INFLUENCE OF MECHANICAL HARVESTING ON QUALITY OF SMALL FRUITS AND GRAPES

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There has been a revolution in recent years in the area of small fruit and grape harvesting. Hand labor has become both scarce and costly, thus invention and development of mechanical harvesters have become important research objectives for research scientists in Land-Grant Institutions, in the U.S. Department of Agriculture (USDA), and in private industry.

Not only is collecting and transporting a high percentage of the yield to processors important, but it is also essential to maintain or even improve the quality of the harvested fruits. Quantity and quality of the raw product as well as that of the finished product depend upon conditions during harvesting, handling, transporting, and processing. These can be influenced by environmental conditions, cultural practices, and chemical harvesting aids, as well as by physical transfer of the fruits from where they grow to where they are processed. Mechanical harvesting has shown a high degree of success in small fruit and grape production when these influences are considered. More and the techniques associated with mechanical harvesting that are necessary to achieve quality in small fruit crops and grapes and their products are being discovered. Most small fruit crops can now be mechanically harvested with varying degrees of success; however, this report will concentrate on the influence of mechanical harvesting on quality of cane fruits, strawberries, blueberries, and grapes. These crops were selected since they serve to illustrate the different types of quality problems that have been encountered.

Cane Fruits

Research on mechanical harvesting of cane fruits has been conducted at several locations in the United States, Canada, and Europe, and the majority of such research has been on red raspberries and blackberries (11, 21, 22, 26, 27, 36, 40, 42, 51, 52, 55, 67, 70, 79). The design and subsequent developments in the cane fruit harvester developed at the University of Arkansas (40, 41, 42, 55, 67, 70) exploit fruit abscission as the basis of harvesting. This harvester utilizes a shaking mechanism to remove the fruits from the canes. Fruits can be harvested selectively as they mature because ease of abscission increases with maturity.

Machine-harvested berries are larger and have a higher percentage of total soluble solids, lower acidity, and superior color than do hand-harvested berries. Processed berries that have been machine-harvested have been rated superior to hand-harvested berries for color, flavor, and firmness (67). Machine-harvested blackberries have higher total soluble solids than do hand-harvested fruit.

One of the most important influences on quality of machine-harvested berries is temperature. Research at the University of Arkansas (70) has shown that blackberries which are mechanically harvested and processed immediately have good processed quality compared to berries that are machine-harvested at high temperature (70°C). Machine harvesting at the lowest possible temperature would be advantageous for maintaining fruit quality during handling and storage. Removal of field heat from the berries immediately after harvest by refrigeration or by the use of a high CO₂ atmosphere (e.g., 20% to 40%) can prolong postharvest quality of machine-harvested blackberries after harvesting the fruit at high temperature (70).

Strawberries

Historically, strawberries have been considered to be among the least adaptable crops to mechanical harvesting. There are 2 obstacles: 1) lack of cultivars with firm fruit that ripen uniformly; and 2) weight of fruit on high-yielding cultivars causing the fruits’ supporting truss to sag to the ground. Mechanized-harvesting and handling systems have still been developed with varying degrees of success (9, 10, 12, 13, 24, 29, 31, 43, 44, 74, 75, 84, 86, 94).

Several harvesting principles were evaluated in the process of developing a mechanical harvester for strawberries at the University of Arkansas (43, 63, 74, 75, 76, 77). One approach included cutting or clipping fruit from the plant, but a majority of the large fruit was not harvested since they were on the ground. A harvester was designed at the University of Arkansas that utilizes a pneumatic stripping system, in which a stream of air lifts the fruit into position and a comb-brush picking belt strips the fruit from the plant. The strawberries are given a once-over harvest when a majority of the crop has developed acceptable color.

Work at the University of Arkansas has shown that certain strawberry clones (e.g., ‘Cardinal’ and A-5344) are more adapted to machine harvesting, cleaning, and sorting without loss of quality (63, 64, 66, 68, 76, 77). These cultivars have concentrated ripening patterns and firm fruit. Each cultivar also has an optimal time of harvest, after which quality and/or usable yield will decrease (63, 64, 66, 68, 72, 76). Most cultivars suited for machine harvesting in Arkansas have a 5- to 6-day optimal period for a once-over harvest (63, 68).

