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Strawberry Mechanization

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STRAWBERRY MECHANIZATION

Culture
Breeding
Harvesting
Post Harvest Clean-up
Fruit Quality and Utilization
Economic and Human Factors

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Justin R. Morris, University of Arkansas

Prepared from a conference of state and federal research and extension workers, growers, processors, and manufacturers, December 6 and 7, 1979, at the University of Arkansas, Fayetteville. Cost of publication provided by the Pacific Northwest Regional Commission.

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FOREWORD

The mechanization of the harvest of strawberries has been a perplexing subject of research and development for more than a decade. Although much progress has been made, the advancements have been slowed by the complexity of the problem and the diversity of adjustments in the production and handling systems needed to accommodate mechanical harvesting.

"Strawberry Mechanization" involves more than the harvest operation. Cultural systems are changed, different cultivars are needed, and post-harvest handling and cleanup become a crucial part of the system. The economics are altered and even consumer attitudes and buying habits may be affected.

This conference dealt with all aspects of strawberry mechanization. The objective of the conference was to present an up-to-date picture of research and development, recognizing at the outset that many questions remain unanswered. The unanswered questions include: (1) Should strawberry breeders continue their work in the same direction as they have to date or have more recent machinery developments altered the needed characteristics in new cultivars? (2) How will mechanizing the operations to handle this crop fit into the future prospects of the industry? (3) What are the major obstacles yet to be solved in strawberry mechanization? (4) What are economic and social impacts? (5) Should public agencies continue research in this area or should this responsibility be given to the private sector? (6) What methods are available to solve the problem of processing and marketing the total usable product from the harvester (green and ripe fruit)?

These proceedings are a record of the papers presented and serve as an up-to-date reference on the subject. The conference organizers are hopeful that the current status of work on strawberry mechanization has been brought to a clear focus, providing a sense of direction for future work. Sponsors of the conference also wish to thank the speakers for their participation, the University of Arkansas for providing the meeting facilities, the Pacific Northwest Regional Commission for assistance in printing costs, and others who helped to make the conference a success.

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CULTURAL SYSTEMS FOR MECHANICAL HARVESTING IN MICHIGAN

Larry J. Bradford, Richard L. Ledebuhr, C. M. Hansen

Summary. The cultural practices relative to growing strawberries for mechanical harvesting are discussed. These include uniformity of plant density, precise row width, level, stone-free beds, weed control, pest control, and fertilization, which are concerns of the better growers. Greater care is needed in growing crops to bring about a successful mechanical harvest.

Since the inception of mechanical harvesting of strawberries, it has been well understood that the machines alone, regardless of make, could not do a satisfactory job without modification of cultural practices. When growing strawberries, numerous factors must be considered to enhance the percentage recovery of fruit by mechanical harvesting (1).

It is necessary to plant and maintain a uniform, continuous, matted row. Skips or vacant areas in a row break up the flow of plant material and fruit in the non-air recovery machines and contribute to fruit loss. The fruit clusters in a continuous row without skips tend to lay on either side of the row, making it possible for the crop lifters to pick up the fruit much more effectively. It is more difficult for the crop lifters to recover fruit which lies in the row where skips occur because a number of the peduncles lie parallel to the row. Also, the missing plants in the row provide an opportunity for the air pick-up machines to draw dirt into the fruit. Care should be exercised in planting, in selection of planting stock, and in replanting areas where plants have not taken root.

Row widths are an important factor in the efficient recovery of fruit by mechanical harvesters. Row widths should be accurately maintained to match the uptake mechanisms of the harvesters. Generally, the row must be 20 to 30 cm (8 to 12 in) narrower than the overall opening of the uptake mechanism. This allows for fruit alongside the row to be within the opening of the machine. Fruit lying in a position outside the header width generally will not be recoverable and will be lost during harvest. Keeping the rows narrowed and confined has shown that a larger percent of fruit will set on the outside of the rows. This is a desired position for the clusters as far as optimizing harvester recovery.

Precision control of row width and spacing is very necessary where the two-row harvester is utilized. Growers have found it possible to control row width and spacing by timely application of chemicals, under shrouds of a spraying apparatus.

The harvester pick-up mechanisms perform best on a level bed. Cross flow cultivation after harvest and rolling the matted-row bed in early spring have been found useful in forming level beds. In some areas of the United States, where the raised bed concept is used, earth-forming machines can be used to form a level surface.

A good weed control program through the use of proper herbicides is mandatory. Use caution when operating conventional cultivators, for they tend to leave a cloddy, uneven bed often ridging the soil on either side of the plant row. Excess weed growth hampers the effectiveness of all harvesters. Unfortunately, in Michigan we do not yet have a sufficient range of herbicides to control weeds under all conditions. Two recently developed herbicides show promise in giving desired weed control.

It is important for the grower who wishes to use cultural practices compatible with mechanical harvesting to avoid planting in fields that contain an excessive number of stones. Stones should be removed prior to planting the crop. Rolling the field in early spring tends to reduce the possibility of stones being picked up by the harvester.

Diseases can be a problem with mechanical harvesting, particularly when the fruit is ripening. Since it is necessary to wait until a maximum number of berries is ripe, the opportunity for bacterial and fungal infection remains at a high level.

Mechanical harvesting of strawberries requires an intensive insect control program. The ripening or overripe fruit attracts a host of insects which may, if unchecked, render the fruit unacceptable by the processor.

Cross-row cultivators have proved to be an effective tool in the renovation process after harvest. These machines remove plants that have become dislodged during the harvest operation, open up the row for sunlight and air penetration, remove a good portion of the trash, and tend to level the bed.

Soil types have some effect upon successful mechanical harvesting when the floating or contact type of header is used. Plants grown on light soils tend to loosen as the header floats over the row bed. Many of these plants become dislodged and fail to regrow. This is evident in first-year fields where matted rows are not well established. Firmer soils tend to anchor plants and lessen their opportunity of being dislodged by the harvester.

We have touched upon cultural practices which are now available for mechanized harvesting of strawberries. A number of factors or concepts need to be explored in regard to their relationship to mechanical harvesting. These deal with (1) plant spacing, (2) plant breeding for new varieties, (3) fertilization, (4) irrigation, and (5) innovative means of weed control. Also, we have not yet determined the relationship between plant population and yields in the matted row.

We do not presently have a strawberry which is totally acceptable for mechanical harvesting. Plant breeders must concern themselves with development of a variety that has concentrated ripening characteristics as well as high yields. Plant breeders are well aware that the variety to be mechanically harvested must be disease resistant and have other characteristics that are compatible with this method of harvesting. Mechanical harvesting will also require development of two or more varieties capable of growing in the same area that have concentrated ripening at different times during a harvest season. This is necessary to extend the available harvest time with an early, mid, and late season ripening crop.

Microclimate within the same field, where elevation and soil types differ, will affect the ripening period. The field should be laid out to allow separate harvest of earlier ripening areas, thus preventing mixture of green and ripe fruit. More contour farming may be necessary to optimize full ripening in different areas of a field. The use of fertilizer and irrigation needs to be explored to determine their effect on those areas in the field which will cause different responses as to foliage growth and fruit ripening.

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WEED CONTROL AND RELATED CULTURAL PRACTICES FOR MACHINE-HARVESTED STRAWBERRIES

W. Arden Sheets

Summary. Control of weeds, regardless of harvest method, is one of the most important cultural practices in the economic production of strawberries. Most chemical herbicides registered for strawberries are the pre-emergent type, hence the timing of application is of utmost importance. Density of weeds is a more important consideration than weed size. Vining-type weeds such as morning glory and wild buckwheat are especially troublesome. Non-tillage is a must for machine harvesting; therefore, the herbicide program has to control not only a broad spectrum of weed species but also excess strawberry runners.

A smooth, firm, dustless surface is ideal for machine harvesting. All cultural practices should contribute to these conditions.

INTRODUCTION

Success in mechanical harvesting of strawberries starts with a full stand of plants, good weed control, proper field conditions such as a firm, smooth, dust-free ground surface, the correct row width to fit the picking mechanism, and good control of disease and insect pests. We can talk about pickers, strippers, rollers, pinchers, pullers, blowers, lifters, pluckers, and suckers from now until eternity; however, none of them will reach a high degree of efficiency when applied to a poor field. Indeed, a good mechanical concept may be discarded if not thoroughly tested under ideal situations. This is not to say that we can always grow "ideal" strawberries, but we know what needs to be done and can strive to achieve that goal.

Maximized profit from strawberry production comes from a "full" stand of plants. In the following discussion we assume to start out with this situation; however, I fully realize that all too often a "poor" plant stand is the norm.

DISCUSSION

Weed control

No single practice in the commercial production of strawberries, outside of picking, is more important than weed control. Effective weed control, particularly with perennial weeds, begins as early as one or two years before planting. Quackgrass, perennial morning glory, Canadian thistle, and red sorrel are examples of weeds that cannot be economically controlled in established strawberry fields either chemically or mechanically.

Control of weeds can be very expensive. A recent estimate in Oregon indicates that the average cost per acre in the establishment year is about $148 and lowers to $110 in producing years.[1]

In some respects the method of harvest, i.e., hand or machine, makes little difference on the necessity for good weed control. Competition for water and nutrition between the crop and weeds is the same regardless of how the harvesting is done.

With hand harvesting, the presence of weeds is a psychological and physical factor of considerable magnitude. Pickers who show up the first day of harvest may not be seen again if they are expected to work in a weed-infested field, particularly if thistles, cockleburs, sandburs, and similar spiny-type weeds are present. Besides being downright uncomfortable, these weeds cause a lower output per picker by increasing search time.

On the other hand, machines have never been heard to complain about a few thistles. If the thistles are too numerous to cut through, the header can be raised over them. The amount of fruit in such weed patches will probably be insignificant anyway.

Weed control in strawberry crops is important regardless of the growing method. It makes little difference whether strawberries are grown in matted rows, beds, single-plant hill systems, raised beds, or on flat land, irrigated or dry.

What is a weed? Perhaps the classic definition of a weed being any plant that is out of place will suffice. This is a broad definition, but is not too bad when we also need to consider superfluous runner plants as weeds. We can categorize these out-of-place plants into broadleaves, grasses, annuals, biennials, perennials, winter weeds, and summer weeds. They are all "bad" weeds, with some being worse than others.

This report will primarily consider the annual broadleaf and grassy weeds common to the strawberry-producing areas of western Oregon and Washington. Some of those species may be a factor only in the Pacific Northwest, and some may also be important in other producing areas. They are:

Broadleaf (dicots) weeds

Common chickweed (*Stellaria media*), clover (*Trifolium spp.*), dog fennel (*Anthemis cotula*), groundsel (*Senecio vulgaris*), hawksbeard (*Crepis spp.*), henbit (*Lamium amplexicaule*), knotweed (*Polygonum aviculare*), lambsquarters (*Chenopodium album*), wild lettuce (*Lactuca sp.*), red-root pigweed (*Amaranthus retroflexus*), pineapple weed (*Matricaria matricarlodes*), wild radish (*Raphanus spp.*), shepherdspurse (*Capsella bursa pastoris*), and vetch (*Vicia spp.*).

Grassy (monocots) weeds

Barnyard grass (*Echinohloa crusgalli*), annual bluegrass (*Poa annua*), yellow nutgrass (*Cyperus esculentus*), wild oats (*Avena fatua*), and annual ryegrass (*Lolium multiflorum*).

No single herbicide currently registered will control all weed species found in strawberry fields. To overcome this situation, two procedures should be considered:

1. Tank-mix combinations of two or more herbicides; and

2. Use of herbicide rotation where possible (9).

Oregon State University currently recommends use of chloroxuron (Tenoran), dinoseb, amine salts (Premerge or Sinox PE), diphenamid (Enide), napropamide (Devrinol), simazine (Princep) and 2,4-D amine or acid. These all can be used alone and some can be used in combination, such as chloroxuron plus diphenamid, simazine plus chloroxuron, and napropamide plus simazine. Simazine and 2,4-D also have been combined effectively (7).

Unfortunately, the status of chloroxuron is somewhat shaky since Ciba-Geigy is no longer manufacturing it; however, considerable quantities are in the "pipeline," so it should be available for a while. This product is the only available material that has both pre- and post-emergent activity. Treatments applied after weed emergence and before weeds are one to two inches high have been quite effective (5, 6). Addition of a wetting agent at the rate of 0.5 percent by volume has permitted a 50 percent reduction of chloroxuron without sacrificing weed control (4).

Vetch and clover infest many fields. The vining growth habit of these legume species can cause serious trouble during harvesting operations. Of the pre-emergent herbicides, diphenamid is the most effective at controlling this type of weed. After emergence, 2,4-D can be used. Rates up to 1.0 pound per acre can be tolerated safely (8). In Oregon, use of 2,4-D is recommended after harvest until August 15 and between October 15 and March 1 (2). The period between August 15 and October 15, when 2,4-D is not recommended, is fruit bud differentiation time.

Emerged broadleaf weeds can also be controlled with dinoseb applied during the dormant season. This is considered to be in the late fall following three nights of temperatures below zero degrees Celsius and before active crown growth appears in late winter.

Napropamide (Devrinol) was first registered for use in Oregon, then in Washington. Since earlier this year, it has had federal registration. One characteristic of Devrinol is its longevity. In an Oregon test on a sandy shot loam soil with 3.0 percent organic matter, excellent weed control was observed 8 months after treatment; the test area had 55 inches of precipitation during those 8 months (9). To reduce cost without sacrificing weed control, use half of the labeled rate of Devrinol combined with the full rate of simazine (9). This combination also controls a very wide spectrum of annual weed species--both broadleaves and grasses.

There is evidence that Devrinol delays pegging (rooting) down of runners; therefore, there is some reluctance to use it prior to the fall treatment in the planting year. By this time adequate runner plants have become established. If runners are not desired, then Devrinol can be used right after planting for both weed and runner control.

Due to rapid photodecomposition, Devrinol should be incorporated either mechanically or by irrigation soon after treatment. The label gives explicit instructions in this regard.

There may be some question why DCPA (Dacthal) is not considered. Although tested for many years, DCPA is ineffective against groundsel, pineapple weed, and dog fennel, all common to the Pacific Northwest. It has been said that "Dacthal is a pretty good weed killer if you combine it with a good herbicide." Dacthal plus Tenoran was very effective in controlling a wide range of weeds when Dacthal alone was a failure (4).

Runner control

This is closely related to weed control, but it is more difficult. Perhaps the best way to solve the problem is to let the runners develop into a matted row of desired width and then trim or spray off the excess. If rolling discs or colters are used, smooth out the furrow or cutter mark and then irrigate to refirm the soil surface.

Controlling excess runner growth with chemicals such as dinitro and paraquat is possible by using a directed spray behind or beneath a shield. However, problems do exist:

1. Several applications per year are necessary, and dinoseb is currently registered for use only during the dormant season;

2. Paraquat is not currently registered for any use on strawberries.

Research work should be undertaken to develop data necessary to obtain a Special Local Need registration (Section 24C) for both dinoseb and paraquat for runner control in strawberries.

Tillage

In recent years the concept of minimum-till and no-till has been developed in some agronomic crops. In the Northwest no-till is now used on many acres of horticultural crops including tree fruits, nuts, canefruits, and blueberries. Although the amount of tillage in strawberries has been reduced since the development of chemical herbicides, some cultivation is still practiced for several different reasons.

Certainly, weed control is one reason for tillage, either to rid the field of existing weeds or to incorporate a herbicide. Another reason is to maintain a dust mulch for soil moisture retention (the validity of this is a good debate topic). Also, the surface needs to be smoothed after mudding through a field with a duster or sprayer. Another reason for tillage is to "soften the ground for the picker's (hand)." Also, I have had growers say they cultivate because they "like the smell of newly turned earth."

Some strawberry growers say that tillage need only be done prior to planting, but after planting it should be strictly no-till. Personally, I think a compromise is in order.

Although much testing has been done over the years with foliar feeding and fertilizing through trickle irrigation systems, the bulk of strawberry fertilizer is still applied in dry, granular form. If phosphorus is needed, for example, it will not be foliar-absorbed from sprays and will not be very helpful when applied on the soil surface. Subsurface application is difficult without "stirring" the soil to some degree.

In Oregon, we recommend that fertilizing be done only during the summer or fall. If the soil surface is left smooth after fertilizing, irrigation or rainfall prior to the next harvest season will firm the soil.

Some erosion occurs in nearly every field, particularly during the winter months. More erosion occurs where the soil is loosened with tillage, but it also takes place in no-till situations. Some type of tillage is then necessary in the spring to re-create a smooth surface. Irrigation should follow tilling to firm the soil and "glue it together."

Several applications of various pesticides are necessary to produce high-quality strawberries. In most cases, application by airplane is not satisfactory. The alternative is to make trips through the field with a ground rig. All rigs leave tracks, deep ones under muddy conditions. Proper timing of application and dry soil conditions do not always coincide. Tillage may be necessary to smooth the soil surface.

To summarize, keep tillage to a minimum, till as shallowly as possible, leave a smooth surface, and irrigate after tilling.

Growing systems

Raised beds have been used, but they present some problems. If chemical weed control fails, there is little or no possibility of cultivation. Under Northwest growing conditions, bed erosion can cause serious problems. Also, mechanical planters are not available for raised beds. An advantage of the raised bed is that it permits strawberries to be grown on soil that may otherwise be too wet. The raised beds permit root development above the saturation zone.

The "flat" system permits cultivation if necessary and mechanical planters can be used.

Single-plant hill systems have an advantage when hand harvesting, but this may not be the case with machine harvest. Better disease control has been noted with this system because of greater air circulation and more thorough coverage when applying fungicides. However, plants in a hill system develop considerable vegetation. In Oregon, one-year-old plants of the 'Hood' and 'Northwest' varieties produced an average of 96 and 56 petioles, respectively, with an average length of 23 and 20 cm (3).

Single-plant hills are difficult to maintain because runners are difficult to control. Often, the hill-system plantings soon develop into matted rows.

Matted-row or solid-bed systems are easy to develop by letting the runners take root. Disease control may not be as good because of dense vegetation. This growing system may necessitate a slower ground speed of the harvester compared to the single-row hill system.

Whatever growing system is used, matching the width of the row or bed precisely to the width of the picking head is most critical. Fruit that extends beyond the picking mechanism on the sides of the row is lost. In many instances the rows or beds have been too wide. Apparently the length of the fruit spurs has been underestimated. In one instance, measurements on one-year-old 'Hood' and 'Northwest' plants indicated fruit spurs were 18 and 19 cm (approximately 7½") long while on two-year-old plants they were 12.4 and 13.7 cm long (3).

I appreciate the opportunity to meet with such a distinguished group of people who are working on a difficult project. Some say that mechanization of strawberry harvest will never be accomplished. I remind these folks of an old proverb, "Blessed are those that expect nothing, for they shall not be disappointed." Thank you.

