are high.

Literature Cited


INFLUENCE OF HARVESTING METHODS ON QUALITY OF DECIDUOUS TREE FRUITS

Adel A. Kader
Department of Pomology, University of California, Davis, CA 95616

Quality of deciduous tree fruits is determined by several factors, including appearance (size, shape, color, absence of decay and other defects), texture, flavor, and nutritive value. Harvesting methods, especially those involving a once-over procedure, may determine uniformity of maturity at harvest, which, in turn, influences these quality attributes. Maturity also affects susceptibility of the fruit to water loss and mechanical injury.

The harvesting system used and its management have a direct effect on incidence and severity of mechanical injuries on fruits; such injuries can result in tissue browning, accelerated water loss, and increased decay incidence. Mechanical injuries can also induce some undesirable compositional changes, such as loss of ascorbic acid content, and stimulate CO$_2$ and C$_2$H$_4$ production by fruits. Mitchell et al. (27) found that both impact and vibration injuries hastened deterioration, increased respiratory activity, and slightly increased C$_2$H$_4$ production of sweet cherries. An increase in C$_2$H$_4$ and CO$_2$ production by apples in response to bruising also has been reported (9, 23). We found (unpublished data) that impact bruising of clingstone peaches resulted in about 50% higher CO$_2$ and C$_2$H$_4$ production rates during the initial 12 to 24 hours of holding at 20°C; rates then returned to near those of control fruits.

Changes in the handling system necessitated by mechanizing harvest operations also can influence postharvest quality deterioration rates directly by affecting incidence and severity of mechanical damage and indirectly, by affecting speed of delivering fruits to a packinghouse or processing plant, and cooling and other temperature management procedures between harvest and preparation for market or processing. Generally, more damage can be tolerated with fruits used for processing than with those which are marketed fresh because processing is usually done within a relatively short period of time following harvest. Also, the severity of mechanical injuries may be reduced by processing, e.g., by peeling or trimming damaged surface areas and by reduction of discoloration intensity during heating.

The number and magnitude of impacts from drops on hard surfaces or on other fruits and vibration bruising while on horizontal conveyors or during transit are the main causes of damage to fruits which are mechanically harvested and handled. The magnitude of both quality and outright product losses are maturity-, time-, and temperature-dependent (29). As the fruit ripens and softens, it becomes much more susceptible to mechanical damage. Symptoms of mechanical injuries become more noticeable with time, especially at higher temperatures. Current technology limits shake-catch harvest to fruits for processing and fruits which can withstand some impact (10). Zahra and Johnson (38) estimated that 38% of the fruits for processing but less than 1% of fresh market fruits are harvested mechanically. The extent of harvest mechanization in the United States during 1979 was estimated to be 100, 85, 15, 13, 10, and 5% for prunes, sour cherries, sweet cherries, peaches, and apricots and apples, respectively (5). No mechanical harvesting of nectarines, plums, or pears was reported.

Claypool (7) and LaBelle (18) reviewed the effects of mechanization on harvest quality and indicated that mechanical damage was the principal reason why most mechanically harvested fruits are considered unsuitable for the fresh market. Other limiting factors include excessive variation in maturity and the amount of unwanted plant parts (leaves, twigs, etc.) and defective fruits present in machine-harvested lots. The latter 2 problems require sorting of harvested fruits to eliminate defective ones and remove debris. Horsfield et al. (13) found that removing culls at the harvester rather than at the central sorter or at the cannery was better because it was less costly and caused the fewest bruises. Uniformity of maturity at harvest is influenced by cultivar, cultural practices, use of growth regulators, and climatic conditions. Fruit maturity has an important effect on the force required for removal, on mechanical properties, and on relative susceptibility of the fruit to mechanical damage. Until cultivars with uniform fruit maturity are developed, selective harvest will be needed. Lack of uniformity in maturity among fruits in once-over harvesting operations was identified as the most important factor influencing fruit quality (29).

Fruit injury in mechanical harvesting can occur during detachment from the tree (due to impacts with leaves, twigs, and other fruits while being shaken), while falling through the tree, and during catching and collecting operations. Mechanical injuries result from improperly padded surfaces, poor protection from fruits falling on each other, poor conveyor design and operation, and container-filling devices that permit a free fall of fruit for a distance sufficient