Quality of machine-harvested fruit from certain strawberry cultivars is also improved by prior hand-picking (71, 72). Fruit remaining on the plants after one or 2 hand-harvests had a higher
percentage of ripe fruit in the once-over harvest than did machine-harvested fruit not preceded by a hand-harvest. After one or 2 hand-pickings, total soluble solids, shear or firmness, and color intensity of the composite once-over machine-harvested fruit was the same as or higher than that of hand-harvested fruit (72). Percentage of total soluble solids, acidity, and color were lower, in general, as compared to those of hand-picked fruit, but these qualities tended to improve as the number of hand-pickings prior to machine harvest was increased (72). Sensory evaluation of fruit prepared from both machine-harvested and hand-picked fruit was rated as acceptable (71, 72).

One of the most objectionable aspects of machine-harvested strawberriess is the presence of green fruit from once-over harvests. In-plant equipment has been developed with the capability of separating berries into distinct maturity classes (63, 64, 66, 68, 76, 77). Many immature fruit can be sorted from ripe fruit in the basis of differences in berry size. Sorting can be done by the in-plant cleaning line with a tapered-finger, continuous sizer (63, 64, 68, 76, 77). Percentages of mature and immature berries obtained by sorting them into small (mostly green and inceptile) and large (mostly ripe) categories depends upon cultivar and harvest date. Large green fruit that is sorted with the large ripe fruit eventually ends up in the processed product. Research has shown (68, 90) that strawberry products containing as much as 50% immature fruit can be utilized in the production of commercially acceptable jam. Later work has shown that strawberry jam made from cultivars having extremely high anthocyanin levels can contain as much as 75% large immature fruit and still be rated acceptable (92). Immature fruit did not influence color quality of jam but did influence color loss and discoloration during storage at 2°, 25°, and 35°C (92). Total anthocyanin levels were more important in attaining acceptable color than the percentage of ripe fruit in the jam (91, 92).

Puree is used in the manufacture of these acceptable products that are produced from mechanically harvested fruits (90). The need for decapping the strawberries is eliminated since the calyx can be removed by the screen in the pulping machine.

Whole fruit is required if preserves are to be manufactured. Also, frozen strawberries in whole or sliced form demand a premium price. If machine-harvested strawberries are to be utilized in this market, then the fruit must be decapped after it has been machine-harvested and cleaned. Numerous attempts have been made to develop a decapping machine for strawberries, but a totally successful unit that will handle the volume of fruit desired by the processing industry has not yet been devised. Work is currently underway on this problem at Michigan State University, at the University of Arkansas, in Canada, and by private industry. Strawberries are highly perishable; however, Morris and Cawthon (56) have shown that extremely firm-fruited strawberries for processing can be mechanically harvested, properly cleaned and handled, and then held for up to 48 hr at 24°C and for 7 days at 1.7° without excessive quality loss. Fungicide dips before storage suppress mold growth and reduce loss of soluble solids (36).

Additional work by Morris et al. (57, 65) showed that an acetalddehyde atmosphere and a combination of atmospheres and dips are effective in maintaining good color, freedom from browning, and product acceptability of machine-harvested strawberries held for 72 hr at 24°C. Fruit stored in an acetalddehyde atmosphere increased in acidity after 72 hr of storage due to the conversion of acetalddehyde to acetic acid, but acitidy returned to near-initial levels after 120 hr.

The 2 major limiting factors in the system for the total mechanization of the strawberry industry are more adapted cultivars and the need for a commercially acceptable decapping system. Additional research will also be required in the area of postharvest handling.