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STRAWBERRY MECHANIZATION IN FLORIDA

C. M. Howard and E. E. Albregts

Summary. Mechanization of bedding, soil fumigation, and polyethylene mulch application for strawberry production has evolved in Florida over the past 20 years. Although some of the equipment now being used may have been adapted from machinery used on other crops, most of it has been designed and built by strawberry growers and local metal workers. The harvest season extends continuously over a 3- to 4-month period in Florida and all fruit is intended for fresh market use. Because of this, there is little interest in Florida in mechanical harvesting of strawberries. The only research on mechanical harvesting in Florida has been cooperative work in which researchers from other states have tested their machines on plot areas made available by researchers in Florida.

INTRODUCTION

The annual hill system of culture has been used for strawberry production in Florida for many years. In this system, individual plants are set in October or November and, except in northern Florida, fruit begins to ripen 70 to 90 days later in December or January. Fully ripe fruit is then harvested continuously on a 3- to 4-day schedule into or through April.

Soil fumigation and polyethylene mulch came into use in the late 1950's and early 1960's. For the first few years, plants were set by hand or machine and then established on previously fumigated beds. After the plants began to grow, the mulch was placed over them, slits were cut in the mulch to pull the foliage through, and soil was placed on the edges of the plastic along the sides of the bed. By the mid-1960's, nearly all growers were applying mulch at the time of the fumigation, then making holes and hand setting the plants directly through the mulch 3 to 4 weeks later.

The early equipment that was devised for bed shaping, fumigation, and mulch application was inefficient and difficult to use, and each operation had to be done separately. The first efficient equipment used for simultaneous bed shaping and mulch application was designed and built in the mid-1960's. After an initial raised bed of loose soil was made, this equipment made it possible (by attaching all equipment to the same tractor) to fumigate, shape and press the bed, and apply the mulch in one operation. Third-generation equipment is now coming into use. This equipment makes a firmer, better shaped bed, performs a more efficient job of mulch application, and eliminates the necessity of forming an initial bed of loose soil. Since none of the first-generation equipment is now in use, only the second- and third-generation equipment will be described here. These will be discussed under a "systems" approach.

DISCUSSION

Regardless of whether the older or newer bedding equipment is being used, the first operation is to mark the field lightly so the final beds will be aligned with the permanent irrigation lines. This is usually done by four or six metal rods extending downward from a tool bar mounted on the rear of a tractor. After the tool bar is lowered to a point where the rods contact the soil, the tractor moves across the field, with each rod marking the alley between adjacent beds. The tractor wheels are then run on these marks in all subsequent operations. Where fertilizer banding is not practiced, a "gandy" type spreader is used to place several streams of fertilizer on the level soil after marking is completed. This fertilizer is then incorporated more or less throughout the soil when the initial bed is made by the second- or third-generation bedder.

Fumigation equipment

Although some Florida strawberry growers still use liquid fumigants, most use MBC-33 (66% methylbromide, 33% chloropicrin). Therefore, only the equipment used with MBC will be described here. Essentially the same fumigation equipment is used in both the second- and third-generation systems.

This equipment consists of a frame attached to the tractor or bedder that holds the fumigant cylinders, a shutoff valve, and a regulator and pressure gauge, or a regulator and flowmeter, either of which can be adjusted to maintain the desired pressure of the fumigant delivered through tubes to the shanks which inject it into the soil. Orifices and check valves are placed at the tops of the injection shanks. The orifices, combined with a specific pressure setting of the regulator, ensure delivery of a specific amount of fumigant through each shank. By using proper pressure and orifice size, any desired tractor speed can be used to deliver the proper rate of chemical. The check valves prevent draining of the lines when the fumigant is shut off at the end of a row, so the fumigant flow begins almost immediately when the shutoff valve is turned on again.

Second-generation bedding system

In this system, bedding disks are used to form an initial, loose soil-bed immediately after marking is completed. Either simultaneously or in a separate operation, cultivator sweeps are run behind the rear tractor wheels to deepen the alleys and add soil to the sides of the beds. Any fertilizer to be banded in the bed is placed at the proper depth in one or more narrow bands. Fumigation and final bedding (bed shaping and pressing, mulch application) are done simultaneously with one tractor. When small tractors (20 to 30 hp) are used, the frame holding the fumigant cylinders is attached to the side of the tractor and the fumigation shanks are attached under the center of the tractor. The bedder is then attached to the rear of the tractor. When larger tractors (40 to 70 hp) are used, the frame holding the cylinders is attached to the front of the tractor or forms an integral part of the bedder and the fumigation shanks are built onto the front of the bedder.

The bedder is constructed from sheet metal. The front of the bedder curves upward and rises about 20.3 cm (8 in) above the bottom (or pressing plate) of the bedder. The pressing plant is about 70 cm (2 ft) long and is shaped so that the center of the final bed will be crowned 2.5 to 5 cm (1 to 2 in) higher than the outer edges when beds are designed for two rows of plants. The pressing plate forms a flatbed top when wider beds designed for four rows of plants are used. A metal runner 12.7 to 20.3 cm (5 to 8 in) deep and about 10.2 cm (4 in) wide is attached underneath the pressing plate on each side. These runners form a trench on each side of the bed. A roll of polyethylene mulch is mounted on rollers near the rear of the bedder and feeds out onto the bed as the tractor moves forward. Floating rubber wheels attached to arms on the rear of the bedder press the edges of the mulch into the trenches made by the runners. Covering disks, attached to arms extending along the sides to a distance approximately 91.4 cm (3 ft) behind the rear of the bedder, then move soil into the trenches and cover the edges of the mulch immediately behind the wheels. The arms are attached to the sides of the bedder at its approximate center and pivot in the vertical plane. Stops attached to the sides at the rear limit their downward movement. Thus, the covering disks are free-floating to some degree, but can be raised free of the soil when the bedder is lifted. The rubber wheels and the covering disks are adjustable in all directions to compensate for different soil conditions. A weight or spring-loaded arm keeps tension on the top of the roll of mulch to stretch it slightly along the bed as the rubber wheels stretch it across the bed, thus insuring a tight fit over the bed.

As the bedder is pulled over the initial loose beds, the front of it is maintained slightly higher than the rear. Thus, the front of the bedder pushes soil off the bed, the pressing plate compresses it downward, and the runners compress it inward. By lowering or raising the bedder with the tractor hydraulics, more or less soil is pushed off the bed, and the final bed height can be varied from approximately 7.6 to 20.3 cm (3 to 8 in).

The main disadvantage of this bedder is that it will not perform properly unless the soil moisture is within an optimum range. If the soil is too dry, the shoulders of the bed will collapse before the mulch is pressed into the side trenches. The resulting beds will be poorly shaped and the edges of the mulch will not be buried to the optimum depth. If the soil is too wet, the mulch repeatedly slips out from under the wheel on one side or the other. This necessitates frequent stops and machinery adjustments (usually none of which remedy the problem until the soil dries somewhat). Wet soil also cakes in spots on the pressing plate or runners and prevents proper bed formation. Most of the caking problem has been eliminated by attaching sheet plastic to the underside of the plate and the inner sides of the runners. Another disadvantage of this bedder is that it magnifies any imperfections in straightness of the initial beds, at times causing crooked rows that may interfere somewhat with later operations (hold punching, spraying, and cultivating the alleys).

Third-generation bedding system

This system eliminates the necessity of forming an initial, loose soilbed. After any broadcast fertilizer has been tilled in and the alleys are marked, the bedders are used directly on the level fields. However, bedding and mulch application are usually performed in separate operations.

The third-generation bedders are constructed of plate steel and are much sturdier than the second-generation bedders. They consist of a pressing plate and side plates that usually extend downward 15.2 to 25.4 cm (6 to 10 in). An extension on the front of each side pulls in soil from about 30.5 cm (1 ft) on each side of the final bed area. The soil is funneled through the bedder and is compressed very firmly downward and inward. Some of this bedding equipment is designed to form two or three beds at a time.

The third-generation bedders must be used on relatively wet soil to form the beds properly. They form very firm, straight, nearly perfectly shaped beds, but tractors of 40 or more horsepower are required to pull them.

After the beds are made and fertilizer to be banded is placed in the beds, fumigant is injected into the beds by attaching the injection shanks to the front of the bedder or using a separate identically shaped machine of lighter construction. Light pressing during this operation eliminates trenches made during fertilizer application and seals in the fumigant.

The third-generation mulch applicators are normally used in a separate operation after fumigation. They are of metal frame construction with rubber guide wheels that run against the perpendicular sides of the bed to keep them exactly centered over the bed. Rubber wheels also hold the edges of the mulch down until covering disks place soil on them. The covering disks face almost directly downward, so they place only a thin layer of soil approximately 2.5 to 5 cm (1 to 2 in) deep on the edges of the mulch. Distance from the shoulder of the bed to the soil is then approximately 10.2 to 22.8 cm (4 to 9 in), and any fruit that hangs over the edge of the bed later generally does not come in contact with soil.

Two rolls of mulch are carried on these applicators. As the end of one roll is reached, a person riding on the applicator feeds the end of the second roll into the applicator simultaneously with the last 1 or 2 m of the first roll. There is only a slight hesitation in forward movement as a new roll is started.

There are several variations in the third-generation equipment. In some instances the fertilizer banding equipment is combined with the bedder and in other instances the fumigation equipment is combined with either the fertilizer banding equipment or the mulching equipment. With any of these options, two operations are completed in one pass over the bed. The third-generation equipment does a considerably better job of bedding and mulch application than the second-generation equipment does, but larger, more powerful tractors are required to operate it.

RESPONSE OF SEVEN STRAWBERRY CLONES TO HAND PICKING PRIOR TO ONCE-OVER MACHINE HARVEST

J. R. Morris, S. E. Spayd, D. L. Cawthon,
A. A. Kattan, and G. S. Nelson

Summary. Four of the seven clones tested did not benefit in total yield from one or two hand pickings prior to once-over machine harvest. Four of the clones could be hand picked once without a significant reduction in machine-harvested yields. 'Sunrise' increased in total yield with hand harvesting but fruit were soft and poorly colored. 'Cardinal' had fruit quality and a ripening pattern suitable to a combination of hand and machine harvesting. The composite once-over machine-harvested fruit after one or two hand pickings showed the same or higher soluble solids, shear-press firmness, puree viscosity, and color intensity as hand-harvested fruit. In clones with high-quality fruit, the presence of immature fruit in the once-over harvest did not detract from puree color or flavor acceptability. A-5344 possessed both yield and quality characteristics desired for a completely mechanized harvest for processing.

INTRODUCTION

The mechanical strawberry harvester developed at the University of Arkansas and now being used by the commercial processing industry along with an in-plant cleaning line is based on once-over harvest (9, 10). Other workers (1,2,3,4,12,14) have tested experimental harvesters which utilize the once-over harvest concept. This study was conducted to determine whether some clonal types would benefit in total yield and fruit quality by use of one or two hand pickings prior to the once-over mechanical harvest.

MATERIALS AND METHODS

The study was conducted during 1977 in a 4-year-old, matted-row strawberry planting at the Main Station, Fayetteville. Field plots were 4.6 m long with 4.6 m skips between plots. Row spacing was 120 cm with 60 cm of flat surface on top of the beds for production.

Seven clones were tested for their response to hand picking before once-over machine harvest with a one-row model of the University of Arkansas-Blueberry Equipment Company, Inc. (BEI) strawberry harvester. The clones were selected on the basis of traits suited to mechanical harvest (10). 'Cardinal' and 'Earlibelle' were selected for their high-yielding capabilities. 'Sunrise' was used because of its high yields and its ability to concentrate fruit ripening (8). A-5745, a sister breeding line to 'Cardinal', had many of the same yield and fruit quality characteristics as 'Cardinal'. A-5344, A-5350, and A-5309 were selected on the basis of their tendency to concentrate fruit ripening.

Plots were either not hand picked (OHP) or hand picked once (1HP) or twice (2HP) before machine harvest. The 1HP and 2HP plots were hand picked the first time on May 9 and the 2HP plots were picked a second time on May 13. The OHP plots of 'Sunrise,' A-5350, and A-5309 were machine harvested on May 12; 'Earlibelle' and A-5344 on May 13; and 'Cardinal' and A-5745 on May 16. All 1HP plots were machine harvested on May 17; all 2HP treatments were machine harvested on May 20 except 'Sunrise' (May 18). A completely randomized field design with eight replications was used (Fig. 1).

After hand-picked fruit from each plot were weighed and washed, a sample was sealed in a 211 x 400 can and immediately frozen. A 100-g sample of decapped fruit was used to determine firmness by shearing on an Allo-Kramer shearpress. Machine-harvested fruit from each plot were weighed prior to washing, cleaning, and sizing on the University of Arkansas in-plant cleaning line (10). Fruit in each size category (small = mostly green and large = mostly ripe) were weighed and 100 g of decapped large fruit were sheared to determine firmness. Composite samples of machine-harvested fruit were recombined on a percent weight basis using the small and large size categories, and a sample from each plot was sealed in a 211 x 400 can and frozen for later analysis.

Hand-picked fruit and composite samples of machine-harvested fruit were sealed in 303 cans and frozen for taste panel evaluation. Prior to sensory evaluation, fruit were thawed and pureed, and sugar was added with a fruit-to-sugar ratio of 4:1. Flavor was rated by five trained panelists on a scale of 1 to 5, with 5 = best and 3 = marginally acceptable.

Percent soluble solids, acidity, viscosity, and Gardner Color and Color Difference Meter tangent^{-1} b/a values were determined as described by Morris and others (10).

RESULTS

Main effects showed that hand picking once or twice before machine harvest increased total yields (Fig. 2). This increase did not occur for all clones, however. Hand picking before machine harvest did not significantly increase total yields of 'Earlibelle,' A-5344, A-5745, or A-5350.

Total yields of 'Cardinal' and A-5309 benefited from one hand picking but there was no further benefit from a second hand picking. 'Sunrise' was the only clone that had significantly higher total yield with two hand pickings before mechanical harvest.

No relationship was found between high-yielding clones and gain in total yield from hand picking before machine harvest, since a gain from hand picking was obtained from both a low (A-5309) and a high ('Sunrise') yielding clone. The yield gain with hand picking probably resulted from harvest of early ripening soft fruit before they decayed. Therefore, clones that did not gain in yield from hand picking before machine harvest may prove to be clones that possess fruit with good field-holding characteristics. 'Sunrise' and A-5309 benefited greatly from hand picking, and both have soft fruit.

Figure 1. The 1973 model of the University of Arkansas-Blueberry Equipment, Inc. (U. of A.-BEI) harvester operating on one of the 168 research plots used in this study. Beds were shaped as described by Morris (10) to form a flat surface that aids in maintaining the harvester's high picking efficiency. When averaged across the three hand-picking treatments and eight replications, picking efficiency between the seven clones ranged from 94 to 95 percent. Hand picking prior to machine harvest slightly improved the picking efficiency of 'Cardinal', 'Earlibelle', and A-5745.

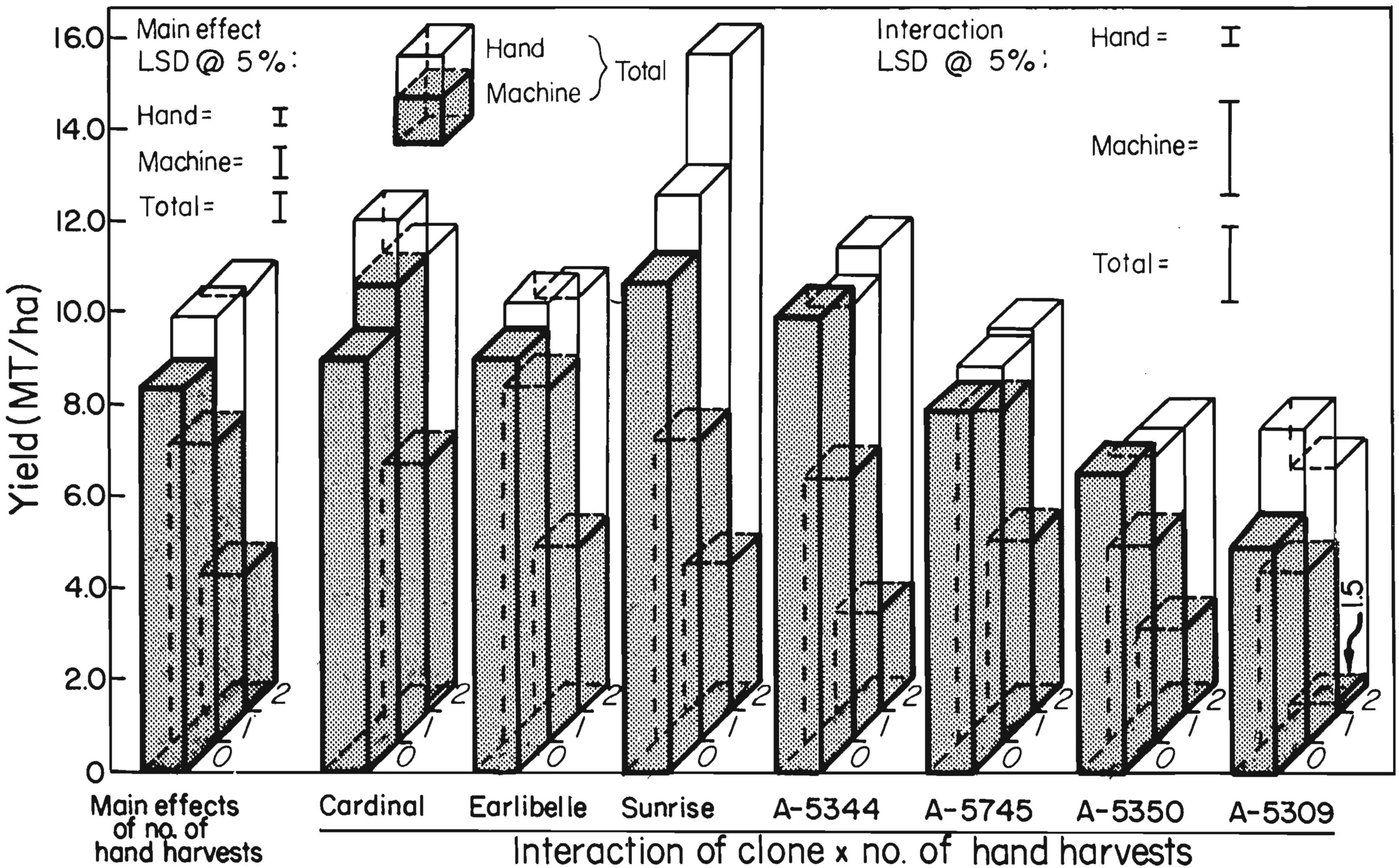

Figure 2. Main effects of 0, 1, and 2 hand harvests prior to once-over machine harvest and the clonal interaction on machine, hand, and total yield of seven strawberry clones.

As expected, the main effect of hand harvesting was a reduction in yield of machine-harvested fruit with each hand harvest. However, 'Cardinal', 'Earlibelle', A-5745, and A-5309 could be hand picked once with no significant reduction in yield of machine-harvested fruit. After two hand pickings the machine-harvested yield of all clones had been reduced, but 'Cardinal', 'Earlibelle,' 'Sunrise', and A-5745 still had relatively high machine-harvested yields (6.7, 4.9, 4.6, and 5.1 MT/ha, respectively. 'Sunrise', A-5344, and A-5309 had the smallest percent of machine-harvested fruit after two hand pickings, suggesting that fruit of these clones ripened earlier and had a more concentrated ripening pattern. The behavior of 'Sunrise' was in agreement with results of Moore and Brown (8). Low yielding, concentrated ripening clones like A-5309 would have questionable suitability for hand picking prior to once-over harvest.

