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 peelable 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. Slight damage, evidenced by bruising of the tomato flesh without skin rupture, is not of major concern. Moderate damage is characterized by cracks 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. 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).

INFLUENCE OF MECHANICAL HARVESTING ON THE QUALITY OF FRUIT VEGETABLES

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duced the amount of soil and the microbial population on tomatoes delivered to the processor in a study by York et al. (60). However, O'Brien et al. (39) reported that the system resulted in an increase in fruit damage due to the additional handling steps required for central sorting. In California, central sorting now is used only for cleaning up loads rejected for defects such as mold.

Studies have shown that the time lapse between harvest and processing is an important factor, with severe damage at the bottom of the bin significantly higher for a period greater than 8 hr, compared to a lapse time of less than 6 hours (37). The average lapse time between harvest and processing in this study was about 7 hr, but periods as high as 11 hr were observed. Lapse time is comprised of delay time in the field, actual hauling time, and delay time at the processing plant prior to unloading, and can be minimized through proper scheduling.

Fruit maturity at harvest has a major influence on the amount of damage observed in the fruit delivered to the processor (39). Substantial reductions in severe damage are possible by harvesting in advance of regular maturity, when grass-green fruit may be only 2%. Leonard et al. (31) reported that the percentage of fruits with visible locules diminished from 15.1% for fruit harvested at regular maturity to 2.3% when harvested 12 days prior to regular maturity. Moreover, the percentage of peelable tomatoes was much higher for the early harvested fruit.

The magnitude of severe damage is highly correlated with fruit temperature at the time of harvest (37). Tomatoes harvested in the afternoon exhibit a larger percentage of fruits with exposed seed locules than tomatoes harvested during the night and early morning. Time of harvest is an important management tool used by growers to minimize fruit damage.

The effect of mechanical harvesting on ascorbic acid content has not been determined. However, the results of a study by Krochta et al. (29) using hand-harvested fruit subjected to controlled damage did not show any decrease in ascorbic acid content of the fruit flesh. Fruit damage is reduced by early harvest, but Liu and Luh (32) have shown that tomato pastes made from fruit harvested before regular maturity are lower in carotenoids and in free amino acids, total nitrogen, and water-soluble pectins (33). However, the practical consequences of machine harvesting before regular maturity with respect to these constituents has not been reported.

Studies of fruit damage, processing loss, and product quality have been conducted for the most part with 'VF-145-7879' or a similar round cultivar. Comparable studies with the square round cultivars which are less prone to damage have not been reported.

**Fresh market tomatoes**

Mechanical-harvesting systems for fresh-market tomatoes have been developed in California, Florida, and South Carolina (6). The problem of puncture injury caused by fruits with stems was noted by Deen et al. (12). Sims et al. (50) reported that more cuts and punctures were observed on machine-harvested 'Walter' and 'Florida MH-1' than on hand-harvested controls, although the differences were not significant statistically. Cuts and punctures were higher for 'Walter' than for 'Florida MH-1' and this was attributed to the larger percentage of stems retained by the 'Walter' fruit. Although no differences in bruising were found, machine-harvested fruit had twice as much sand abrasion. Nevertheless, the authors concluded that the overall level of physical damage inflicted on the machine-harvested fruits was within acceptable limits for marketing.

Studies by Studer and Chen (54) with 'Castle X29' and 'Royal Flush' showed no significant differences between machine-and hand-harvested, mature-green fruit with respect to internal quality score, scuffing, and cuts. The percentage of fruits exhibiting puncture injury was higher for 'Royal Flush' than 'Castle X29', and puncture injury was significantly higher for machine-harvested than for hand-harvested 'Royal Flush'. Again, the high stem retention rate, 90%, for 'Royal Flush' appeared to explain the differences in observed frequency of puncture injury.