**Blueberries**

Commercial harvesters have been used by the blueberry industry since 1966 (1, 47). These large, over-the-row harvesters shake and dislodge berries from the bush. Fruit are caught in pans and conveyed to the rear of the machine where trash and leaves are removed by high-velocity air. Fruit from the harvester are then poured into airblast cleaners that remove any remaining trash and small green berries. The remainder are dropped onto sorting belts for removal of green, decayed, or bruised fruit and then loaded into shipping containers.

Austin and Williamson (1) reported that the amount of ripe rabbiteye blueberries lost on the ground is greater when the berries are harvested by machine than when they are harvested by hand; however, proper pruning of rabbiteye blueberry bushes can increase the efficiency of machine harvesting. Mainland et al. (46, 47) reported that marketable fruit of machine-harvested highbush blueberries was from 4% to 44% less than that of the hand-harvested blueberries (47). Some green and unripe fruit had to be removed by grading in addition to fruit being lost on the ground. Machine-harvested fruit in the ripe category were 4% to 32% softer than hand-harvested fruit (46, 47).

Sorting and grading machine-harvested fruit on a commercial cleaning line further softens the berries and cause more decay in storage (46, 47). New methods of sorting blueberries are necessary for machine harvesting to be totally successful. Several techniques have been developed (2, 15, 28, 53, 85), including sizing, fiber optics light measurement, vibration, and density sorting. Sizing has not been an effective means of sorting for quality since this method does not discriminate between ripe and overripe fruit (2). The fiber optics light method uses the anthocyanin content of the berries as a means of separation (53, 85). Mature berries have higher anthocyanin levels than immature berries, thus this method sorts berries into maturity classes (green, ripe, and overripe). The low-frequency vibration method separates blueberries on the basis of firmness (15, 28). This method separates green (very firm), ripe (firm to soft), and overripe (very soft) berries according to their “bounce.” Also, the USDA (98) has developed a new hydrotransportation system for blueberries which is superior to the standard grading line, due to the removal of a higher percentage of undesirable fruit (green, soft, bruised, etc.).

Decay of machine-harvested blueberries during postharvest holding is perhaps the biggest problem of the industry (4, 15, 18, 19, 30). Cappellini et al. (19) reported that 15.2% of the blueberries in New York markets were defective, and about two thirds of this was due to decay. Ballinger et al. (3) mentioned that bruising softens berries and increases decay after storage for 7 days at 21°C (46).

Temperature during storage is a critical factor in the development of decay in blueberries. Ballinger et al. (4) reported that berries held at 22.2°C developed an unacceptable 20% decay level within 1 to 5 days, whereas those held at 1.1° required 12 to 32 days, depending upon the ripeness of the berries. Fruit with a total soluble solids : acid ratio over 30 (very ripe) should be processed within 24 hr and should not be sold on the fresh market (4). Blueberries should be stored at 0° (17, 34). Precooling blueberries to 2° reduced decay when they were held for 24 hr at 21° after a 3-day simulated transit period at 10° (35). Fungicide sprays and dips, hot fungicide dips, and hot water dips reduced postharvest decay and maintained quality during holding (18, 30).

The application of ethephon to the bush prior to harvest accelerates color development, abscission, and maturity of blueberries (25, 32, 33, 37). Ethephon reduces the amount of force necessary to dislodge the berries from the bush (33); thus, fruit were damaged less during machine harvest and shelf-life was increased.

Additional research is needed in the area of bush adaptation and modification to improve harvesting efficiency. Also, continued research will be required to improve the postharvest handling systems for machine-harvested blueberries, particularly those for the fresh market.