The machine picking efficiency [machine picking efficiency = (wt. of machine-harvested fruit) ÷ (wt. of machine-harvested fruit + fruit left by machine) x 100] did not differ significantly between clones (ranging from 94 to 95%), but hand picking prior to mechanical harvesting slightly improved harvesting efficiency of some clones. Clones with the largest primary fruit (data not shown)--'Cardinal', 'Earlibelle' and A-5745--increased in picking efficiency by four percent when the large, early ripening fruit were picked by hand. These large, heavy, primary berries were probably not as accessible as the remaining fruit to the pneumatic lift of the machine's picking head.

Raw product quality

Hand picking either once or twice increased percent ripe berries (by weight) in the once-over machine-harvested fruit when means were pooled across clones (Table 1). 'Cardinal' was the exception by requiring two hand pickings prior to machine harvest to increase percent ripe fruit. Visual observations indicated there was a longer time lapse for 'Cardinal' than the other clones between ripening of large primary fruit and the remainder of the crop. Therefore, one hand picking of 'Cardinal' was necessary before the majority of the crop entered the ripening pattern exhibited by the other six clones.

When means were pooled across the seven clones, one hand picking was required for machine-harvested fruit to have equal or higher percent soluble solids than hand-picked ripe fruit (Table 1). An increase in the leaf-to-fruit ratio as a result of hand picking prior to once-over mechanical harvest might explain the increase in percent ripe fruit and soluble solids. 'Cardinal', which had a different ripening pattern, was an exception since it required two hand pickings before the level of soluble solids were equal to that of hand-harvested fruit.

Main effects for acidity showed that hand harvesting prior to machine harvest resulted in mechanically harvested fruit of significantly higher acidity than hand-harvested fruit or once-over harvested fruit not preceded by hand picking (hand harvested = 1.06%, OHP = 1.04%, 1HP = 1.11%, and 2HP = 1.14%, expressed as percent citric). This difference would not be commercially important.

Table 1. Main effects of harvest method and the interaction of clone x harvest method on strawberry fruit quality

Treatment	Ripe fruit (%)	Sol. solids (%)	Shear (kg/100g)	Viscosity (sec/25rev)	Color		Flavor[y] (1-5)
					Tan-1 b/a[z] (rad)	Visual[y] (1-5)	
Harvest Method							
Mach. harv. OHP	73	5.9	42	14	.39	4	4
1HP	89	6.8	36	22	.37	4	4
2HP	90	7.6	36	93	.36	4	4
Hand picked	--	6.6	33	9	.37	4	4
LSD @ 5%	2	0.2	6	19	.01	NS	NS
Clone x Harvest Method							
Cardinal							
Mach. harv. OHP	79	6.3	41	17	.37	5	4
1HP	77	6.3	32	15	.37	5	4
2HP	88	6.9	45	55	.35	5	4
Hand picked	--	6.9	34	8	.36	5	4
Earlibelle							
Mach. harv. OHP	78	5.8	57	15	.41	4	4
1HP	93	6.3	28	20	.37	4	4
2HP	91	6.9	28	60	.36	4	4
Hand picked	--	6.0	27	8	.37	5	4
Sunrise							
Mach. harv. OHP	74	5.7	19	4	.42	3	4
1HP	94	6.9	18	8	.39	3	3
2HP	93	7.1	25	11	.39	3	4
Hand picked	--	6.4	19	4	.40	3	3

Table 1 (continued)

Treatment	Ripe fruit (%)	Sol. solids (%)	Shear (kg/100g)	Viscosity (sec/25rev)	Color: Tan^{-1} b/a[z] (rad)	Color: Visual[y] (1-5)	Flavor[y] (1-5)
A-5344							
Mach. harv. OHP	81	5.7	75	14	.39	4	4
1HP	96	7.1	64	15	.37	4	3
2HP	92	8.1	56	103	.35	4	4
Hand picked	--	6.5	55	10	.37	4	3
A-5745							
Mach. harv. OHP	70	6.1	45	20	.37	4	4
1HP	88	6.4	57	19	.37	4	4
2HP	93	7.2	43	86	.35	4	4
Hand picked	--	6.7	39	9	.38	4	4
A-5350							
Mach. harv. OHP	64	5.6	40	15	.37	4	4
1HP	81	6.8	41	64	.37	5	4
2HP	93	8.0	35	181	.35	5	3
Hand picked	--	6.2	42	14	.36	5	4
A-5309							
Mach. harv. OHP	72	6.9	14	9	.42	3	4
1HP	92	7.8	13	7	.40	3	4
2HP	87	9.3	20	154	.37	3	3
Hand picked	--	7.6	14	5	.39	3	3
LSD @ 5%	6	0.5	16	50	.01	1	1

[z]Lower tan^{-1} b/a values indicate better color (6).

[y]A scale of 1 to 5 was used, with 5 = excellent and 3 = marginally acceptable color and flavor.

Fruit firmness is important since fruit integrity is lose when soft fruit is handled over an in-plant cleaning and grading line. Only large fruit of all treatments were used to determine resistance to shear since this fruit has the greatest potential for reductions in fruit integrity. When means were pooled across clones, firmness of hand-harvested fruit ancd machine-harvested fruit preceded by one or two hand pickings were softer than machine-harvested fruit not preceded by hand picking (Table 1). This difference was a result of extremely firm, once-over machine-harvested 'Earlibelle' and A-5344 large fruit. Regardless of harvest method, A-5344 had the firmest fruit that handled the best of all clones during the cleaning and grading operations. For all harvest methods, 'Sunrise' and A-5309 had soft fruit that did not handle well across the cleaning and grading line.

High viscosity values are considered desirable by the puree processing industry. Two hand pickings prior to once-over harvesting resulted in a puree voscosity higher than the other three harvest methods (Table 1). This was especially true for A-5344, A-5350, and A-5309. 'Sunrise' had extremely poor viscosity for all harvest methods.

Two hand pickings prior to once-over machine harvest resulted in superior puree color, as indicated by lower $\tan^{-1}$ b/a values, and this was true for all clones (Table 1). However, it was visually impossible to distinguish color differences between the 4 harvest methods except for 'Earlibelle' and A-5350. For all of the harvest methods, 'Cardinal' had excellent visual color ratings, while 'Sunrise' and A-5309 had marginally acceptable visual color. High color ratings for 'Cardinal,' which has ripe fruit of high anthocyanin content (11,13), were attained even though only 79 percent of the machine-harvested fruit was ripe after no hand picking and 77 percent after one hand picking. In comparison, hand-picked (100% ripe) 'Sunrise' and A-5309 rated only marginal visual color acceptability. Previous work has shown that as much as 50 percent immature, green fruit can be used in the manufacture of preserves and jams without seriously affecting quality in clones with high anthocyanin levels, such as 'Cardinal,' 'Earlibelle,' and A-5344 (11.13).

When means were pooled across clones, puree flavor was unaffected by harvest treatment (Table 1). There were significant but unexplainable differences for the interaction of clone and harvest method. However, these data illustrate the flavor acceptability of puree prepared from composite samples of once-over machine-harvested fruit.

DISCUSSION

For once-over mechanical harvest, strawberry clones should have high yields of highly colored, good quality ripe fruit with sufficient firmness for handling across an in-plant cleaning and grading line. Three of the seven clones tested were not suited to machine harvest, with or without hand picking before the once-over operation. Although 'Sunrise' has high yields and a concentrated ripening pattern, its poorly colored fruit was too soft for proper handling in an in-plant cleaning and grading line. Both A-5350 and A-5309 had low yields regardless of harvest method. Clones that have high yields and do not concentrate fruit ripening, such as 'Cardinal,' 'Earlibelle,' and A-5745, can be hand picked once without a significant reduction in machine-harvested yield.

In a once-over harvest operation, the early ripening primary fruit of 'Cardinal' are sacrificed to decay to allow for the majority of the crop to ripen. Such a fruit-ripening pattern was not found in the other clones tested. On this basis, 'Cardinal' represents a clone that would be suited to a combination of hand and machine harvesting. This is in agreement with Moore and others (7) since preliminary tests indicated that 'Cardinal' was suited to hand picking and to once-over machine harvesting for processing in Arkansas. 'Linn' exhibits many of the same fruiting characteristics in the Pacific Northwest (5).

Hand picking A-5344 before once-over machine harvest was not necessary because of its concentrated fruit-ripening pattern and superior firmness and field-holding capability. Although this clone has poor vegetative growth and runner plant production, it possesses the fruiting characteristics desired for a completely mechanized harvest.

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BREEDING STRAWBERRIES FOR HARVEST MECHANIZATION IN ARKANSAS

J. N. Moore and W. A. Sistrunk

Abstract. Breeding strawberries for adaptation to mechanization presents some unique problems. Characters that should be considered in breeding are: concentration of ripening, maximum productivity, ease of fruit detachment, and fruit firmness, color, and processing quality. In addition, such generally important characteristics as disease resistance and climatic adaptation must not be overlooked. Season of ripening should be considered to provide a series of cultivars to be once-over machine harvested at different times in the season for greater machine utilization.

INTRODUCTION

Commercial strawberry acreage in Arkansas, and in most other states in the U.S., has been on a slow, but steady decline for three decades. The most important factors contributing to this decline have been high harvest labor costs and lack of sufficient harvest labor. These problems have stimulated research on methods of mechanized harvest at several experiment stations. Research on machine design and cultivar modification for mechanically harvesting strawberries has been conducted at the Arkansas Agricultural Experiment Station since 1967.

Breeding strawberries for adaptation to mechanized harvest presents some unique and difficult barriers. The fruit of the strawberry is very delicate and requires gentle handling. Furthermore, the fruit is borne near the ground, making retrieval by machine difficult and limiting the systems available for fruit removal. Perhaps the greatest obstacle, however, is the nature of the fruiting habit of the strawberry. Fruits borne at different positions on the cymose inflorescence ripen at different times, resulting in an extended period of fruit maturation. This presents a major problem in developing cultivars adapted to once-over harvest. The following are some of the characters being investigated in relation to genetic modification of the strawberry for harvest mechanization.

PLANT CHARACTERS

Concentration of ripening

Since most strawberry harvesters are designed for 'once-over' harvest, utilizing a stripping principle, concentrated maturity appears to be of paramount importance. The development of concentrated ripening types is a major objective in several strawberry breeding programs and evaluation of

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concentration of fruit ripening at specific times during the harvest season is a routine procedure (1,6,7,8,11,18). Concentration of ripening is under genetic control and amenable to improvement through breeding (7). Early rpiening clones tend to transmit a higher degree of concentrated ripening to their offspring (8).

High productivity

While concentrated ripening is considered important in mechanical harvesting of strawberries, Moore and others (12) have pointed out that the major breeding objective is to develop cultivars producing high yields of acceptable fruit at a specific time. The actual usable yield at a given time is the product of the percent of the fruit that is ripe and the total amount of fruit on the plant. Thus, increasing either the concentration of ripening or the total volume of fruit on the plant will result in greater usable yields of fruit. Moore and others (12) point out, for example, that 'Cardinal,' with a concentrated ripening percentage of only 38 percent but a total yield of 27,642 kg/ha, produced a usable yield of 10,504 kg/ha in a once-over harvest compared to Ark. 5085, which had a higher concentration of ripening (52%) but a much lower total yield (10,526 kg/ha), resulting in a usable yield of only 5,474 kg/ha. 'Cardinal' has been reported to produce the highest usable fruit yield following mechanical harvest in other tests (14). High positive correlations have been reported between high once-over yields and high seasonal yields by conventional harvest (1,12).

FRUIT CHARACTERS

Fruit detachment

The strawberry fruit has no natural abscission layer. At harvest, the fruit is removed either with the calyx attached to the fruit because of pedicel breaking, or with the calyx attached to the pedicel and pulled away from the fruit (capping). Differential capping force of ripe and unripe fruits has been suggested as a possible method of selective harvest of ripe fruits in a multiple harvest system (10). Genetic sources of "easy" capping have been identified (4,5,8), methods of objectively measuring required forces developed (3), and inheritance of fruit detachment determined (2,8). Successful development of a cultivar with mature fruit that can be removed with very little force could result in a multiple harvest system in which all fruit could be removed at the optimum stage of maturity.

Fruit firmness

Firmness of fruit is perhaps the most important fruit character in relation to mechanical harvest. Fruit must be firm enough to be collected by the machine, pass through the cleaning and grading process, and still be in good condition for processing. Also, firm berries will hold better in the field, allowing a longer delay in harvest for more fruit to ripen (13).

The development of cultivars resistant to fruit rot would have a similar effect (1). Physical and chemical factors relating to strawberry fruit firmness and methods of testing for fruit firmness will be discussed elsewhere in this Proceedings. In our work, firmness has been shown to be subject to genetic improvement, and firm parents tend to transmit the character to their offspring.

Fruit quality

Mechanically harvested strawberries are presently used for processing. The fruit must, therefore, have those characteristics that produce an acceptable processed product. A strawberry cultivar that can be mechanically harvested but is inferior in processed quality is of no value to the industry.

Fruit firmness and color are perhaps the major quality attributes required for processing cultivars (15,16,17). These characters, along with other important quality characteristics, are discussed elsewhere in this Proceedings. Food value is an important quality component and should receive more attention in future breeding. For example, strawberry clones vary greatly in ascorbic acid content, and inheritance of this character has recently been reported (9).

Other fruit and plant characters

In selecting for mechanical harvesting, routine breeding objectives such as disease resistance and climatic adaptability must not be overlooked. Also, time of fruit ripening may take on additional importance. A series of cultivars that can be once-over harvested at different times during the season are necessary for more efficient machine usage and to spread the volume coming to the processing plant.

EVALUATION OF SELECTIONS

Annual evaluations are made of many plant and fruit characters of all selections in the Arkansas breeding program. Subjective evaluations are made in the field of firmness, color, and disease resistance. Replicated trials at several locations provide yield data. Concentration of ripening is determined by harvesting usable fruit at specific times during the season (11).

Extensive objective and subjective evaluations of the quality of fresh and processed fruit are conducted annually in cooperation with horticultural food scientists (15,16,17). The results of these tests are important not only for determining selections to release as new cultivars, but also for making genetic advance in the breeding program (16).

Selections that have been determined to have good production and processing qualities and appear to have promise for mechanical harvest are entered in replicated trials for actual harvest by machines and once-over yields and quality are determined (13,14).

ACCOMPLISHMENTS AND PROSPECTS

In 1974, the cultivar 'Cardinal' was released by the Arkansas Agricultural Experiment Station partly because of its adaptability to machine harvest. 'Cardinal' has been reported to yield 7.8 tons per acre of usable fruit in a once-over harvest operation (14). Furthermore, it has been superior in all tests of processing quality (17).

Several selections have been identified that are prepotent for certain characters. Ark. 5344, for example, is extremely firm fruited and transmits that character in breeding. A number of selections have superior processing qualities (17).

The past development and identification of superior genotypes for mechanical harvesting is expected to accelerate future breeding progress. However, successful production of superior cultivars for mechanized harvest can be accomplished only through a team effort of plant breeders, engineers, and food scientists.

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BREEDING STRAWBERRIES FOR MACHINE HARVEST IN THE PACIFIC NORTHWEST

F. J. Lawrence and L. W. Martin

Summary. Thirty-seven strawberry cultivars and selections were evaluated for effectiveness as parents in transmitting traits that will facilitate machine harvest. The most effective parents were the cultivars (cvs) 'Totem,' 'Benton,' 'Linn,' 'Olympus,' and five selections from the cooperative Oregon State University-USDA (OR-US) breeding program. Data were collected on these traits: 1) capping ease; 2) concentrated ripening; and 3) fruiting habit. 'Olympus' and OR-US 4637 were effective in transmitting capping ease; 'Totem,' 'Benton,' OR-US 4637, and OR-US 4003 transmitted good fruit support; none were especially effective in transmitting concentrated ripening.

INTRODUCTION

The strawberry processing industry of the Pacific Northwest is still dependent on hand harvest for its raw product. The reasons for research into harvest mechanization for this industry have been clearly set forth in prior publications (2,8,12). But the rapid rise of production costs caused by inflation, labor, and pesticide regulations have surpassed previous estimates. Total strawberry production costs for one year in Oregon (Washington County) have increased by more than 38 percent since 1975 (6,13), with harvest costs increasing more than 50 percent.

The Oregon strawberry industry has supported work in the machine harvest and handling of strawberries through the Oregon Strawberry Commission since 1967. Part of this work is directed toward the introduction of new cultivars adapted to this type of harvest. New cultivars that maximize fruit production and quality are needed to fit the system of mechanized harvest and handling. New cultivars in the United States, such as 'Stoplight' (5) from Iowa, 'Cardinal' (11) from Arkansas, and 'Linn' (8) from the cooperative Oregon State University-USDA program, have been introduced for machine harvest trials.

This paper summarizes some of the cooperative USDA-Oregon strawberry breeding work related to mechanical harvest for the period 1976-1979.

MATERIALS AND METHODS

Parents were selected on the basis of previous breeding performance and test crosses were made with cvs or selections showing some specific trait that appeared useful for machine harvest. Traits such as capping

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ease, fruiting habit, and crop concentration were recorded for certain cross progeny and selected parents.

Each year mechanized harvest and processing were completed on certain cultivars and promising selections from the cooperative USDA-Oregon program and other stations, especially selections from the British Columbia (BC) breeding program. Usable fruit yields from these harvests were also considered in parent evaluations. The industry-suggested minimum of usable yield was designated as 8.96 MT/ha (4 t/a), up from the previous goal of 6.72 MT/ha (3 t/a)(6).

Capping ease

All parents and some progeny were rated for capping ease by one or more of three methods: 1) with a battery-operated, portable field capper, 2) by the OSU capper-stemmer in the Food Science Pilot Plant, or 3) by hand separation. The portable field capper had two rollers similar to the processing lab capper and could handle single fruits with an attached stem. Progeny ratings were made by randomly selecting 20 plants from a cross and scoring the capping index of 10 ripe fruits harvested with the calyx and pedicel intact from each plant. A capping index of 1 to 10 was used, with 1 being very easy to cap and 10 very difficult to cap. Although several categories of separation were recorded, only two classes were considered critical: capped and uncapped.

Fruiting habit

This character indicates the ability of the main stem or peduncle to support ripe fruit above the ground when more than 50 percent of the fruit on the inflorescence was mature. This was a visual estimate, scored on the basis of 0 to 9 (0 = completely prostrate and 9 = all ripe fruit supported above the ground).

Concentrated ripening

This trait was estimated by the percentage of fruit ripe at one time. For nonharvested clones, a visual score was made on a scale of 0-9: 0 = 0 to 9 percent ripe and 9 = 90 to 100 percent ripe. Ratings were made on at least two dates. For replicated plots the rating was calculated on the basis of the greatest single hand-harvested yield as a percentage of the total yield. For once-over, machine-harvested plots, the rating was determined as the ratio of ripe fruit to total yield after stemming (8).