Comparisons of mature-green fruit carefully hand-picked with machine-harvested fruit of 'Jackpot', 'Valley Pride', 'Goldsmit 101', and 'Caslemart' were made in a later study by Studer et al. (55). Evaluations made after an 11-day storage period revealed no significant differences in internal quality scores, bruises, or deformations. Frequency of cuts and punctures was invariably higher for machine-harvested fruit, although only in 3 out of 16 comparisons were these differences statistically significant. Skin abrasion on machine-harvested fruit was higher for 3 out of 4 cultivars and significantly higher for 2 out of 4. Commercially hand-picked and machine-harvested fruit of 'Caslemart', 'Royal Flush', and 'Casleprize' also were evaluated for damage. Significantly higher levels of puncture injury were found for machine-harvested 'Royal Flush' and 'Casleprize', both of which are characterized by high stem retention. No clear trends favoring either hand or machine harvesting with respect to cuts and abrasions were found in this part of the study.

The sand and marl soils of Florida impose special challenges to the development of mechanical harvesting. Deen et al. (10) reported that modified processing tomato harvesters used in one study on marl soils caused a 10% increase in fruit damage. The use of plastic mulch has greatly reduced the amount of soil picked up by the harvester. However, harvesting tomatoes from mulch-covered beds is still under development and comprehensive fruit damage evaluations have not been reported.

Hayslip and Deen (19) mentioned damage is generally no greater for tomatoes harvested with the IFAS semimechanical harvester than for hand-harvested fruit. This harvesting concept was developed to permit harvest at a more advanced stage of fruit maturity, with the red-ripe fruits being sorted out from mature greens and field-packed in shallow containers.

Evidence to date strongly suggests the quality of fresh market tomatoes need not be compromised when the fruit is machine-harvested mature-green. However, the possibility of increased damage certainly exists and the commercial success of this practice depends largely on management decisions regarding field preparation, cultivar selection, fruit maturity at harvest, and harvest crew management (51). The development of acceptable jointless cultivars would solve the problem of puncture injury. However, these fruit are less easily detached by the harvester. Thus, a more aggressive shake is required to achieve adequate fruit separation from the vines. The need for reliable and automatic transfer conveyor position control, mentioned in regard to processing tomatoes, also exists for the harvest of fresh-market fruits.

The quality of fruit harvested at advanced maturity may be superior (27), and some consumers may prefer this fruit to that harvested at the mature-green stage (22); however, the deleterious effects of bruise injury on the quality of this fruit would negate any potential gains in overall quality, unless an acceptable cultivar can be developed with the firm, red-ripe fruit characteristic of 'Florida MH-1'. A practical system for harvesting and marketing this type of product is yet to be developed, but the potential rewards appear to justify continued effort to do so.

**Pickling cucumbers**

Ennis and O'Sullivan (15) provided an excellent review of research dealing with many aspects of cucumber quality, including effects of mechanical harvesting. Studies by Garte and Weichman (18) showed that respiration rates for mechanically harvested cucumbers were higher than for those hand-harvested, presumably due to higher incidence of mechanical damage. Marshall et al. (35) evaluated mechanical damage exhibited by commercially harvested fruits. Smashed or broken cucumbers accounted for 12.1% of the machine-harvested fruit delivered to the processor. Handling operations after harvest appeared to significantly affect the frequency of balloon bloating during brining. Abrasion injury was higher for the smaller fruit sizes and these fruit suffered serious damage as a result of co-mingling with larger fruits in the handling and fruit transfer system. Fruits harvested in the morning were more susceptible to abrasion injury than those harvested in the afternoon, this being attributed to the higher turgidity of the morning harvested fruits. They observed an average elapsed time between harvest and brining of 19 hr for machine-harvested fruits. The effect of time delay between harvest and processing on fruit quality has not been reported. Effects of various handling operations on fruit quality were studied by Heldman et al. (20). They found that the cumulative frequency of visible but minor defects, such as abrasion injury,
increased with the number of handling steps. Increase in visible damage was related to the magnitude of drop heights experienced by the fruit. The frequency of balloon bloaters after brining was associated with these handling operations (such as mechanical size grading) that subjected the fruits to numerous shocks of small magnitude. They suggested limiting maximum drop heights to 0.8 m.