**Grapes for juice and wine**

Major developments in juice and wine grape harvest mechanization occurred in the early and mid-1960s (81, 87, 88, 95) and mechanization was practiced commercially by the late 1960s (6, 23, 38, 50). Mechanically harvested grapes can have better quality than hand-harvested grapes when delivered promptly to the processing unit (38, 82, 99). However, there are still several inherent problems which lead to quality loss associated with machine harvesting. The following factors influence quality of machine-harvested grapes:
Machine effects. Today, many of the commercial harvesters employ the use of “pivotal strikers”, which consist of a double bank of flexible horizontal rods that strike and shake the vine to remove fruit. The “trunk shaker” or pulsator harvesting concept is another commonly used method in California. This method incorporates 2 parallel rails to impart horizontal vibration to the upper trunk and/or cordon. The trunk shaker is only effective in removing fruit in contact with a rigid trunk or cordon, and much less MOG is harvested. Some of the newer machines have combined the 2 principles and reduced the number of horizontal rods. One commercial company refers to its unit as a “pivotal pulsator”. This unit results in less leaf removal and vine damage since it operates at a lower speed. It has been reported that shorter stroke lengths result in more damage to the grapes, but the frequency of the beater does not affect the amount of damage (87). Fruit are removed with all harvesting methods as cluster parts or as individually torn berries. Perhaps the major quality problem with mechanically harvested grapes is fruit damage from the beater rods or slappers and the handling after harvest (14, 20, 49, 73, 87). The percentage of intact, mechanically harvested berries may be as low as 40% (73).

Cultivar and production system effects. A mechanical harvesting crew will deliver about the same amount of fruit to the processing unit as do hand-harvesting crews with certain cultivars that are readily suited for mechanical harvesting (20) (e.g., ‘Concord’, ‘Niagara’, ‘Flora’, ‘Thompson Seedless’, ‘Gewurztraminer’, and ‘Cabernet Sauvignon’). Much less fruit may be delivered to the processor with hard-to-harvest cultivars (e.g., ‘Emerald Riesling’, ‘Grenache’, ‘Zinfandel’, and ‘Muscat Canelli’) than do hand-harvesting crews.

Structure of the cluster framework and its adherence to the vine and to the berries are the main factors that determine how easily and in what condition the fruit is removed. Fruit of most cultivars are removed primarily as single berries. This is particularly true of berries with fairly loose attachment. Cultivars with a firm berry attachment and a tough or wiry cluster framework are the most difficult to harvest mechanically. ‘Emerald Riesling’ has berries that are held securely by the internal vascular system (“brush”) of the pedicels. The harvester must “juice” the fruit off the vine, leaving the cluster framework and the large, wet brushes behind. The soft, juicy berry texture of ‘Seminon’, ‘Muscat Canelli’, and ‘Burger’ presents harvesting problems because of juice loss during fruit handling. Conversely, the very firm berries of easily harvested ‘Tokay’ and ‘White Malaga’ undergo almost no juiceing during machine removal (20).

Larger fruit and those harvested later in the season are more susceptible to mechanical damage (49, 73). The ease or difficulty of mechanical harvest also depends upon training system, type and condition of the trellising system and wire, and vine vigor.

Many cultivars of muscadine grape (Vitis rotundifolia, Mich.) do not ripen uniformly, thus once-over harvesting removes immature as well as mature berries. The presence of immature fruit is undesirable since it lowers the quality of the processed product. A system for sorting machine-harvested muscadine grapes into maturity classes has been developed at the University of Arkansas (45). This system utilizes brine solutions of different strengths to separate the grapes according to specific gravity. Thus, ripe berries with good quality can be separated rapidly and inexpensively from immature berries with poor quality.

Muscadine grapes are also unique in that an abscission layer forms as the berries mature. This layer is so complete within some cultivars that fully ripe fruit will drop in advance of the mechanical harvester’s collecting mechanism. The University of Arkansas designed an extended collecting unit, which is adaptable to the front of any conventional commercial harvester, that prevents the loss of these overmature fruit.