RESULTS AND DISCUSSION

The majority of the strawberry selections, with machine-harvest traits, had at least one of the following nine clones as one parent: 'Benton,' 'Linn,' 'Olympus,' 'Totem,' OR-US 3965, OR-US 4003, OR-US 4350, OR-US 4596, or OR-US 4637 (Table 1). This does not mean the other parents used during this period did not contribute valuable traits to their seedling progeny. An example is OR-US 4233 (OR-US 2931 x 'Alaska Pioneer').

It was outstanding in providing easy-cap seedlings, but the fruits were completely unsatisfactory for color and firmness with every combination.

Capping ease

East of capping is one of the most important traits in selections for machine harvest, and all nine prime parent clones were assigned a capping index for a period of 2 years, to determine their possible contribution to seedling progeny (Table 2). 'Olympus' was a good parent in transmitting capping ease and may be different genetically from the other clones. Different genetic systems were proposed by Brown and Moore (3), although selecting parents on the basis of phenotype was suggested by Barritt (1) as a method of producing easy-cap progeny.

The other eight parents did not show evidence of transmitting capping ease beyond that expected for their capping index. 'Olympus' is usually combined with other parents that have firm fruits and lower capping indices. However, 'Olympus,' with a mean capping index of 7.5, had 14 percent of the F_1 seedlings exceeding this value. This could be important in obtaining large populations of easy-capping types. The performance of 88 clones on the portable field capper was measured against the OSU capper-stemmer over a 2-year period. The correlation coefficient was $r = 0.464$, significant at the one percent level. Although this r value is significant, the portable field capper was no more effective than the hand ratings for selecting the best capping types for the capper-stemmer.

Fruiting habit

The fruiting habit of the strawberry is especially important in recovery of fruit in the mowing method of harvesting. The closer the mature fruit is to ground level, the lower the recovery percentage. Previous breeding for types that supported ripe fruit above the ground resulted in selections with lower yields, primarily because of smaller and fewer berries per inflorescence (10).

A certain amount of fruit accessibility may be supplied by cultural practices (2). A high-yielding but mostly prostrate cultivar, such as 'Olympus,' may be harvested satisfactorily by mowing utilizing special cultural techniques and plastic mulch. 'Totem,' 'Benton,' OR-US 4637, and OR-US 4003 support a number of mature fruit above the ground and fruit recovery percentages from mowing harvests range from 70 for 'Benton' to 82 for OR-US 4637. Other selections and cultivars used as parents had fruit recovery percentages ranging from 60 for OR-US 4350 to 74 for 'Linn.'

Fruit recovery rates of at least 85 percent are not unrealistic and are essential to obtain good yields for the mowing method of harvesting. The better the fruit support, the better the association with a high percent of fruit recovery. However, a clone with well-supported fruit may fail to have good recovery. An example is a clone with a brittle pedicel that snaps from the vibration of the cutter bar, causing individual fruits to drop to the ground. The degree of association between fruiting habit and recovery percentage is shown by a coefficient of determination of $r^2 = .688$, $n = 163$, significant at the one percent level. Ratings of seedling progeny indicate the parents 'Linn,' 'Olympus,' OR-US 3965, OR-US 4350, and OR-US 4596 were not effective in providing seedlings with erect fruiting habits.

Concentrated ripening

Usable fruit yields of 8.9 MT/ha cannot be obtained without a high percentage of the fruit ripe at one time. Concentrated ripening increases efficiency through less waste, and better product utilization provides advantages important to the processor.

The nine parent clones ranged in concentration of ripening from 75 percent for OR-US 4637 to 61 percent for OR-US 3965 and OR-US 4350 (Table 3). This range is well below the goal of 90 percent (7) that will be necessary for efficient handling in the processing plant, although certain products may utilize some nonripe fruit (11). For the OR-US crosses rated in 1976-1978, none of the nine parents appeared to transmit any increase in concentrated ripening to their seedling progeny beyond what might be expected, because none of the nine parents exceeded 75 percent ripe fruit at one time.

BC 70-17-12, recently named 'Tyee' (4), was evaluated by machine harvest in 1976-1977 and in 1979 and has exceeded 85 percent of ripe fruit in a once-over harvest. It also has good processing qualities. This cultivar should be valuable in future breeding for machine-harvest types.

The examination of nine parents has shown many good traits such as capping ease and productivity transmitted to progeny and no single superior trait, other than the capping ease of 'Olympus.' Therefore, after rapid initial gains in concentrated ripening and capping ease, progress toward greeding cultivars that fit a machine harvest and handling system will be controlled by yield and quality factors. This has been brought about by increasing usable fruit yields and fruit quality to combat increased costs and to provide a competitive product.

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Table 1. Important parents in USDA-Oregon State University strawberry selections for machine harvest, 1976-1978[1]

Parent	Number of crosses	Percent of parent in pedigree of all selections [2]
Totem	23	24.5
OR-US 4003 (MD-US 3184 x OR-US 2414)	13	24.0
OR-US 3965 (Earlibelle x Hood)	11	23.0
Benton	15	19.0
Olympus	22	18.5
OR-US 4350 (MD-US 2927 x Shuksan)	12	14.5
Linn	17	13.0
OR-US 4596 (OR-US 3653 x OR-US 2931)	5	10.0
OR-US 4637 (Senga Precosana x OR-US 3708)	6	3.5

[1]Based on the percentage of parent in the pedigree of the sections.

[2]Totals more than 100% due to intercrossing prime parents.

Table 2. Summary of capping-ease indices of nine prime parents in USDA-Oregon State University strawberry breeding program, 1976-1978

Parent	Capping index[1] for parent	Number of crosses	Capping index of all other parents	Percent of progeny above value of capping index of parent
OR-US 4637	7.9	3	6.2	11.1
Linn	7.8	5	6.5	8.0
Olympus	7.5	5	6.3	14.2
Totem	7.2	5	6.3	4.1
Benton	6.6	5	6.0	3.9
OR-US 4003	6.3	2	6.2	8.8
OR-US 3965	6.0	3	6.1	3.9
OR-US 4596	5.7	2	6.0	3.2
OR-US 4350	5.2	2	6.7	1.6

[1]Mean of hand capping, portable field capping, and processing lab capping values.

Table 3. Summary of concentrated ripening performance of nine parents in USDA-Oregon State University strawberry breeding program, 1976-1978

Parent	Parent value[1]	Number of crosses	Mean rating value of all other parents	Percent of progeny above parent value
OR-US 4637	7.5	2	6.3	1.5
OR-US 4003	7.4	2	6.2	2.0
Olympus	7.2	3	6.2	3.0
Totem	7.1	3	6.1	3.5
Benton	7.1	2	7.2	1.0
Linn	6.9	2	7.3	2.5
OR-US 4596	6.8	2	6.3	4.0
OR-US 4350	6.1	2	7.3	1.0
OR-US 3965	5.9	2	7.2	3.0

[1]Parent value is a mean of field and processing lab values.

CHARACTERISTICS AND PERFORMANCE OF THE 'LINN' STRAWBERRY IN 1979

F. J. Lawrence

Summary. Commercial plantings of 'Linn' show adequate production of firm fruit suitable for hand harvest. Experimental machine harvest was carried out at two locations with three different harvesters (2). 'Linn' is more susceptible to mildew than 'Hood' or 'Totem.' The plant vigor varies with location and does not appear related to diseases. The berry is high in acid and holds color satisfactorily but is tart when eaten fresh.

INTRODUCTION

'Linn' was introduced as a productive, moderately vigorous strawberry cultivar with firm fruit for machine harvest trials, combination hand harvest and machine harvest, or hand harvest (1). Limited commercial plantings were available for observation in 1979 from plants set in 1978.

DISCUSSION

Production

Yields on several plantings were estimated from 11.2 MT/ha (5 t/a) to 17.9 MT/ha (8 t/a), and this compares favorably with other cultivars such as 'Hood' and 'Totem.' Flowering continued over a longer period than expected, and some tertiary berries that ripened quite late did not have adequate size. This long flowering span also resulted in a decrease in ripening concentration, although more than 50 percent of the crop was obtained in two pickings. The fruit was exposed and easily located for hand harvest, although exposure was detrimental during extremely high temperatures when some berries were damaged by the heat. Severe showers also caused some surface injury to exposed fruit. The berry has a reflexed calyx when ripe, and this aids in hand picking.

Plant vigor

The plant vigor was variable from one location to another, more than the variability within a planting. No disease was associated with plant vigor, although in British Columbia 'Linn' did not appear as virus tolerant as 'Totem.' Some red stele was found in a planting, but no more than in 'Hood' plantings nearby. 'Linn' appears to be more suited to certain locations (perhaps soils) and not as widely adapted as 'Hood' or 'Totem.' Although 'Linn' has not had a sever winter test, observations to date indicate that it is more hardy than 'Hood' and equal to 'Totem.' 'Linn' has adequate runners to establish a good row where the hill system is not practiced, but does not produce as many runners as 'Hood.'

Fruit

The primary fruits were of good size and the secondaries adequate. The base of the fruit lacked red color unless left for several days after the remainder of the fruit was red. This lack of pigment was noticed by the processor, but the berry color does not become dark if harvest is delayed. The berry is quite tart when eaten fresh as the acidity is quite high, although the soluble solids are equal to other cultivars now in production. This acidity is an advantage in processing because bright color retention is good in the frozen product. The 'Linn' has the firmest berry of any cultivar now in production in the Northwest and has received high scores for sliced texture and wholeness. However, the skin of the berry is not tough and can be damaged by abrasion and puncture during handling. Longitudinal cracks were noted on some fruit, mainly the primaries. These cracks are a detriment to good berry appearance but did not show evidence of rot.

Disease resistance

Reference has been made to the tolerance of 'Linn' to virus in British Columbia and to red stele infection. 'Linn' is more susceptible to mildew than 'Hood' or 'Totem' but less than 'Northwest.' The effects of mildew, if any, on the vigor and production of 'Linn' are unknown. Data from the Oregon State Agricultural Experiment Station progress report--Strawberry Mechanization, 1979 (2)--indicate 'Linn' has a lower mechanical damage percentage than 'Benton' and 'Olympus,' but a higher percentage of fruit rot.

Machine harvest

'Linn,' along with 'Olympus' and 'Benton,' was harvested with the SKHS Co., Inc., Oregon State "Clipper," and the Blueberry Equipment, Inc. harvesters at two locations in 1979, and the data are summarized in a progress report by Martin and others (2). This is the first year of a 2-year project on machine harvesting and handling.

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'TYEE,' A NEW STRAWBERRY CULTIVAR SUITED TO MACHINE HARVEST

Hugh A. Daubeny, F. J. Lawrence, Lloyd W. Martin, and Bruce H. Barritt

'Tyee' is a new strawberry cultivar developed at the Agriculture Canada Research Station, Vancouver, British Columbia. It is a seedling from a 1970 cross of 'Totem' x 'Olympus.'

'Tyee' has performed well throughout the Pacific Northwest. In the northern part of this production region, it has outyielded 'Totem,' the established cultivar. In the southern part of the region, its yields have been comparable with those of 'Hood' and 'Olympus,' the established cultivars there.

DISEASE AND INSECT RESPONSES

'Tyee' is at least as tolerant as 'Totem' to the virus strains that are common on strawberries in the Pacific Northwest; 'Totem' is recognized as one of the most tolerant cultivars grown (1). It is resistant to powdery mildew (*Sphaerotheca macularis*) and slightly susceptible to leaf spot (*Mycosphaerella fragariae*). It has shown field resistance to red stele (*Rhytophthora fragariae*) at two sites.

'Tyee' fruit has shown lower incidences of preharvest fruit fruit rot (*Botrytis cinerea*) than any other cultivar grown in the Pacific Northwest. It has also shown resistance to postharvest fruit rots caused by both *B. cinerea* and *Rhizopus* spp.

Compared with 'Totem,' 'Tyee' has shown greater resistance to two-spotted spider mite (*Tetranychus urticae*).

PLANT AND FRUIT TRAITS

The plants are very vigorous with upright petioles supporting shiny, dark green leaves. There is abundant runner production in the years of planting. The inflorescences are produced below the leaf canopy. 'Tyee' has shown somewhat more winter hardiness than 'Totem' at Abbotsford, B.C.; 'Totem' is recognized as one of the most winter hardy commercial cultivars grown in the Pacific Northwest (1).

The fruit is borne on medium-length, erect scapes that usually do not fall to the ground as ripening occurs. Size is usually smaller than 'Totem' and similar to 'Olympus.' Shape is globose conic, with the primaries often ribbed; later ripening fruit are usually smooth. Ripening season is usually several days later than 'Totem.' The calyx is reflexed and capping is easy when the fruit is fully ripe. The yellow achenes are slightly raised. The fruit is slightly firmer than 'Totem' but not as firm as 'Linn.' Colour is a bright medium red and will sometimes show a white core line. Flavor is slightly more aromatic than 'Totem.' Quality is similar to 'Totem' when processed as a whole or sliced frozen product and subsequently thawed.

SUITABILITY FOR MACHINE HARVEST

'Tyee' gives the appearance of a concentrated ripening habit, since primary fruits remain sound and retain their attractive bright red appearance as many of the later fruits ripen. This can be partially attributed to the low incidence of *B. cinerea*-infected fruit at harvest. The concentrated ripening habit, along with erect fruit scapes, makes 'Tyee' suited to machine harvest.

The suitability to machine harvest has been demonstrated with the Oregon State "Clipper" harvester. 'Tyee' has consistently had a high percentage of ripe fruit when harvested by this machine (Table 1). Plant stands in 1976 and 1977 were much better than in 1979 and account for the differences in total yield. Yields of usable 'Tyee' fruit from machine harvest (fruit without damage that is capped and needs no hand treatment before freezing or processing) greatly exceeded 'Hood' fruit in both years (1976, 1977) the two cultivars were harvested. The good quality of the sliced frozen product from machine-harvested 'Tyee' fruit is shown by the Oregon State Food Science and Technology Department evaluation score of 5.5 and also the scores in Table. 1.

The low capping score in 1979 may have been caused by the change made in the capping rollers of the OSU capper-stemmer, but the fruit of 'Tyee' would be readily capped on the new Canners Machinery Limited "decapper."

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Table 1. Machine harvest[1] and processing characteristics of 'Tyee' and 'Hood' at Aurora and Corvallis, Oregon

Year	Cultivar	Total yield (kg/ha)	Percent ripe	Percent capped[2]	Percent recovery	Usable ripe (kg/ha)	Quality[3]
1976	Tyee	19,365	85	71	80	10,785	6.5
	Hood	14,785	59	76	65	2,970	4.4
1977	Tyee	18,225	72	72	65	6,415	5.5
	Hood	8,480	70	63	90	3,700	4.8
1979	Tyee	10,370	86	44	78	3,920	6.0

[1]OSU "Clipper" harvester.

[2]OSU stemmer-capper.

[3]Quality scale: 9 = excellent, 5 = acceptable, 1 = very poor.

THE PHILOSOPHY OF MACHINE HARVESTING OF STRAWBERRIES

Ervin L. Denisen

My first suggestion that a mechanical strawberry harvester might be possible was in 1958 (8), when it was proposed as a hobby idea for an amateur horticulturist. Our first attempts at mechnical harvesting of strawberries were made in 1960 when we purchased a stone scoop and conducted trials on about 30 cultivars to consider the feasibility of picking strawberries by machine (1).

The following conclusions were made following these trials: 1) It is possible to harvest berries by placing a closely spaced tine scoop into the foliage of a planting of ripe strawberries, then lifting the scoop and collecting the berries; 2) Some cultivars are better adapted than others to mechanical harvest because a higher percentage of berries mature at one time; 3) Some cultivars have physical characteristics such as firmness or resilience that render them more adaptable to mechanical harvest; 4) Because this type of machine could not distinguish between green and ripe berries, great emphasis was placed on "concentrated ripening," a term devised to describe total or nearly total ripening of entire crop at one time; 5) To be picked mechanically, berries must have either a brittle peduncle attachment or an "easy-cap" tendency, i.e., the stem and calyx must come free with a relatively slight pull (3); 6) A tufted calyx helps to reduce bruising by providing a cushion between one berry and another; and 7) Given the numerous differences among cultivars in the trade, it should be possible to produce new adapted cultivars through breeding and selection. At this point our breeding program acquired a new objective--to produce cultivars more adaptable to machine harvesting (7).

Time has shown that, through breeding, we can increase the concentration of ripening along with many other desirable features. The principal limitations have been lack of funds and shortage of qualified manpower. There must be a cooperative effort by horticulturists, engineers and processors in a team endeavor. Several teams are in evidence in areas where concentrated effort has been applied (2,3,4,9).

When reports of our early trials on mechanical harvesting (5,6) were disseminated, there was considerable interest on the part of growers. The comments ranged from "It can't be done!" to "Where can we buy one?" This intense interest has prevailed over the years. I described our results or progress at many meetings in many parts of the United States. Members of the International Society for Horticultural Science expressed considerable interest at two meetings I attended (1966 meeting at College Park, Maryland,

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and 1974 meeting at Warsaw, Poland). I observed some field trials conducted by a co-worker (Dr. S. Sansavini) at the University of Bologna in Italy. The rotating device used to push the berries into a hopper had too much force and actually made mush of the berries. The Italians had several other innovations, but none the same as ours. The important point is that desire for mechanical harvesting of strawberries exists on a worldwide basis.

One of the most beneficial meetings I attended was in Chicago in 1968, held under the auspices of the U.S. Department of Labor and participated in by engineers, horticulturists, sociologists, and economists. Harvest mechanization of fruits and vegetables (4) was the topic of the meeting. Results of the meeting were published, setting forth the objectives or procedures to follow for the next decade or two.

Great progress has been made in arriving at a system for mechanical handling of strawberries from production to harvest to processing, but considerable resistance has been encountered. Much of the resistance came from strawberry producers, but some was from researchers. I suppose this resistance can be compared to that protesting the advent of the automobile earlier in this century. However, progress marches on even in the face of adversity. We salute the Arkansas team for their accomplishments and for getting their results out to the public where it can be expanded upon (10). The "Research Workers Conference on Strawberry Mechanization" at the University of Arkansas (Department of Horticultural Food Science), December 6-7, 1979, is an excellent culmination of cooperative endeavor in this area of research.

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DESIGN AND DEVELOPMENT OF THE ARKANSAS STRAWBERRY HARVESTER

Glenn S. Nelson and Justin R. Morris

Summary. Researchers in the departments of Agricultural Engineering and Horticultural Food Science developed and field-tested a mechanical strawberry harvester in 1967. Results obtained on research plots of 'Tennessee Beauty' and 'Surecrop' varieties indicate that the machine can harvest between 50 and 80 percent of the crop in a once-over operation.

An experimental grading system was developed based on the premise that maturity of harvested strawberries is a function of size. The system provided satisfactory results under field tests; however, some hand sorting of the fruit was required.