Rozat et al. (44) studied the performance of a pinch-roll-type harvester for small pickles. This machine has been commercially accepted for once-over harvesting of larger size fruits (greater than 3.8 cm in diameter). They reported a loss of 65% of the available mass of size 1 fruit (up to 3.3 cm in diameter) at the pinch rolls. In addition, 28% of the total recovered fruit was found unacceptable for processing due to damage. Thus, losses are substantial although these mechanical harvesters are used extensively. A once-over cucumber harvester based on a threshing principle was evaluated by Van Ee et al. (57). The experimental machine was found to be equally effective in detaching fruits of all sizes. Recovery rates of 80% were reported, with most of the losses due to fruit shatter from the vines at the pick-up rather than in the threshing mechanism itself. The results of fruit quality evaluations have not been published. A selective (multiple pick) harvester has been tested extensively by Humphries (26). This machine is most effective in removing the larger-size fruits. No data with respect to fruit damage have been reported for this selective harvester.

Significant advances have been made in both harvesting and bringing technologies (9, 16, 17, 45), which offer the potential of improvements in recovered yield and reductions in damage at harvest and in yield of processed products. However, fruit-damage evaluation studies mentioned earlier strongly suggest that the fruit-handling system plays a key role in the maintenance of fruit quality. Thus, additional efforts to improve handling between the harvester and the brine tank appear to be warranted in order to reduce abrasions, bruising, and impact injury. Studies by Colwell et al. (8) show that the value of the crop is very sensitive to the timing of a once-over harvest. Thus, research is needed to improve the ability of the harvester to operate under adverse weather and field conditions. It is doubtful that significant improvements in the quality of machine-harvested cucumbers can be achieved without concerted cooperative efforts between growers and processors. A payment system based on measured cucumber quality would encourage growers to exercise careful control and supervision over the harvesting and handling operations. However, rapid objective measures for assessing bruise and abrasion injury prior to brining currently are not available.

Sweet corn

Dean and Showalter (11) provided a detailed description of sweet corn mechanization in 1969, and the situation has not changed appreciably since then. One manufacturer now provides a fresh-market corn harvester which cuts the shanks close to the ear, thus reducing handling and waste disposal costs at the central packing plant (28). A study by Showalter (49) showed that a potential for kernel damage at the base of the ears exists with this machine. Damage was highest where the shanks were trimmed to 4.3 cm or less in length, while undamaged ears had shank lengths of at least 6.3 cm. Injury to the kernels was minimal when the machine was properly adjusted and ear size and maturity were uniform. Harvest by machine may improve quality over that obtained through hand-harvest due to the faster rate of harvest and reduced holding time in the field. Harvesting during the cooler nighttime conditions also is possible when machines are used. Maintenance of quality depends critically on cooling of the corn immediately after harvest, with storage thereafter as close to 0°C as possible. Requirements for harvesting and handling sweet corn for processing are less stringent than for fresh-market corn. However, careless handling after harvest can seriously degrade quality. (53).

Pod vegetables

Duncan (14) provided a thorough description of mechanical harvesting equipment for pod vegetables in use or under development in 1969. The podstripper machines in use at that time were tractor-mounted and were employed primarily for snap bean harvesting. Spring-mounted tines on a side-mounted, inclined reel served to strip the pods from the plants, grown in rows generally spaced 91 cm apart. Snap beans which are broken in harvesting or handling are subject to the development of discoloration at their broken ends. Showalter (47, 48) pointed out the location of the abscission zone between the pod and plant stem, and found that a predominant detachment mode was at the pedicle attachment to the stem. Similar results were reported by Humphries et al. (27). Along with those by Bassett (2), also showed that pod detachment force was clearly cultivar-dependent and increased with bean maturation (pod size). Bedsole and Morgan (3) described the stripping-tine-pod interaction modes likely to result in pod breakage, which continues to be a serious problem associated with mechanical snap bean harvesting. Swingle et al. (56) reported a direct relationship between harvester reel speed and the frequency of broken pods. Studies by Showalter (46) showed that pod damage was highly dependent upon cultivar, primarily due to the cultivar effect on pod detachment force.