Effects of harvest temperature and interval between harvesting and processing. A considerable time delay between mechanical harvesting and delivery to the processing plant can result in increased enzymatic activity and browning, oxidation (i.e., loss of color), and development of off-flavors and microbial growth (14, 20, 49, 50, 82, 93). Temperature from the time of harvest to the time of processing probably influences the quality of machine-harvested grapes more than any other factor (5, 6, 7, 8, 39, 49, 50, 58, 61, 62, 80, 82). Grapes placed in pallet boxes after harvest do not increase in temperature for 72 hr (58). The initial temperature of the grapes at harvest governs the storage temperature, regardless of the external air temperature. High temperature at harvest in combination with a delay in processing leads to rapid development of grape juice quality (5, 7, 8, 39, 58, 62). Grapes harvested when fruit temperature is high about (35°C) produce high levels of alcohol and acetic acid, both of which are signs of microbial spoilage, and have poor color (62). The alcohol and acetic acid contents of mechanically harvested grapes begin to accumulate 12 hr from the time of harvest if grape temperature at harvest is as high as 29°C and increase rapidly after 18 hr of holding at 29°C or 24°C. Decreases in soluble solids, flavor, and color quality parallel the increases in alcohol and acetic acid (5, 7, 58). Off-flavors in the processed juice product can be expected when alcohol levels reach 0.25%.

High temperatures (above 25°C) of grapes at harvest usually are not a problem in cool areas (14, 39, 49, 73), but grapes in hot areas, such as the San Joaquin Valley of California and in the southern United States, should be harvested during cool periods of the day or at night to minimize quality loss (7, 8, 39, 58).

MOG effect. Machine-harvested grapes may contain a rather high percentage of MOG such as bark, canes, leaves, and petioles (48, 49, 83). All of this material may not be removed and eventually may reach the processed products. Cultivars which are more difficult to harvest usually contain more MOG than do easily harvested cultivars (49). MOG may be reduced by cultural practices (83) or improved cleaning machinery (48). It is also imperative in mechanically harvested vineyards trellised on wooden stakes that a magnet be installed on the machine’s discharge conveyor to collect staples and other iron-containing objects.

Effect of postharvest handling system. Addition of SO₂ to machine-harvested grapes decreases quality loss during holding (8, 14, 20, 58, 61, 62, 78, 80). Addition of 80 to 160 ppm sulfur dioxide immediately after harvest slowed postharvest deterioration of machine-harvested grapes by delaying alcohol accumulation and loss of soluble solids for 24 hr when held at 35°C (58). Also, SO₂ discourages bacterial spoilage that might be expected at high fruit temperatures over a long period; it also serves as an antioxidant to prevent juice browning. Higher rates of SO₂ applied to machine-harvested grapes at a low temperature (24°C) delayed alcohol production for 42 hr (58).

The type of containers used for hauling the grapes to the processing unit can influence product quality. Initially, 0.91- MT (1-ton) capacity wooden bins with food-grade plastic liners were used to accommodate the fruit; however, many operations on the West coast have shifted to a 3.6- to 4.5- MT (4- to 5-ton) capacity hydraulic, self-dumping vineyard gondola that dumps the harvested grapes from the vineyard into bulk tank trucks which are hydraulically dumped at the processing plant. These bulk collection units have not reduced the quality of the processed product (49, 50, 80).

There is currently a trend toward crushing the grapes in the field as soon as the fruit are discharged from the harvester and transporting the juice to the processing unit. O’Brien and Studer (80) developed a closed gondola tank for collecting crushed grapes and juice from the harvester with a steamer-crusher. This system is effective in controlling microbial growth and oxidation since it permits injection of CO₂, N₂, or SO₂ into the tank.

Cost and convenience of the various hauling systems have been major contributing factors in determining the system selected by a given processor; however, additional research is needed in this area.

Guidelines for operators of commercial harvesters. The following guidelines were developed by our grape research group at the University of Arkansas in cooperation with the commercial grape-processing industry to maintain or improve the quality of machine-harvested grapes: 1) select the proper rpm of the shaking mechanisms or strikers and the proper ground speed for the harvester for each cultivar and crop load situation (the importance of proper machine adjustments and operation cannot be overemphasized); and 2) establish a time limitation from harvesting to processing plant.
delivery. The time limitation will depend on cultivar (2 to 4 hr for grapes used for premium white wines and 8 to 14 hr for grapes used for red wine and grape juice).