INTRODUCTION

Until recently, little research was directed toward mechanical harvesting of strawberries. Since the beginning of the strawberry-growing industry, harvesting has been accomplished by picking the fruit by hand and placing it in containers. Procurement and management of labor are rapidly becoming more difficult and costly. Studies of production costs have shown harvesting to be the largest single cost involved (1). From one-half to three-fourths of the total cash price received by the growers is paid to hand pickers and for services provided the pickers. As a result, many strawberry producers are looking to mechanical harvesting as a means of reducing production costs.

It has been recognized that development of a successful strawberry harvesting machine would be difficult and time-consuming. There are many strawberry varieties and each has varietal characteristics that must be taken into account. Plant breeding programs are under way in various parts of the country. However, development of a variety that is ideal for mechanical harvesting and also acceptable for commercial consumption is a long-range project. Consequently, mechanical harvesting research is necessarily restricted to the strawberry varieties now in production. Diversity of cultural practices in strawberry-producing areas further complicates the picture. A single-plant row or hill system is common in some areas, while in others matted rows of various widths are predominant. The soil may be tilled so that the planting area is essentially flat, or it may be formed into raised beds. All these factors have some influence on mechanical harvesting, and one machine will not function effectively under all conditions.

METHODS

Development of a mechanical harvester

The feasibility of developing a mechanical strawberry harvester was explored at the Arkansas Agricultural Experiment Station (2,3).

Preliminary work indicated that a continuous harvester must perform three basic functions: strip fruit from the plants, separate fruit from the leaves and other foreign material, and convey fruit to containers for further handling or processing. These operations must be performed in a manner that will maintain product quality. Since most of the mature fruit lies directly on the ground, an unusual picking device is required to lift the fruit without disturbing the soil surface or damaging the berries.

Based on these criteria, a single-row, tractor-drawn harvester was developed. The machine's basic functional components are a main carriage frame, a comb-brush stripping mechanism, a pneumatic system, and a conveying and collecting system. A schematic drawing of the harvester showing flow patterns of air and berries is shown in Figure 1.

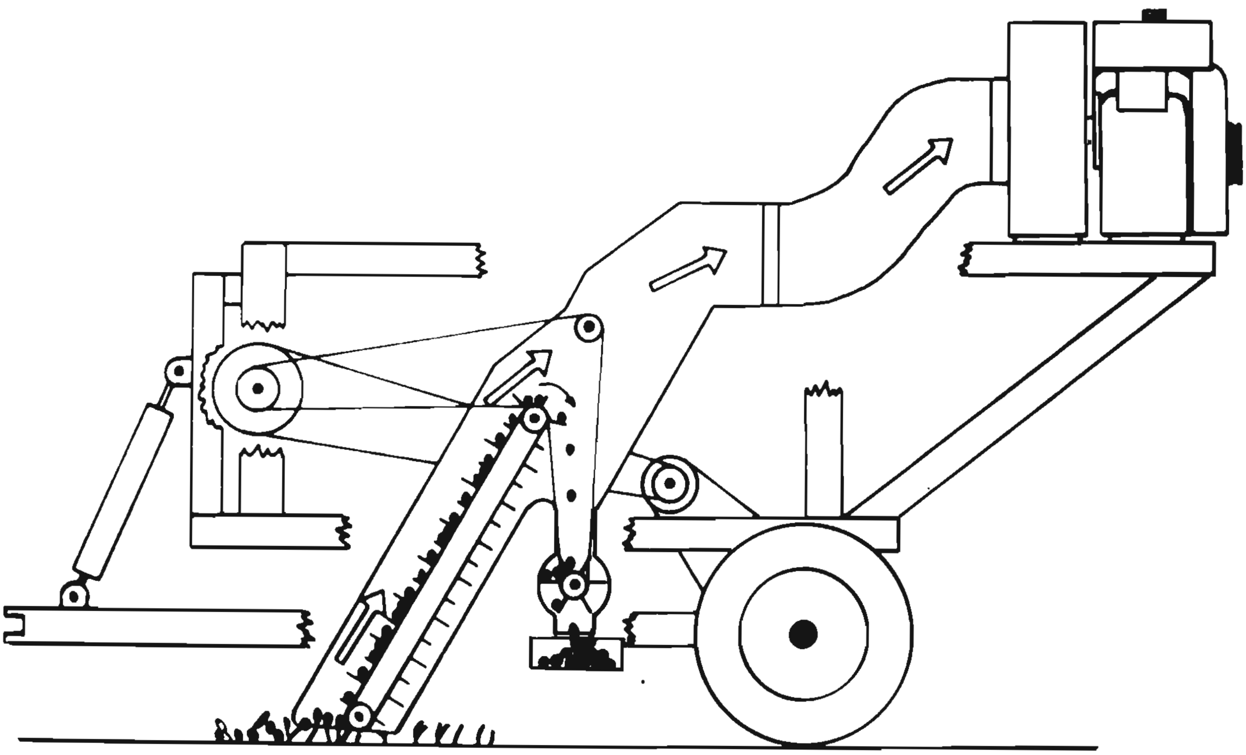

Figure 1. Schematic drawing of experimental strawberry harvester showing flow patterns of air and berries.

A production prototype of the University of Arkansas harvester built by Blueberry Equipment Company, South Haven, Michigan, is shown in Figure 2.

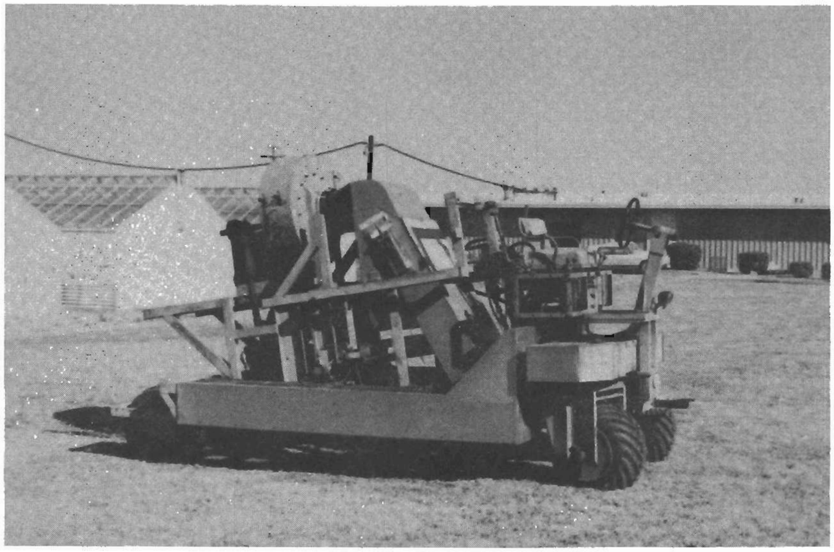

Figure 2. Production prototype of the University of Arkansas strawberry harvester built by Blueberry Equipment Company, South Haven, Michigan.

The development program was devoted primarily to the pick-up mechanism, which features the combination of a pneumatic system and a comb-brush stripping mechanism. During the picking operating, a high-velocity air lifts the fruit from ground level to a position above and in front of the comb-brush mechanism in the picking chanber. Moving on a continuous belt, the comb-brush mechanism strips the fruit from the plants and conveys them to an air-lock valve. From this valve the fruit are deposited in containers.

The combs are 37.5 cm long and are spaced 10 cm apart along the continuous belt. The combs consist of a series of fingers 6.25 cm long spaced one cm apart. Synthetic bristles slightly longer than the fingers serve to gently dislodge berries lying on the ground.

In addition to setting up the fruit for the combs, the high-velocity air flowing through the conveyor partially separates the fruit from leaves and other foreign matter.

Field tests were conducted to determine the optimum adjustment of machine components for maximum harvesting efficiency. The following optimum adjustments were determined:

1. The lower edge of the picking head should be controlled automatically at a distance of 3 cm above ground level.

2. Air should enter the lower edge of the pick-up chamber at approximately 1,800 m per second.

3. Since the speed of the continuous belt containing the comb-brush mechanism is a function of ground speed, the ratio of belt speed to ground speed should be adjusted to allow each comb to sweep independently through a swath distance of approximately 5 cm.

Yield and quality of mechanically harvested strawberries

The experimental strawberry harvester was field-tested in 1967 on conventional plots of 'Surecrop' and 'Tennessee Beauty' varieties.

Following the 1966 harvest the plant beds were narrowed to a width of 20 cm and reshaped with disk-hillers. In early spring of 1967 half of the plots of each variety were further shaped and rolled to provide beds with broad, flat tops for the developing fruit. Presenting the fruit on a flat plane was deemed advantageous since the harvester uses a pneumatic stripping device.

Sections of the plots were once-over harvested at three dates--one day apart for 'Surecrop' and two days apart for 'Tennessee Beauty.' After machine harvest, berries remaining on the plants were picked by hand to give total yield at each harvest. Harvesting began when about half of the crop was suitably ripe for processing.

Before machine harvesting began, the foliage above the fruit was removed and the intake of the harvester was set 3 cm above ground level. This sacrificed a certain percentage of harvester efficiency; however, it eliminated fruit damage and excessive soil contamination. The collected fruit, when washed and graded, appeared acceptable for processing. Both varieties were equally adaptable, and the results were combined in data presented in this report.

Once-over harvesting of present strawberry varieties results in harvested berries of several maturity levels. These are referred to in this report as acceptable (red, ripe color), color-inception (slightly pink color), mature-green, and immature.

Data in Table 1 indicate that shaping the beds did not affect total yields, but it materially improved harvester efficiency to a level that may prove the feasibility of once-over harvest, even with existing varieties. From 50 to 75 percent of the total crop was harvested in a once-over operation.

Table 1. Effect of plant-bed preparation on strawberry yields and harvester efficiency (seasonal and varietal means)

	Total crop		Acceptable crop	
	Natural bed	Shaped bed	Natural bed	Shaped bed
Total yield, t/ha	10.47	10.85 NS	5.67	5.18 NS
Machine yield, t/ha	6.08	8.11 *	2.69	3.52 *
Machine efficiency, %	58	75*	52	68*

*Significant at one percent level.

Maximum yields of both varieties were at the 50 percent acceptable stage (Table 2). The mechanically harvested crop contained a proportionally higher percentage of under-ripe fruit because of their position on the plant. Fruit size gradually declined with delay in harvest. However, statistical variance in fruit size among maturity stages was 10 times greater than among harvests, indicating that grading for maturity might be accomplished with the use of "continuous-sizing" grading equipment.

Table 2. Maturity distribution of harvested strawberries (varietal means from shaped-bed plots)

	Total yield of			Seasonal average		
Maturity level	1st harvest (%)	2nd harvest (%)	3rd harvest (%)	total yield (%)	machine yield (%)	fruit wt. g/fruit)
Decayed	9	10	15	11	10	6.6
Acceptable	44	50	46	47	43	8.0
Color-inception	16	15	17	16	16	5.4
Mature-green	14	15	12	13	16	4.0
Immature	17	10	10	12	15	1.8
Yield, t/ha	9.80	11.94	10.83	10.85	8.11	-
Weight, g/fruit	5.7	4.8	5.0	4.2	5.3	

An average of 30 percent of the mechanically harvested fruit was in the mature-green and color-inception stages. If it were economically feasible, these could be ripened to acceptable color within 2 to 4 days if held at 75°F. (2,3).

Grading of mechanically harvested strawberries

Development of the mechanical harvesting principle introduced an area of investigation concerning separation of harvested strawberries into maturity levels.

A prototype "continuous-sizing" grader was constructed and underwent limited testing in 1968. This grader could be mounted as an integral part of the harvester. The unit's basic functional components are a feed table, pneumatic cleaning system, tapered-finger sizing device, vibrator unit, and collecting system (Fig. 3). The feed table and tapered-finger sizing device are rigidly attached to the vibrator unit and function as a vibrator-actuated conveyor to move berries through the system. The frequency of the vibrator unit can be varied from 200 to 1,000 cycles per minute. The tapered fingers are 90 cm long, and the spacing between the fingers varies from 0.60 cm at the intake end to 5 cm at the discharge end.

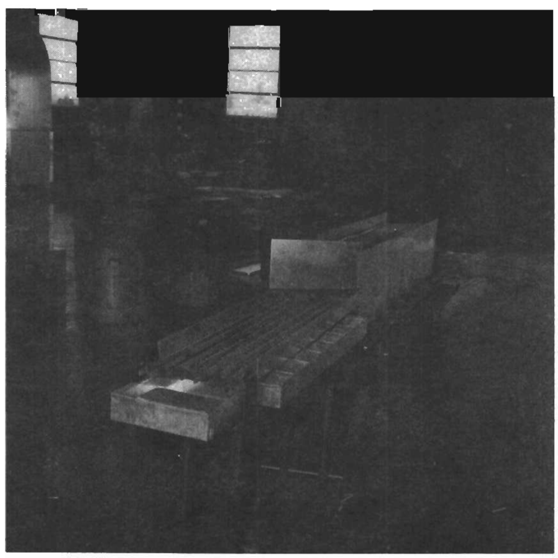

Figure 3. View of experimental grader showing details of tapered-finger sizing device and collecting system.

Berries deposited on the feed table are automatically spread uniformly across the width of the table while being moved forward by the shaking action of the conveyor. From the feed table the berries are dropped through an airstream onto the feed end of the sizing device. The berries are vibrated along the tapered fingers and are allowed to drop through at various points into the collecting device. The collecting device consists of seven trays located directly below the tapered fingers. This permits the harvested fruit to be separated into seven groups according to size. Best selective separation was obtained with the vibrator unit operating at a frequency of 460 cycles per minute with a 2.5-cm stroke.

Table 3. Performance of experimental grader for sorting strawberries into six groups according to size

Tray number	1	2	3	4	5	6
Total weight/g	216	2,307	4,198	3,552	1,370	108
Total no. of berries	170	835	783	434	97	7
Grams per fruit	1.27	2.76	5.36	8.20	14.10	15.63
Maturity level						
Immature						
Percent of wt.	100	20.46	4.31	0.20		
Percent of no.	100	31.37	10.35	1.62		
Mature-green						
Percent of wt.		37.66	14.85	1.73		
Percent of no.		38.63	18.83	3.13		
Color-inception						
Percent of wt.		27.40	34.84	12.84	1.20	
Percent of no.		20.54	36.60	15.20	3.00	
Acceptable						
Percent of wt.		14.30	46.00	85.23	98.80	100
Percent of no.		9.46	34.22	80.05	97.00	100

Data shown in Table 3 indicate that strawberries can be graded for maturity with "continuous-sizing" equipment. Some hand sorting will be required if similar systems are used commercially. Some overlap of maturity levels occurred between successive trays. However, approximately 90 percent of the total weight of fruit collected by the fourth, fifth and sixth trays was of the acceptable maturity level. About 81 percent of the fruit collected by the third tray was of the acceptable or color-inception level. The acceptable berries collected by the third tray were small in size as compared to those collected by the last three trays. Practically all green-mature berries were deposited in the second and third trays.

CONCLUSIONS

Results presented in this report indicate that once-over mechanical harvesting is feasible even with existing strawberry varieties. Genetic, cultural, and physiological approaches which may concentrate fruit set at a higher single plane position on the plant would automatically increase the percentage of acceptable yields. Research is in progress in these areas, as well as in the development of field equipment for harvesting and handling operations.

With continued progress in the development of mechanical harvesters, a substantial part of the total strawberry acreage could be picked mechanically. Some changes will be required in the handling operations to accommodate the mechanically harvested fruit. For example, there will be increased sorting and grading requirements resulting from the presence of both green and overripe fruit. Most of the fruit will have the calyx and part of the pedicel attached, and these must be removed before the berries can be processed.

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MECHANICAL HARVESTING OF STRAWBERRIES IN MICHIGAN

C. M. Hansen and R. L. Ledebuhr

Summary. There has been an ongoing refinement process of the components of the strawberry harvester since work was initiated in 1968, leading to a machine which is efficient and dependable. A combination of uniquely designed crop lifters, double sickle bar, and Hume-type reel, along with proper cultural practices, can result in a high recovery of fruit in a once-over harvest. Foliage and trash removal is accomplished by a series of modulated airstreams at different locations on the harvester. Fruit that is generally harvested in clusters is singulated into a more usable product by equipment in the processing plant. Plastic boxes are used to collect and transport the strawberries from the field to the processing plant. Field trials in different parts of the country indicate the harvester is adjustable to different row configurations and cultural practices.

Mechanical harvesting of strawberries began in 1968 as a Michigan Agricultural Experiment Station project. The initial work involved the use of broad fingers or a series of narrow scoops that dipped into the row in the direction of travel, lifted the fruit onto a conveyor belt, and deposited it in a container.

In an effort to extend the testing period, a dozen strawberry plants were grown in a number of long narrow boxes in the greenhouse. The boxes of ripe fruit were placed in a field simulator where the picking device was tested. Following successful laboratory tests a field unit was designed and fabricated for tests the following June. The results were not encouraging. About the only thing learned with respect to this research was that a picking device that performed well on greenhouse-grown fruit will not respond satisfactorily in the field because the field-grown plants have a much more profuse foliage.

Another prototype strawberry harvester made use of a two-part system requiring removal of the foliage above the fruit, followed by actual harvesting of the fruit by vacuum and stripper fingers. The principal difference between the MSU device and the Arkansas unit was that the tines on the flights inclined toward the direction of travel, removing the fruit from the plant. The vacuum system carried the fruit into a plenum chamber where the fruit dropped into a collection tray. The trash and leaves passed on out through the suction fan. The forward travel of the machine was .4 km (¼ mph). Compared with four hand pickings, this harvester removed 61 percent of the fruit in one pass. Tests have shown that hand labor harvests 85 percent of the crop in grower fields.

In order to develop a completely mechanized system for handling strawberries from the field to pack, work was initiated on a decapper in cooperation with Canners Machinery Limited (hereafter referred to as CML), of Simcoe, Ontario (1). The decapper derived from this work will be discussed in another paper. It is important to point out that strawberries that are mechanically harvested for the decapper need to have stems at least 2.5 cm (1 in) long. Searching for a harvest mechanism that would produce a suitable product led to examination of the work reported by Booster and Kirk (2) on the "clipper" method of fruit removal. About this time the National Institute of Agricultural Engineering in Silsoe, England, had a prototype that reportedly was ready for the field (3). CMS made arrangements through a manufacturer, Smallford Planters, Ltd., of St. Albans, England, to have the component parts of the picking unit incorporated into the harvester to be assembled at Simcoe. The fruit singulator, developed in 1975 at Michigan State University in cooperation with CML, was mounted on the rear of the harvester to prepare short-stemmed fruit for the decapper. The first year's experience with the harvester and decapping systems is discussed by Denisen and others (4). This economic feasibility study shows that with high yields and proper cultural practices, recovery can be quite satisfactory. The grower with poor cultural practices had lower yields, 12,000 kg/ha (5.4 t/a) lost $1,400/ha ($560/a). The accounting method used in the study required that all charges for the mechanized system be paid by the grower.