Interest in high-density plantings has lead to the development of a new type of harvester, which now is being used not only for snap beans but also for southern peas, lima beans, and green peas. These machines are also pod-strippers, but the picking reel is positioned across the front of the machine, which permits operation in closely spaced rows. A study of an early model of such a "high density" bean harvester by Williamson and Smittle (58) again showed that pod damage was related to reel speed. Net harvest efficiencies, which varied from 59% to 77% for a range of cultivars, were positively correlated with reel speed. Thus, higher reel speeds resulted in more damaged pods but also in a higher recovered yield. Consequently, choice of reel speed is of economic importance to both grower and processor. Their study also showed that pod breakage was cultivar-dependent, irrespective of reel speed, and that harvest efficiency was improved where the plants were most erect.

Hoffman (23) found that weight loss in snap beans was highly correlated with the number of broken or missing epidermal hairs on the beans. A later study by the same author demonstrated that machine-harvested beans lost more weight than did hand-harvested beans (24). Weight loss was correlated with epidermal hair concentration per unit area. Hoffman concluded that abrasive damage to the beans during harvest resulted in broken epidermal hairs which do not heal. His data showed the epidermal hair concentration was highly variable among cultivars. Thus, he suggested that snap bean cultivars be selected for minimum hair concentration and for easy abscission between pod and pedicel so as to reduce abrasive damage to the beans during harvest.

Southern peas used for freezing are harvested in a mature-green stage. Substantial losses can occur during shelling due to the difficulty of extracting the seeds from the pods at this stage of maturity. Brittingham and Mortensen (5) reported typical losses of 15.3% to 18.6% for a range of cultivars. However, cultivar variations in shelling loss were apparent, with maximum losses of over 45% observed for some cultivars. Measurements of pod-opening force were made by Dougherty et al. (13), who found the force to cause tensile failure of the pod suture was always higher at the intermediate (preferred) maturity than for pods at the mature stage (overnature for purposes of processing). Hoover (25) also found that shelling efficiency improved with maturity, and losses could be reduced by storing the pods at 21°C and 38°F for up to 24 hr prior to shelling. However, he pointed out that pod storage, especially at the higher temperatures, would result in seed quality reduction. Smith and Kays (52) found that the desirable green seed color in commercially handled loads of southern peas harvested by pea combines was rapidly lost after harvest and that color loss was more pronounced at higher seed temperatures. Holding seeds, which were harvested at 30°F, for up to 7 hours also resulted in a significant increase in off-flavor.

Green peas are harvested primarily by mobile viners, which pick up the precut and swathed vines and shell the peas by means of beaters inside a slowly revolving drum. The cutting and swathing operation is eliminated when the recently introduced pod-stripper harvesters are used. However, the vining apparatus is similar for all of these harvesters, and it is this operation and the subsequent
handling and transport operations which most seriously affect green pea quality. Casimir et al. (7) studied the effects of beater speed on pea yield and visible damage. Yield decreased above and below an optimum beater speed of 183 rpm. A stationary viner yielded 73% of the pea weight obtained in hand-shelled checks. Moreover, a mobile pea combine yielded only 78% of the yield from a stationary viner. Thus, pea losses during harvest can be significant. The smaller, less mature peas were found to be more susceptible to mechanical injury, and, under ideal conditions, 25% of the peas in the canned samples were found to be damaged. Damage to the peas results in lower maturometer readings, as reported by Moyer et al. (36). Their studies showed a consistent inverse relationship between the maturometer index values and the angular speeds of the beaters.

The peas are transported in bulk loads. The depth of the load must be carefully controlled, depending on the maturity of the peas, to prevent crushing during transport. Prompt delivery and processing are essential. The combined effects of bruising and delay between vining and processing have been shown by Makower and Ward (34) to result in an off-flavor in green peas.

Mechanical harvesting of pod vegetables is a well-established commercial practice. However, problems of pod and seed damage and recovery do exist. These problems might be addressed in part through selection of new cultivars. Henderson et al. (21) found, for example, that susceptibility to broken-end discoloration of snap beans was highly variable between cultivars and suggested that resistant cultivars might be obtained through a breeding program. Damage could be reduced by selecting cultivars which have low pod detachment forces. The use of an abscission chemical may be applicable, although in tests by Palevitch (42) using ethepon as a defoliant could be reduced by selecting cultivars which have low pod detachment forces. The use of an abscission chemical may be applicable, although in tests by Palevitch (42) using ethepon as a defoliant could be reduced by selecting cultivars which have low pod detachment forces. The use of an abscission chemical may be applicable, although in tests by Palevitch (42) using ethepon as a defoliant could be reduced by selecting cultivars which have low pod detachment forces.