Other factors to be considered are fruit temperature, SO₂ usage, and quality standards required for the final product: 1) Apply SO₂ when harvesting under high-temperature conditions, at the rate of 100 ppm as the grapes pass over the final delivery conveyor; 2) prepare vineyard to eliminate MOG problems. This may require mechanically trimming low-hanging canes that interfere with harvest, removing bird nests, removing tall weeds, preparing a smooth surface to the vineyard floor, and stopping all cultivation in sufficient time prior to harvest to minimize dusty conditions during harvesting; 3) inspect the vineyard for foliar-feeding insects and, if necessary, apply required special sprays sufficiently ahead of harvest; 4) provide a bin or conveyor inspector as part of the harvesting crew. This individual would remove MOG; watch for plugging of cleaning fans, hydraulic leaks, and mechanical failures; and monitor the application of SO₂; 5) keep harvested grapes covered at all times and require a complete washing of delivery bins or containers after the grapes are dumped at the processing plant or winery; and 6) wash and clean cultivars, cultural programs, harvesting principles, postharvest handling of grapes has resulted in a final product quality that is either superior, comparable or inferior to hand-harvested fruit, depending upon how the harvesting system is managed.

Harvesting practices and handling of all small fruit crops before, during, and after harvest will depend to a large extent upon the final destination. Blueberries represent a small fruit crop that is currently being mechanically harvested and sold on the fresh market. Future research and developments on all small fruit crops must provide for less damage, more selectivity, and less unwanted plant debris, which may allow some of these crops to be utilized by the fresh market. Additional research and development must continue with emphasis on development of totally integrated systems.

### Literature Cited

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Mechanical harvesting of certain fruit vegetables has been commercially practiced for many years, but only fresh-market tomatoes have been added to that list since 1970 (6). This review includes those fruit vegetable crops for which machine harvesting is an established commercial practice, and considers aspects of the harvesting and handling systems which affect the quality of the fruits.

Processing tomatoes

Tomatoes are classified at the processing plant as product tomatoes or tomatoes suitable for peeling. The fraction of peetable tomatoes in any given lot of fruit varies according to the type and extent of physical damage displayed. Slight damage, evidenced by bruising of the tomato flesh without skin rupture, is not of major concern in any given lot of fruit varies according to the type and extent of physical damage displayed. Slight damage, evidenced by bruising of the tomato flesh without skin rupture, is not of major concern

Number of handling operations, elapsed time between harvest and processing, fruit maturity, fruit temperature at harvest, and cultivar.

Studies by Ries and Stout (43) have shown that handling tomatoes in bulk containers results in more damage than does handling in lug boxes. The amount of damage increases with increasing fruit depth and is reflected by an increase in the percentage of fruit with visible seed locules (31, 40). Small cracks in the tomatoes which may exist after filling into the container become progressively larger during transport to the processing plant. Thus, efforts to control major damage must be continuous throughout the harvest operation. A major source of fruit cracking is in the transfer of the fruit from the harvester to the container, which is usually a bulk trailer with a capacity of about 12 MT. Fruit depth at the center of the load often exceeds 1.2 m. Cracks result from contact of the fruit with the bottom of the bin or trailer, dynamic loads resulting from fruit-on-bin contact but it does not reduce damage at higher points in the load. According to Pausch and O'Brien (41), damage can be reduced during bin filling by minimizing fruit drop height and by spreading the fruit across the width of the load and cushioning the fruit to dissipate its kinetic energy. Mechanical spreading of the fruit as it drops from the delivery conveyor reduces the number of impacts experienced by fruits directly under the end of the conveyor. However, fruit drop height is monitored and controlled manually on the harvesters, and the effectiveness of this control method is highly dependent upon the machine operators.

Severity of fruit damage is related to the number of handling operations, and increases with each successive operation. The largest increase in severe damage occurs during transportation between field and processor (37). In addition to the static loads imposed on the fruit at the bottom of the bin or trailer, dynamic loads resulting from vibration during hauling also exist. Fruit evaluation after hauling has revealed that the amount of damage in the bottom quarter of the bin was about equal to the total amount in the upper three quarters. Central sorting was a common practice prior to the advent of the electronic color sorter on the tomato harvester. Central sorting re-