The conclusion from this study read, in part, "While it is apparent that changes in cultural practices and harvesting systems will be required, some results were promising. For one grower's condition, economic analysis suggested that the new system may be competitive with the conventional hand-picking system."

FLORIDA TESTS, 1977

Many modifications were made on the harvester at the conclusion of the first year's trials in Michigan. Arrangements were made for field testing an air plant lifter in Florida. These trials were conducted on strawberries that had been planted in black plastic the previous October. Cold weather and poor growing conditions limited the plant size at harvest time.

Only one type of fruit and foliage pick-up system was used on the harvester in the Florida tests. Certain component parts of the pick-up unit were based on the concepts of a harvester designed by C. Hecht of Oregon, hereafter referred to as the "air pick-up header." It made use of high-velocity air jets on either side of the row. The two airstreams impinged in the center of the row in an attempt to lift the plants before they were cut by a double reciprocating sickle. The modifications made at Michigan State University prior to and during the Florida tests included the addition of larger air nozzles and air straighteners in the nozzles, the addition of a shroud over the row to direct the fruit and foliage onto the pick-up conveyor, and a marked increase in air velocity.

An adjustable spring-balanced system gave a desirable flotation feature to the cutter bar. The parallel linkage mechanism also held the cutter bar at a proper working angle, independent of the height of the cut. Mounted directly behind the sickle bars is a conveyor belt that transfers the fruit cluster and foliage into the harvester.

The harvester speed and air velocity were interdependent, as was the density of the foliage. There must be sufficient air to penetrate the foliage in the row to provide a complete lift of all the fruit. Tests showed that bed width for this machine is limited to about 60 cm (24 in). Satisfactory performance was not possible with a wider row. Alternate hand- and machine-harvested plots showed that it was possible to obtain a machine-harvest efficiency of 67 percent, with individual plots ranging between 53 and 86 percent.

There was some concern that the air pick-up system would cause sand particles to penetrate the fruit, thus reducing its quality. A cursory examination of the fruit ('Tioga') showed that this was not a problem.

MICHIGAN TRIALS

Field trials, 1977

A second type of header or pick-up machine was tested in Michigan. It made use of crop lifters similar to those designed by Ivor Kemp. They varied in length, were half the width of the Kemp lifters, and were attached to the bottom of the mower bar. The mower bar attachments were flat spring stock steel, mildly tempered to provide maximum flexibility without being brittle. From the toe castings a rod extended back and upward to a point beyond the sickle bar. Eleven tines enabled the header to cover a row 75 cm (34 in) wide (Fig. 1).

To assist in the movement of foliage and clusters over the cutter bar, a four-bar Hume-type reel was used. The speed of the tines on the reel, which was adjustable, was somewhat greater than ground speed when moving the cut foliage and clusters onto the conveyor. Plant density is an important factor in achieving a high rate of recovery from this type of pick-up mechanism. Dense foliage serves two purposes for this type of header. First, the thick, leafy foliage cushions and supports clusters as they are being cut and moved into the machine. Without the support of the foliage, many clusters would tend to drop down between the crop lifters and be cut and lost at the cutter bar. The other advantage of dense foliage is that the majority of the peduncles grow out to the sides of the row and lie perpendicular to the row. The crop lifters can easily slide under the peduncles and lift them up over the cutter bar. Peduncles lying parallel to the row are generally missed by the crop lifters. Fruit that is set within the row is generally supported by much heavier peduncles that "arch" up from the plants. Even though the peduncles are randomly positioned, the crop lifters will slide under the arches and lift the clusters over the sickle bar.

In preparation for the 1977 mechanical harvesting trials, the strawberry beds were "cross-row cultivated" in the fall of 1976. A European chain and flight-type hay rake, which swept perpendicular to the row, was used for this purpose.

At harvest time the configuration of the beds was quite acceptable, being slightly crowned with some trenching between rows. The foliage, for the most part, was quite profuse--about 45.7 cm (18 in) high and 81 to 91 cm (32 to 36 in) wide. The fruit generally lie on the side of the row.

There was sufficient harvest labor in Michigan in 1977, and for this reason mechanical harvesting assumed a clean-up operation. On an average, 20,163 kg/ha (9 t/a) were hand picked, with much of the remaining crop being harvested by a pick-your-own operation. Under these conditions, it was not possible to determine the efficiency of a mechanical harvesting system. Nevertheless, the mechanical harvester recovered from 3,300 to 7,700 kg/ha (1.5 to 3.5 t/a), depending upon the location in the field. Speeds ranged between .8 to 1.6 km/h (.5 to 1 mph).

The harvester with the crop lifter and reel pick-up header was operated in the portion of the field where the foliage was profuse. The harvester with the air pick-up header seemed to operate more satisfactorily in strawberries that had less foliage.

Since it was not possible to obtain data as to harvest efficiencies, only observations can be reported.

The crop lifter and reel pick-up machine performed more satisfactorily than its 1976 version did. This can be attributed to the narrower and closer spaced crop lifters, the double reciprocating sickle mower bar, and the reel that operated in the foliage above the mower bar. The addition of a second elevator and a second cross-flow fan improved the foliage separation. Foliage separation was also improved by placing an axial flow fan below the grid conveyor. The improved topping and singulating system produced a final product with fewer peduncles and leaves.

The air pick-up header harvester, which was operated in fruit with less foliage, gave a comparable performance as far as the final product is concerned. The additional hydraulic power requirements to operate the fan for the air pick-up system limited the amount of oil that could be used to run other parts of the machine. Foliage clogged the air intakes of the cross-flow fans on both machines. Stems that had been severed from the clusters along with the leaves built up on certain parts of the frame, requiring frequent removal to allow the machine to operate properly. On the air pick-up header machine, goggles were requires for both the driver and attendant to minimize the dust hazard. The air on the header also forced dust and sand in between the moving parts of the double sickle mower bar, causing it to jam frequently.

Michigan trials, 1978

In 1978, two machines were refurbished with improvements based on the previous season's experience (Figs. 1, 2, 3). The main objective was to relocate and simplify the fan and conveyor systems. A trap was incorporated between the elevator sections to reduce the hazard of stones moving

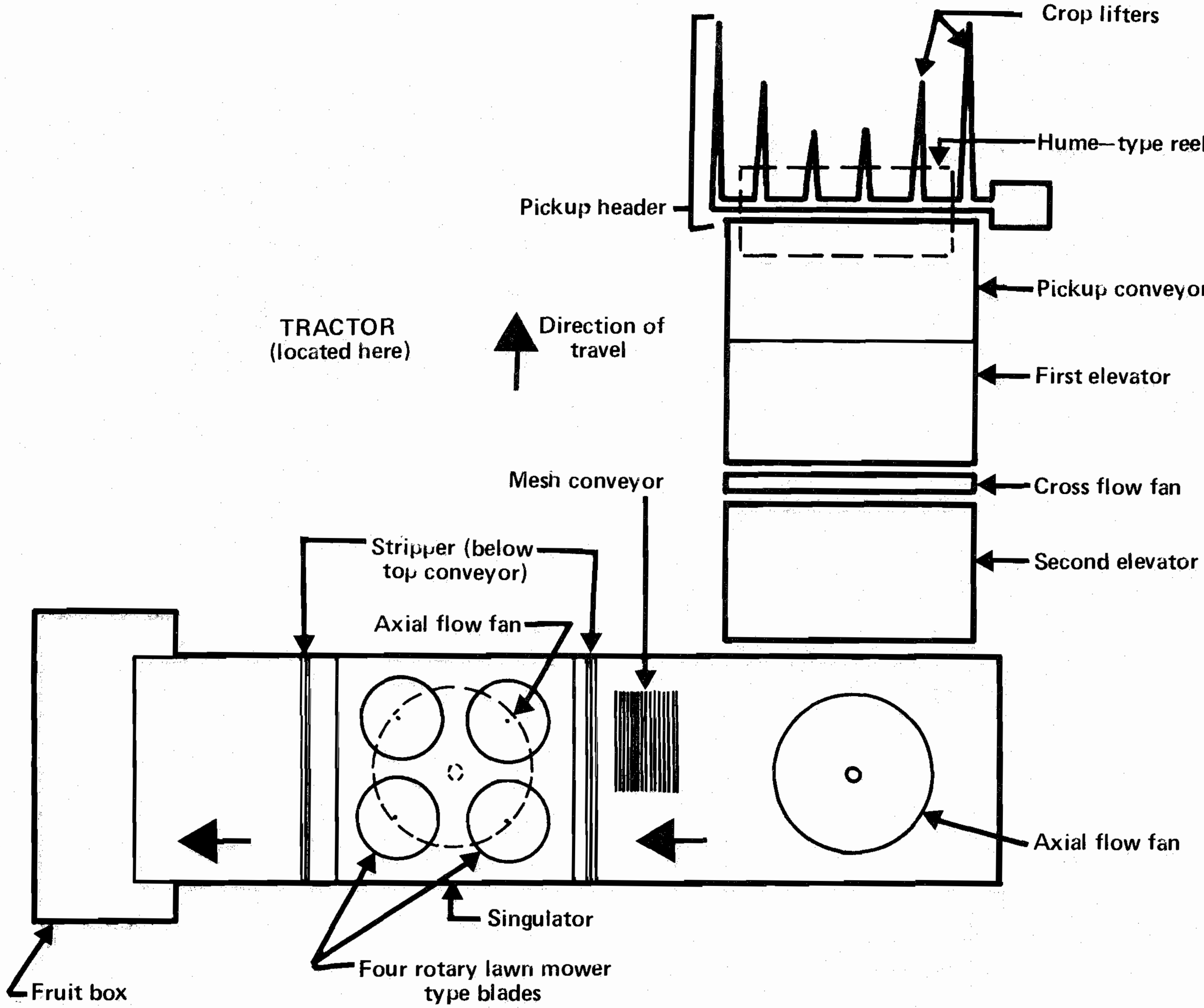

FIGURE 1. Schematic of the harvester, with 1978 modifications (top view).

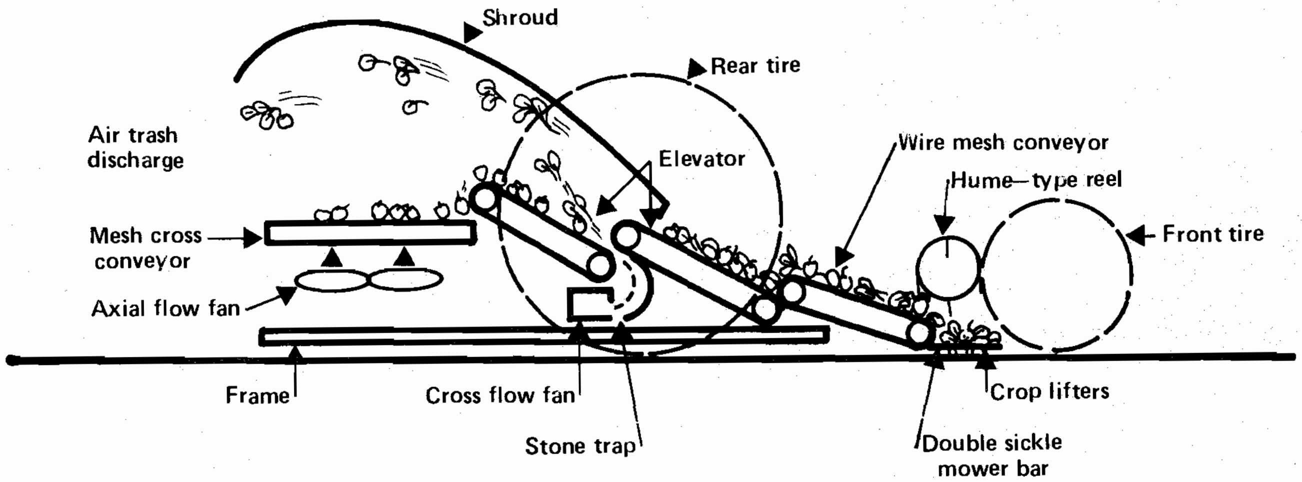

FIGURE 2. Side view of strawberry harvester. (1978)

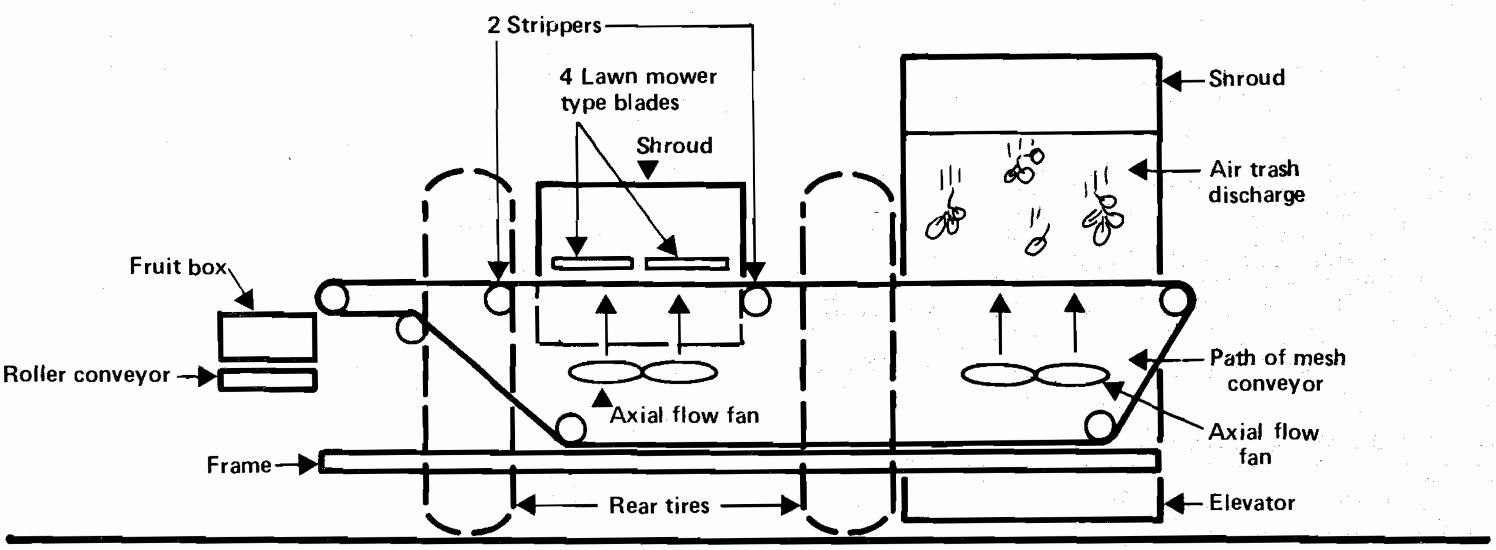

FIGURE 3. Rear view of strawberry harvester. (1978)

through the harvester (Fig. 2). Topper improvements included replacement of the two cross-flow fans by an axial flow fan under the rotary blades of the singulator. The stainless steel mesh cross conveyor was rerouted on the return under the fans (Fig. 3).

A "stripper" was placed under the cross conveyor to remove peduncles that penetrated the wire mesh cross conveyor (Fig. 3).

Only minor operational problems occurred with the harvester through the season. The wooden "lugs" (boxes used for cherries), were difficult to stack, held less fruit, and reduced field efficiency substantially. A total of 30,277 kg (66,760 lb) were harvested on the Kreiger farm. No records were kept on the "clean-up" operation at the Price farm.

Michigan trials, 1979

A 1977 model "air pick-up header" harvester purchased by Mr. Kreiger was modified by driving the pick-up header fan by an independent hydraulic system powered from a front-mounted tractor pump. This machine was used exclusively to harvest fields that had thin foliage and low yields.

The crop lifter reel machines were not modified for the 1979 season. They operated throughout the season with no major breakdown or delays during the actual harvest.

The Grant brothers' harvester

J. and J. Grant of Lake Leelanau purchased a strawberry harvester designed and fabricated by G. Stevens and R. Kreiger.

The 122-cm wide (48 in) pick-up mechanism, much like the Oregon State Clipper, makes use of a fixed tine reel 90 cm (36 in) in diameter to sweep the foliage and fruit across the crop lifters and cutter bar into the first conveyor. Axial flow fans remove the leaves and lift the peduncles for singulation with a lawn-mower-type blade.

The decision to use the non-row planting method was based upon work by Dr. L. Ricketson, Vineland Research Station, Ontario, Canada. The harvester operated satisfactorily, and the Grants plan to continue to modify it to harvest their crop.

CALIFORNIA TRIALS, 1969

Upon conclusion of the 1979 harvest season in Michigan, CML sent one of their machines to California for harvest trial. A few modifications were necessary to adapt the machine to California conditions. The basic adjustment was an adaptation of the header for the highly crowned raised rows common in California.

Performance of the harvester was evaluated on 102- and 152-cm (40-

and 60-inch) rows with and without plastic mulch. The primary reason for this trial was to evaluate the harvester in a clean-up operation salvaging fruit for juice only. A 12-acre block of 'Tioga' variety was used as the test area.

Observations and conclusions of California trials

1. The crop lifter and reel system can be very effective in recovering a very high percentage of fruit from raised rows.

2. Crop lifters can be "tuned" to effectively recover the clusters lying on the sides of the rows. The outside crop lifters were accurately formed to effectively lift clusters as low as 15 cm (6 in) below the cutter bar and, in combination with the reel, carry them up into the header of the harvester.

3. The California soils in the area where tests were conducted were very firm, enabling the header to float accurately on the bed. This greatly enhanced recovery. Also, the toe pieces of the lifters can bear much contact pressure with the bed without damaging plants.

4. The Hume-type reel assisted the flow of fruit and plants over the cutter bar into the header. Its position was adjusted to sweep and lift plants and clusters just ahead of the cutter bar.

5. The fruit was largely in a clustered form that required secondary cleaning and separating before being used as a juice product.

6. The plastic mulch caused no problem for the header because the crop lifters and cutter bar "floated" on the bed. The plastic was firmly anchored to the bed by the plants. The double sickle cutter bar was very effective in cutting the crop lifters free when they became snagged in plastic.

Acknowledgments

The authors wish to express their appreciation to Dr. Charles Howard, Director, Agricultural Research Center, University of Florida, for his assistance in making the field work in Florida possible. Others who have assisted with the work referred to in this paper include people associated with: (1) Canners Machinery, Inc., Simcoe, Ontario, (2) Manistee-Benzie Horticulture Society, (3) Leelanau Fruit Company, (4) National Institute of Agricultural Engineering, Silsoe, England, and (5) Ford Tractor Operations, Ford Motor Company, Troy, Michigan.

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AN UPDATE OF STRAWBERRY MECHANIZATION IN ENGLAND

Larry J. Bradford and Peter Steer

Summary. The 1979 harvest season in England saw the introduction of the straddle harvester which, after some modification, demonstrated its potential as an economically feasible harvester.

Mechanization of the strawberry harvest in England is being carried out by only one company, Smallford Planters, Ltd., of St. Albans. Ivor Kemp, recently retired from the National Institute of Agricultural Engineering at Silsoe, England, is the project engineer. Much of Smallford's original concepts in strawberry mechanization can be found in the CML-MSU harvester. In this machine they have pursued the concept of an over-the-row, straight-line harvester. It can be removed from the propelling unit, originally designed for their black currant harvester, allowing the propelling unit to be used in other cultural operations such as spraying and cross-row cultivation.