Summary

The quality of the product at any given point in the harvesting and handling system cannot be greater than that of the product on the plant. While it is technically possible to maintain product quality at its original value, it is not possible to devise a practical system to do so because of economic constraints imposed on the solution. Nevertheless, product quality deterioration for each of the machine-harvested fruit vegetables can be reduced from current levels through improved designs of harvesters, implementation of cost-effective handling methods and procedures, and selection of superior cultivars. However, both growers and processors must be strongly committed to quality maintenance if maximum benefits from technological advances are to be realized.

Literature Cited


**INFLUENCE OF MECHANICAL HARVESTING ON QUALITY OF NONFRUIT VEGETABLES**

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Quality in this discussion is interpreted as the market quality, and not nutritional quality, of products. Market quality is comprised of the inherent quality and maturity of a product at harvest, and the condition of the product after the harvesting operation. Mechanical harvesting (MH) includes handling steps from removing plants or plant parts from the field (soil or plant) to delivering them onto a field packing facility or field vehicles for subsequent transporting to packing houses or processing plants.

MH is employed when the overall cost of doing so is less than that for manual harvesting of a product. MH is used successfully for many vegetables for processing and fresh market (4). MH may increase or decrease the variability in product maturity, the amount of mechanical damage (bruises, cuts, punctures, abrasions, and skinning) sustained by products, and the amount of subsequent decay of products. The magnitude of these disorders developed depends largely upon the plant and soil conditions at harvest time, the time of day of harvest, product maturity, and the skill of the harvester operator and related workers. When the amounts of any or all of these disorders increase, mechanical harvesting requires more product grading to be successful.

Effects of MH on the quality of vegetables differ with types of vegetables, plant parts harvested, and among cultivars. A brief review of these effects follows.

**Aboveground vegetables**

Asparagus. Nonselective MH causes harvesting of spears too short for traditional marketing, damages tips below the soil surface, and causes too much soil to be mixed with the product. These effects cause reduced yields (4). Some short spears are harvested even by hand-harvesting and, in many operations, are culled. However, one California shipper has developed a profitable market for bulk-packed asparagus tips and short spears.

Brussels sprouts. Leaf damage caused by MH is not a major concern with the processing crop (95% of the U.S. production), but detracts from the appearance of the fresh-market product (4).

**Cabbage.** The processing crop is mechanically harvested in most areas. The amount of leaf damage occurring on the processing crop would be unacceptable on fresh-market cabbage. However, with proper harvesting and handling, cabbage could be mechanically harvested successfully for fresh market (11).

**Cauliflower.** The growth rate of unharvested heads was significantly lower after MH than after hand-harvesting. MH caused more broken leaves than hand-harvesting when plants were very succulent. This could result in increased curd yellowing on the remaining heads. Very slight head damage was observed after jacket leaves had been removed, and damage was not significantly different between hand- and mechanically harvested heads. MH would be more adaptable if the number of harvests was reduced from the number used for hand-harvesting (8).

**Celery.** Although MH is used commercially to harvest some of the crop in both Florida and California, there is very limited published information on the effects of the practice on the subsequent quality of the celery. In both states, MH is used by some shippers to harvest stalks that are trimmed to be packed as celery hearts. Thus, any damaged outer petioles are removed in the trimming operation. In California, celery destined for soup canneries is mechanically harvested. When undercutting is too high, stalks will not remain intact and can be used only for processing. Developing a market for the resulting detached petioles has not been successful commercially.

**Leafy greens.** These include collards, endive, escarole, kale, mustard, spinach, and turnip greens. Proper height adjustment of the lifting-belt is necessary to prevent bunching yellowed or dirty lower leaves, or attached weeds, which detract from the market quality of greens. Time of day of harvest affected bunch crispiness.