The harvester straddles three rows and harvests the middle row. Very little damage to fruit was observed where the wheels tracked. The harvester uses a reel feed and double reciprocating cutter bar to move the berries and foliage into the first elevator-conveyor. The cutter bar worked quite well, but the greatest field losses occurred at this point. The reel was limited in speed options as it was linked directly to the cutter bar. The range of adjustments for height and reach was also limited.

The machine was operated with six crop lifters, with the longer and larger ones located on the outside and a clear space in the center. The lifters were not fully tempered and were subject to bending. Breakage occurred occasionally where the tine dug into the soil and bent under the cutter bar.

The elevator and conveyor systems worked exceptionally well, with no problems throughout the season.

Operational speed of the discharge fan was critical and was directly related to the leaf separation fans. In heavily weeded areas the discharge area plugged up. The problems were corrected by opening up and modifying the discharge area.

The position of the driver, high in the center of the machine, made it difficult to view the cutter bar and thus the operation of controls. Mirrors or marks may assist in this problem.

The harvester pulls a trailer for transporting the lugs of fruit. Some modification will be needed to keep the trailer from fouling the harvester on turns.

In light cropping varieties, one person was able to collect and stack trays; however, in a heavy cropping variety two persons were required.

The rear elevator and box-filling system, as a general rule, worked well. Some berries were lost at the point where they transferred from the conveyor to the elevator. Cleats will be added to the elevator to prevent rollback.

The controls of the harvester were inaccessible to the driver. Repositioning would be needed in a production model so the driver would have access to the controls.

Work rate and retrieval percentages for the machine are contained in the following table. Rates are metric tons and kilometers.

Table 1. Work rates and retrieval percentages

Variety	Date	Total crop yield[1] (t/a)	Crop harvested (t/a)	Percent lifted	Rate of harvesting (km/hr)	Rate of harvesting (hr/a)	Rate of harvesting (t/hr)
C. Vigour	7/10/79	2.8	2.8	71	1.28	3.3	0.6
C. Vigour	7/10/79	4.2	3.4	71	1.12	3.7	0.9
Tenira	7/11/79	3.7	2.9	78	1.44	3.3	0.9
Tenira	7/11/79	NA	3.0	*	1.44	3.0	1.1
Tenira	7/12/79	3.0	2.3	78	1.44	3.1	0.7
Tenira	7/12/79	4.6	3.7	79	2.08	2.2	1.7
Tago	7/13/79	2.7	1.6	59	NA	NA	NA
Tago	7/13/79	2.3	1.6	72	NA	NA	NA
Tago	7/13/79	NA	1.7	NA	1.44	3.1	0.6

[1]Metric tons per acre.

Work was continued the past year in the development of a mechanical decapper. The design concepts of the decapper can be found in the CML decapper. Table 2 gives the results of some variety samples that were mechanically harvested and decapped.

Table 2. Mechanically harvested fruit put over decapper

Variety	Date	Decapped fruit[1] (%)	Pulping rollbacks[2] (%)	Sizer rejects[3] (%)	Grader rejects[4] (%)	Caps[5] (%)
C. Vigour	9/07/79	36	5	14	13	32
Tenira	9/07/79	40	8	8	24	20
Tenira	7/10/79	33	6	10	26	25
Tenira	7/11/79	31	14	11	23	21
Tenira	7/11/79	22	10	11	30	27
Tenira	7/12/79	26	10	11	27	26
Tenira	7/12/79	25	9	11	33	22
Tenira	7/13/79	27	7	10	36	20
Average		30	8	10	30	22
Tago	7/13/79	34	8	12	18	28
Tago	7/16/79	48	5	10	11	26
Tago	7/17/79	30	6	11	29	24
Average		35	7	11	20	27

[1]Decapped fruit consists of berries from which the calyx has been cut with the knife and is suitable for any form of freezing or canning.

[2]Rollbacks are those fruits with or without calyx that were collected at the lower end of the capper.

[3]Sizer rejects are made up of small fruits and pieces of fruit that fall through the sizer belts.

[4]Grader rejects are those fruits picked off the inspection belt which are not free of calyx.

[5]Caps consist of the calyxes with slithers of flesh, pedicels, peduncles, and any odd stolons or leaves that may be in the sample.

MECHANIZATION IN THE ITALIAN STRAWBERRY INDUSTRY

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Labor requirements are very high for Italian strawberry production, which yielded 211,500 metric tons from 13,800 hectares in 1979. This is probably because many strawberries are grown on small farms where labor is provided principally by the grower's family.

One hectare of field-grown (unforced) strawberries in the Po Valley, producing 18 t/ha, needs more than 3,000 hours of labor per year, 1/10 of which is for planting and 2/3 for picking. About 30 percent of the total acreage is forced under plastic tunnels of different sizes to obtain earlier production. Considering that tunnels must be placed in the field, covered with plastic film, opened and closed daily for ventilation during blooming, and finally disassembled at the end of the season, much more labor is required for tunnel (forced) culture than for open air (unforced) culture.

If many cultural practices such as mulching, spraying, herbicide distribution, and soil cultivation were mechanized, a tremendous amount of skilled human labor involved in strawberry production could be saved. Strawberries, after a number of very prosperous years, did not return fair incomes to our growers in the last two seasons.

Pick-your-own farms are unknown in Italy (the main production areas are distant from the largest towns). Of its total strawberry production, Italy consumes around 40 percent, exports 53 percent as fresh fruit, and processes only 7 percent. It is difficult to compete with the cheaper frozen product of Eastern Europe.

Efforts have been made to solve labor problems involving planting and picking (piecework is not permitted in Italy).

PLANTING

Strawberries are grown on black plastic mulched and raised beds. Mulching is normally done mechanically, and runner plants are planted by hand some days later. Planting capacity varies between 900 and 1,400 runners/day/person. A new machine recently introduced by a commercial company is able, in the same operation, to shape and raise a bed, to cover it with plastic film, to insert the plastic line for drip irrigation, to make round holes in the polyethylene film through which the plants will sprout, and to set the plants.

This equipment is drawn by a 63 kw (84 hp) tractor and requires four persons (one tractor driver, two persons to continuously feed the planting pins with runners, and an attending supervisor) to operate it. Planting capacity is 3,000 plants/hour/man. Four people can plant one hectare (40,000-50,000 plants) in less than two days. The holes in the plastic mulch are made by a rotating drum that was built for a prefixed planting density, and the drum must be changed if the planting density varies.

The cost of the machine is about $5,000, and each spare rotating drum costs about $300. Considering the present cost of labor in the Po Valley ($45 for 8 hours), this new machine shows considerable promise.

PICKING

Picking is always done by hand. An average picking rate of 9 kg of berries per hour is considered good. Two types of equipment have been proposed to our growers to reduce picking costs: platforms to transport pickers (already commercially available), and harvesting machines (still under study by several scientific institutions).

Platforms

Two types of picking platforms have been proposed to growers, both designed to carry seated pickers over the plants, but very different as to size and total cost.

The larger one can be used by up to 25 pickers, is 17 m (54.5 ft) wide, and is drawn by a platform operated by a 28 kw (37.5 hp) engine which can operate at speeds of from 14 km/hour to 8 mph (765 ft/min to 0.44 ft/min). Trials in 1978 and 1979 using different speeds (25-45 mph or 1.4-2.5 ft/min) showed that only the lower speed appears profitable, giving an increase in picking capacity of 15 to 20 percent. With higher speeds (35 or 45 mph = 1.9 or 2.5 ft/min), ripe berries were left on the plant (5 and 15 percent, respectively) in spite of the fact that two pickers were placed on each row with the highest speed.

The smaller platform has been designed for four pickers only; it is 4-5 m (12.8-16 ft) wide and is drawn by a diesel or electric engine of 1.5 kw (2 hp). The electric engine is suitable for operating under plastic tunnels, where a diesel engine could be dangerous to the pickers. The electric model can operate for 12 hours, which means more than two days of effective work in the field, considering that the movement of the equipment is discontinuous. One picker also acts as driver. This equipment gave, in some cases, a higher picking capacity of 15 percent.

Certain disadvantages are common to both of these machines: the pickers get tired after several hours of work. As a consequence, the picking rate slows down around midday and in the afternoon. The same pattern does not appear in the traditional hand-picking system, where the picking rate remains constant during the entire day. This is because the pickers are sitting in a fixed position over the plants and have to bend 50 cm or more to pick the ripe strawberries that lie on the raised bed row.

With the traditional harvesting method, pickers can change their position as they move along the rows, and this reduces tiring. As a consequence, the increased platform picking capacity of 15 to 20 percent that was reached during morning trials cannot be sustained through the day. In the afternoon, picking capacity is reduced, sometimes to levels lower than those of traditional picking.

These picking platforms need to be modified by placing the pickers not over the rows of plants, but in the alley between the two rows. Bending would be more limited and picking could be done on both sides of the worker. The result would be a higher and more constant picking capacity.

Mechanical harvesters

Three scientific institutions--Istituto di Meccanica Agraria of the University of Pisa (I.M.A.), Istituto Sperimentale per la Frutticoltura of Rome (I.S.F.), and Centro Studi di Tecnica Frutticola del C.N.R. of Bologna (C.S.T.F.)--cooperated in a special C.N.R. project for mechanical harvesting to design, build, and evaluate different strawberry harvesters.

Considering the varied Italian environmental situations and the more concentrated ripening season in the Po Valley, only the C.S.T.F. harvester is a "once-over harvester" (in which a cutting disk removes the whole plant). The other two institutions, recognizing the longer ripening season of the central and southern Italian areas, are both proposing a machine that strips the berries from the plant. In this case, more than one pass over the plants will be needed to harvest the whole crop.

All three machines are self-propelled and able to operate only on single rows. Only the machine of the C.S.T.F. is designed to operate on plastic mulched beds, while the other two must operate on clean soil or on straw-mulched beds.

The I.M.A. machine has a 11.03 kw (14.8 hp) engine and a minimum speed of 300 mph (986 ft/hr). The "picking head" consists of a rotating retractable scoop 568 mm wide with four series of round tines of 0.8 mm spaced 20 mm apart positioned in front of the machine. The angular speed of the scoop is 2.62 rad/s, corresponding to a terminal speed at the tip of the tines of 0.37 m/s. The berries stripped from the plant fall onto a rotating conveyor belt that lifts the harvested berries to an air blower that separates the leaves from the berries. After some years of trial, this machine appears to operate fairly well if the plants are planted in a well-shaped bed raised 10 to 15 cm above field level and not mulched with plastic film. That means, under Italian field conditions, that the machine would be able to operate only in fields planted to produce fruit for processing, since all fields planted to produce fruit for the fresh market are mulched with plastic.

In trials with 'Pocahontas,' 'Sunrise,' and 'Senga Sengana' the machine harvested from 40 to 60 percent of the berries on the plant, depending on the variety, lost from 5 to 25 percent on the ground and left from 8 to 22 percent on the plant. The berries left on the plant were mainly small, unripe fruits.

The I.S.F. machine has a 5.8 kw (7.7 hp) engine; the "picking head" consists of two roll-brushes mounted horizontal to the ground and making a 30-degree "V" angle with the direction of advancement. The two brushes, rotating in opposite directions, lift the plants and the berries with a movement that is synchronized with the speed of the machine. At the end of the "V", two rotating belts carry a series of plastic-covered iron fingers that strip the larger berries from the plant and lift them to the conveyor belt system of the machine. A hydraulic, but not automatic, system permits the brushes to be adjusted to compensate for field irregularities.

In trials with 'Aliso,' 'Pocahontas,' 'Senga Sengana,' and MD-US 3293, a selection from Beltsville with concentrated ripening, the machine harvested from 23 to 69 percent of the berries on the plant, lost from 4 to 25 percent on the ground, and left from 11 to 73 percent on the plant. The best results were obtained with 'Aliso' and the worst with MD-US 3293, in which small berries with short peduncles passed between the fingers.

The C.S.T.F. machine has two 31.5 kw (42 hp) engines, one directly connected with the driving wheels giving a minimum speed of 450 mph (1,476 ft/hr), and the second connected with all the equipment for berry harvesting. The "picking head" consists of two series of brushes 500 mm long carried by two rotating belts that lift the plants, berries, and leaves to the conveyor belt system of the machine (about 1 m above ground level). The two series of brushes make a "V" angle of about 35 degrees. It is important that the brushes are shaped in a way to clean the plastic mulch, lift and keep the plant erect until a rotating disk cuts it off just above the crown. Two years were needed to develop the latest model, which will be used for extensive trials in 1980. The model also has an automatic hydraulic system to adapt the picking head to ground irregularities of up to 10 cm.

In trials with an old model, in 1977, with 'Pocahontas' and 'Senga Sengana' the machine harvested from 70 to 85 percent of the berries on the plant and lost the rest of the crop on the ground. Nothing was left on the plant because the whole plant was cut off by the rotating disk.

CONCLUSIONS

In recent years, because of inflation, the cost of producing strawberries has increased continuously (from $.20/kg in 1970 to $.70/kg in 1976, and to $1.20/kg in 1979) at a rate of about 22 percent per year. The prices of the domestic and foreign markets followed this trend until two years ago. In the last two seasons the returns were, in many cases, lower than costs. Consequently, ways to reduce production costs are urgently needed. Otherwise, we will probably have a shortage of strawberry acreage and production in the near future.

MECHANICAL HARVESTING OF STRAWBERRIES IN OREGON

Dean E. Booster

Summary. Organized activities dating back to the mid-sixties and involving both the private and public sectors are directly responsible for making strawberry mechanical harvesting a reality in Oregon. Both the stripping method of harvest and the mowing method of harvest have been investigated extensively by Oregon State University. Coupled with the excellent progress in plant breeding and in the development of processing plant equipment and techniques for removing caps and stems from the machine-harvested fruit, a workable strawberry mechanical harvesting system involving the mowing method of harvest is now available to Oregon growers.

INTRODUCTION

Strawberries, one of Oregon's most important small fruit crops, have traditionally been harvested by hand. In recent years, since World War II, strawberry growers have turned to mechanization in an attempt to overcome problems associated with rapidly increasing production costs, uncertainties regarding the availability of adequate labor forces at harvest time, and the fact that picking strawberries by hand is a rather tedious, stoop-labor type of work that is becoming increasingly unattractive to our present-day society. Early attempts at mechanization led to the development of a series of picker aids. Simple, lightweight, wheelbarrow-type carts were used by many strawberry growers beginning in the fifties. The hand pickers placed the fruit directly into containers that were carried on these carts. Use of carts reduced the number of times the berries had to be handled and also relieved the hand picker of lifting and carrying the filled containers from the strawberry row to the check station. Many of these carts are still in use.

Personnel-carrying devices were used for a brief period beginning in the sixties. They ranged in size from one-row to 16-row machines. The multi-row personnel carriers consisted essentially of a picker platform, a cross-conveyor system onto which the pickers placed the harvested fruit containers. These machines were self-propelled and many of them were equipped with lights for night operation (Booster, 1963). Generally speaking, picker productivity was not increased sufficiently to make personnel carriers economically feasible and their use declined.

Iowa and Illinois are credited with some of the earliest attempts to harvest strawberries mechanically (Denisen and Buchele, 1966; Hoag and Hunt, 1965). Results of research in those two states, as well as in Arkansas and Ontario, Canada, were encouraging (Booster et al., 1969). The Oregon Strawberry Council, a grower-processor organization with voluntary membership, began to investigate the possibilities of harvesting strawberries mechanically in 1965. At a special meeting on February 7, 1966, the Oregon Strawberry Council appointed two committees. The first, the Strawberry Harvester Engineering Committee, was responsible for gathering ideas and actively promoting the development of a strawberry harvester. Members of the committee were representatives of strawberry growers, processors, equipment manufacturers, and Oregon State University. The second committee handled legislative and financial aspects of the program (Love, 1966).

Methods of detaching fruit from the plant were identified and tested by members of the Strawberry Harvester Engineering Committee. These included use of comb-like devices to strip the berries from the plant, vibration and stripping combined, vacuum, and mowing off the plants just above the ground. A Strawberry Harvester Field Day was held at the North Willamette Experiment Station on June 9, 1966, to demonstrate potential strawberry harvesting methods, to encourage people to present their own ideas for strawberry mechanical harvesting, and to assist in preparing specifications for a strawberry harvesting machine (Rasmussen, 1966a; Rasmussen, 1966b).

THE STRIPPING METHOD OF HARVESTING

Strawberries are grown in many parts of the world. Varieties and cultural practices may differ substantially with geographic location. Initial investigations were directed toward evaluating the potential of the stripping method of harvest under Oregon conditions.

Half-Row, Stripper-Type Harvester

The Oregon State University Department of Agricultural Engineering constructed and field-tested its first strawberry harvesting machine in 1967. The harvester (Fig. 1) was nicknamed "The Stripper." It was a half-row unit, i.e., it picked only one side of the row, and was pulled behind a tractor. A single-cylinder gasoline engine supplied power to operate the picking mechanism. The picking unit, a hollow, rotating, reel-like device 305 mm (12 in) in diameter and 560 mm (22 in) long, was mounted on a horizontal axis parallel to the row. Curved steel fingers with a radial length of 203 mm (8 in) and a diameter of 6 mm (0.25 in) were attached to bars located around the outer edge of the picking reel. The fingers were spaced 16 mm (0.75 in) apart. The combing action of the moving fingers stripped the berries from the strawberry plants. The detached berries were deposited on a horizontal conveyor, one end of which was located inside the hollow picking reel.

The OSU machine differed from the stripper-type harvesters under investigation in other parts of the country in that the direction of finger travel was perpendicular rather than parallel to the row. Operating from the side of the row enabled the picking unit to reach low-growing fruit with less chance of causing mechanical damage to the crown of the strawberry plant (Booster, 1967).

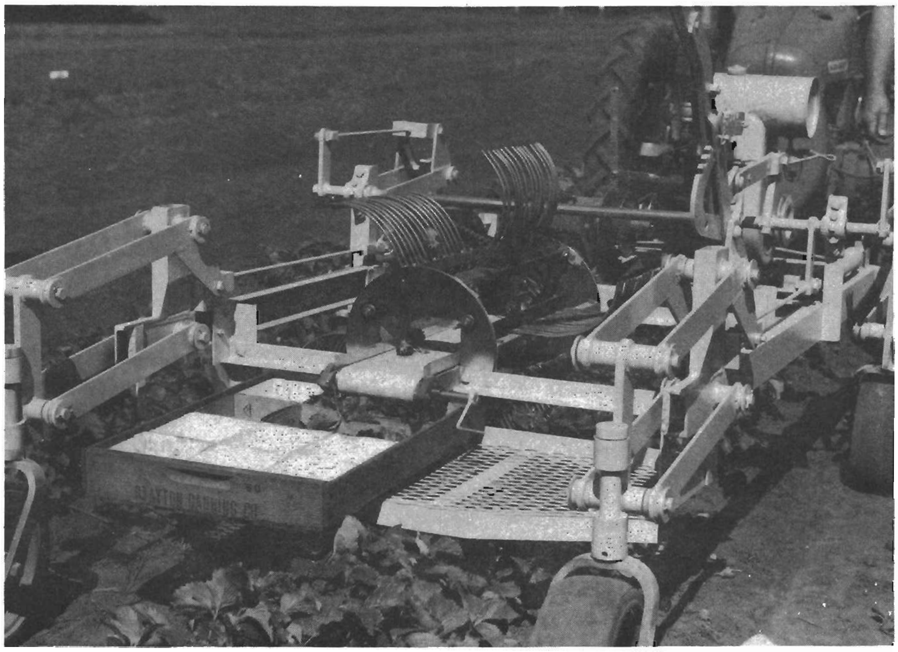

Figure 1. The Stripper harvester utilized curved, steel fingers to detach strawberries from the plants.

Field tests involving several strawberry varieties were conducted at the North Willamette Experiment Station as well as in commercial fields. Initial tests showed that the fingers of the rotating reel could be effective in detaching fruit from the plants. It became immediately apparent from the low picking efficiencies of the harvester, typical of those shown in Table 1, that the row configuration would have to be modified to accommodate the harvester. Quality evaluations of the mechanically harvested fruit were carried out by the Oregon State Department of Food Science and Technology.

Table 1. Picking efficiency of the half-row Stripper harvester compared with hand harvesting (Wrolstad et al., 1967)

Strawberry variety	Fruit harvested per unit row length (kg/m)		Picking efficiency
	Hand harvest	Machine harvest	
Northwest	1.93	0.45	23
Hood	1.28	0.45	35

Mechanical damage to the harvested fruit is summarized in Table 2. Severe mechanical damage included fruit that was broken, torn, seriously abraded, or internally soiled. Surface damage included small surface cuts and small lacerations. Much of the fruit classified as having surface damage was usable for processing into consumer products (Wrolstad et al., 1967).

Table 2. Mechanical damage evaluation of Stripper-harvested strawberries (Wrolstad et al., 1967)

	Northwest		Hood	
	Severe damage	Surface damage	Severe damage	Surface damage
	%			
Total damaged (all stages of maturity included)	6	15	7	21
Damage distribution (within maturity classifications)				
Overripe	14	18	6	14
Fully ripe	6	12	10	29
Moderately ripe	7	14	--	3
Slightly ripe	5	9	--	--
Green	1	1	--	--

Full-Row, Stripper-Type Harvester

A full-row self-propelled harvester (Fig. 2) was constructed and field tested in 1968. The harvester had a 2.54-m (100 in) wheel base, a 1.07-m (42 in) wheel tread, and was equipped with a hydrostatic drive. There were two picking reels, each 381 mm (15 in) in diameter. The larger diameter of the picking reels permitted use of wider conveyor belts than those used on the 1967 model. The picking reels and the fruit handling system, which consisted of two conveyor belts and a bucket elevator, were hydraulically driven. A separate engine was used to drive the fan in the pneumatic cleaning system.

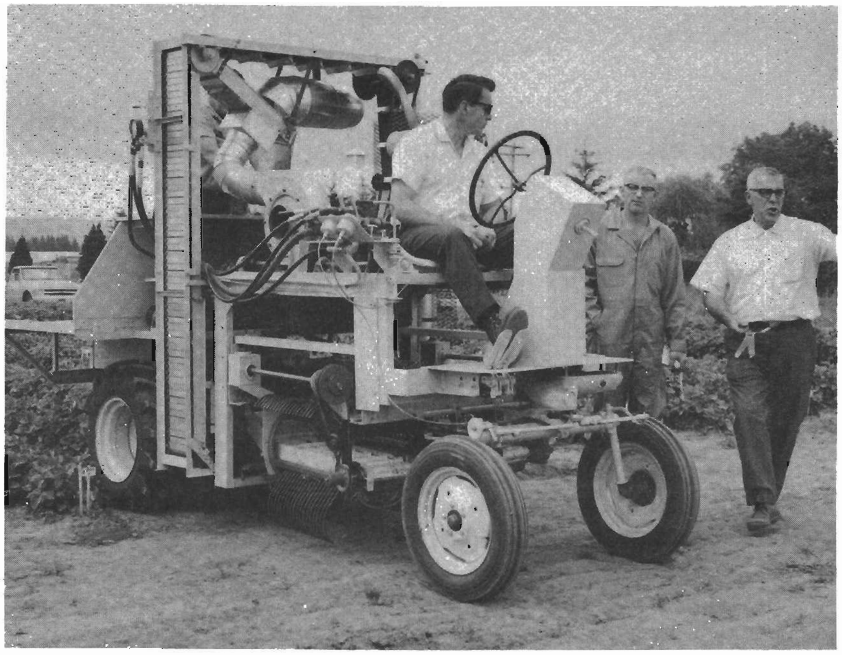

Figure 2. The 1968 Stripper was a self-propelled, full-row harvester and required an operating crew of two persons.

Larger diameter fingers and wider finger spacing were used on the 1968 model. Fingers with a 10-m (0.375 in) diameter and a 19-mm (0.75 in) spacing were incorporated in the machine to investigate the effectiveness of different finger diameters and the selective harvesting potential of fingers at various spacing.

The use of two picking reels permitted simultaneous harvest on both sides of the row. Synchronization of the revolving picking reels was achieved by means of a roller chain drive. Detached berries were deposited on a conveyor belt that moved them to the rear of the machine and dropped them into a bucket elevator that raised them to a convenient height for cleaning and crating. There were no provisions on the harvester for hand sorting the mechanically harvested fruit.

This type of harvester requires single-plant rows of uniform size and shape. Oftentimes, the strawberry plants are grown on ridge rows. The shape of the ridge profile is extremely important in terms of its effect on fruit recovery by the harvester. Good harvesting results were obtained when the path of the stripping fingers closely followed the ridge profile. In some instances, the harvester picked more than 90 percent of the fruit on the plant. When the ridge profile did not have the proper shape, excessive numbersof berries in the center of the row above the crown of the plant were not picked. Plant spacing within the row was also an important factor in fruit recovery. When the plants were close together, better fruit recovery was achieved because fewer berries were located in the center of the row that was inaccessible to the fingers. The picking reels did not operate satisfactorily on wide rows or on extremely large plants. Runner plants were pulled out of the ground, resulting in an increased load on the harvester's cleaning system. Fruit losses on the ground increased when the stripping fingers became plugged with vegetative material. The stripping fingers caused little or no plant damage on well-shaped, single-plant rows.

The 10-mm (0.375 in) diameter spring-steel fingers did not penetrate the plant foliage as readily as the 6-mm (0.25 in) diameter fingers used previously. Finger spacing determines, to a large degree, which berries will be picked and which will not. The 19-mm(0.75 in) spacing was not as effective as the 16-mm(0.625 in) spacing used in 1967 (Table 3).

Table 3. Harvest results of picking reel tests at North Willamette Experiment Station, June 27, 1968 (Booster, 1968)

Harvesting ground speed (km/h)	Picking reel speed (r/min)	Hand pickings before test	Ripe fruit on plot (t/ha)	Ripe fruit not picked by harvester (%)	Ripe fruit picked by harvester: Dropped on ground (%)	Ripe fruit picked by harvester: Recovered by harvester (%)
0.32	21	1	8.85	47.3	18.9	33.8
	21	2	4.33	66.2	17.7	16.1
	21	2	3.97	61.7	28.1	10.5
0.64	21	1	4.80	49.3	14.5	36.2
	21	1	7.31	51.4	10.5	38.1
	14	2	4.53	57.0	23.1	20.0
1.61	21	1	2.22	34.4	18.8	47.0
	21	1	6.77	69.0	12.4	18.6
	21	2	3.07	79.0	6.8	13.6

Mechanical damage to the machine-harvested fruit was not excessive and, in fact, compared favorably with hand harvesting. Quality evaluation of fruit harvested mechanically at the James Heater Farm on July 3, 1968, is shown in Table 4. Hand-picked fruit from the same field was also evaluated for mechanical damage. Fifty-one percent of the berries picked by hand from the same field on the same day showed evidence of some mechanical damage (Booster, 1968). A sample of Stripper-harvested berries is shown in Figure 3. Note that nearly every berry has the calyx and, in many cases, the stem attached. This is typical of fruit harvested with stripping-type devices.

Table 4. Quality assessment of machine-harvested strawberries from the James Heater farm, July 3, 1968 (Booster, 1968)

As received from harvester		Maturity distribution (%)				Quality distribution (%)		
		Immature		Ripe	Overripe	Damage free	Damaged	Mold and disease
Form	%	Green	Red					
Clusters	12.4	--	--	--	--	--	--	--
With caps and stems	32.7	28	16	48	7	44	53	22
With caps only	52.5	18	16	51	15	46	35	18
Free of caps and stems	2.4	--	--	--	78	--	--	--

Figure 3. Although varietal characteristics may differ, nearly all of the berries will have the cap (calyx) and stem attached when the stripping method of harvest is used.

Removal of some of the plant top growth had beneficial effects in terms of harvester operation. Fruit recovery was improved, and mechanical damage to the fruit was reduced slightly. A rotary lawnmower was installed on the front of the harvester to remove part of the leaf canopy.

Picking reel design refined

A new set of picking reels was constructed for the 1969 harvest season. These reels were shorter in length, smaller in diameter, and had 6-mm (0.25 in) diameter fingers with 16-mm (0.625 in) spacing between the fingers. Positive-drive chain conveyors in the center of each picking reel replaced the cleated belts used previously. Depth-gauge wheels were installed to assist in controlling the height of the picking unit above the ground.

Performance of the new picking reels was greatly improved over that of previous models. In most instances, 95 to 100 percent of the fruit was removed from the plant. The fruit recovery rate did not compare with the picking rates, unfortunately. Large numbers of detached berries were dropped onto the ground. Some of the berries fell to the ground because they missed the conveyors as the picking fingers were being unloaded. Others were carried over in clusters and dropped onto the ground between the rows because there was insufficient time for the picking fingers to unload. Tests were conducted with picking reel rotational speeds ranging from 10 to 22 rpm. With this range, picking reel speed seemed to have little effect on removing the fruit from the plants. However, fruit losses were less at the lower reel speeds. Typical harvest results are shown in Table 5.

Table 5. Harvest results of picking-reel tests at the North Willamette Experiment Station, June 12-15, 1969 (Booster et al., 1970)

Strawberry variety	Season yield on replicated hand-picked plots (t/ha)	Fruit recovered in a once-over machine harvest: Non-ridged rows — Percent of total yield	Ridged rows formed by special row-shaping tools — t/ha	Ridged rows formed by special row-shaping tools — Percent of total yield
Northwest	10.09	52	7.40	74
Hood	13.90	58	6.73	49
Tioga	10.98	--	7.62	69
WSU 1224	14.12	--	9.86	70
WSU 1232	16.14	--	10.31	64
WSU 1239	11.43	59	6.28	55

Row shape affects picking unit operation

A cross-sectional view of the full-row picking unit comprised of two picking reels is shown in Figure 4.

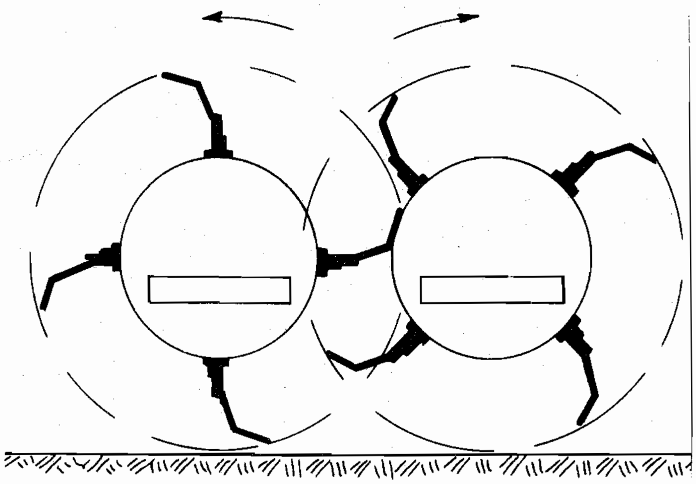

Figure 4. The picking units of the 1968 Stripper consisted of a pair of counter-rotating picking reels.

With the reel-type harvesting device, space adjacent to and immediately above the crown of the plant cannot be reached by the picking fingers. Any fruit located in this area is missed by the stripping pickers and reduces the effectiveness of the harvesting device. In cross-section, the area missed by the picking fingers is approximately triangular in shape, as indicated by the cross hatching in Figure 5.

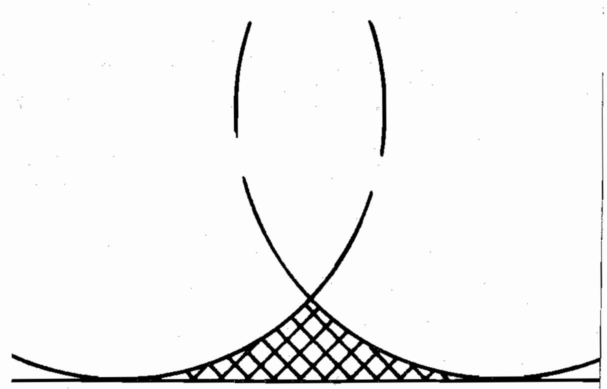

Figure 5. Areas over the center of the row were missed by the stripping fingers.

As shown in Figure 6, proper shaping of the row to conform more closely to the path of the picking fingers would reduce the area inaccessible to the fingers and thereby reduce fruit losses.

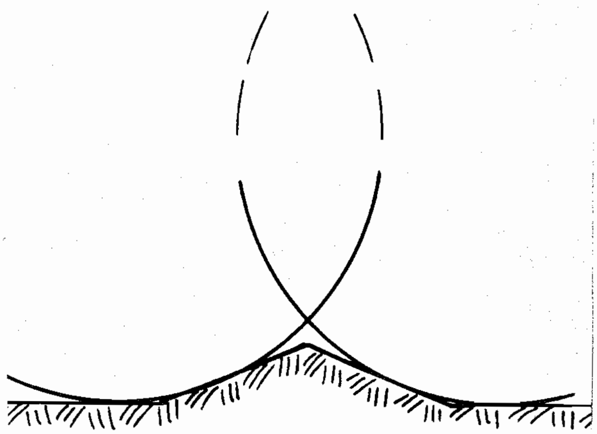

Figure 6. Picking reel effectiveness in fruit detachment and recovery were enhanced by properly shaped rows.

Two pieces of row-shaping equipment, a contour sled and a contour roller, were constructed and tested. Adjustable scrapers on the front of the contour sled move soil from the row centers inward toward the strawberry row to form the desired shape ridge. The contour roller was then used to compact the soil around the plants and to complete the row-shaping process.

Several benefits were derived from the use of the row-shaping devices in addition to reducing the area of the plants which, in unshaped rows, could not be reached by the picking fingers. The smoother soil surface improved the pick-up characteristics of the fingers as well as reducing the number of soil clods picked up during the harvesting operation. Firming the soil adjacent to the plants helped to keep the plants upright and to anchor them more solidly in the ground, thereby reducing the number of plants pulled out of the soil during harvesting operation. There was also some indication that row shaping made the fruit more accessible for hand picking (Booster, 1970).

Chain-bar picking unit

The excessive fruit losses on the ground led to construction of the chain-bar unit near the end of the harvesting season. A simplified diagram of the unit is shown in Figure 7.

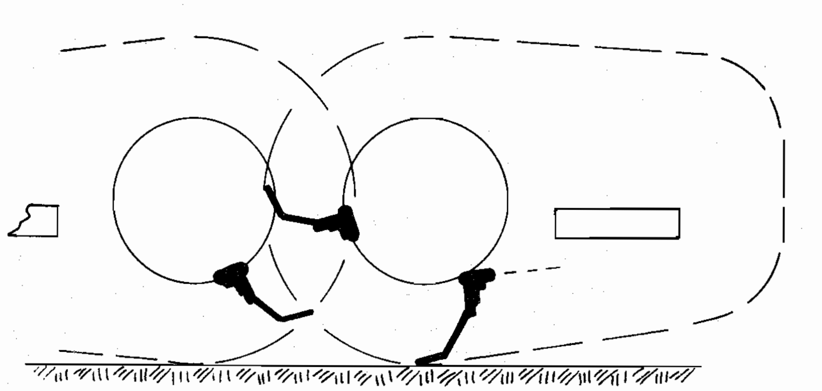

Figure 7. The chain-bar picking unit was developed to increase stripping finger unloading time and thereby reduce fruit losses.

The picker bars containing the stripping fingers were attached to strands of roller chain rather than to the periphery of a hollow reel. This modification approximately tripled the unloading portion of the finger-travel cycle. The chain sprockets were sized so that the finger-travel through the plants was identical to that of the picking reel. Finger size, shape, and spacing on the chain-bar units were identical to those used on the picking reels. Fruit recovery rates with the chain-bar picking unit were noticeably improved over those of the picking reels. Consequently, testing and development of the picking reel unit was discontinued. The Stripper harvester was operated at the North Willamette Experiment Station and on one commercial strawberry farm in 1970. Nearly all of the tests were with 'Northwest' variety. Harvest results of some of the tests are summarized in Table 6. The average yields on plots with 380-mm (15 in) plant spacing with 8.5 mt/ha (3/8 t/a) and 26.0 mt/ha (11.6 t/a) on plots with 152-mm (6 in) plant spacing. The operating speed of the Stripper was approximately 0.40 km/hr (0.25 mph).

Generally speaking, the chain-bar unit was effective in removing fruit from the plants. However, as shown in Table 6, significant percentages of detached berries were dropped onto the ground and lost. Some of the fruit losses occurred when the stripping fingers did not unload properly. In other instances, the detached berries dropped back onto the plants. High-speed motion pictures showed that this loss occurred in at least two ways. The combing action of the fingers through the plant foliage caused some fruit to drop off the ends of the picking

Table 6. Harvest results of chain-bar picking unit tests at the North Willamette Experiment Station, 1970 (Booster, 1971)

Northwest strawberries	15-inch plant spacing 16-plot average	15-inch plant spacing Range	6-inch plant spacing 6-plot average	6-inch plant spacing Range
	%			
Picked and recovered	70	49-82	67	51-77
Picked but not recovered	20	8-34	27	21-35
Not picked	10	2-24	6	2-14

fingers. In other instances, the resilient characteristics of both the fruit and the stems produced a "sling-shot" effect when the berries were stripped off the plants. The detached berries were thus propelled outside the effective combing area of the fingers and dropped back onto the ground.

The chain-bar unit was of simple construction and had relatively few moving parts. It was effective in detaching the berries from the plants when operating on properly prepared rows. Mechanical damage to the harvested fruit and the presence of foreign material were within acceptable limits. The machine-picked berries could be handled in the same containers used for hand-harvested fruit. The major shortcoming of the Stripper was its low field capacity. The harvester had been tested at various ground speeds, but the best results were obtained at speeds of approximately 0.40 km/hr (0.25 mph) (Booster, 1971).

Other Picking Devices Tested

Several other picking devices were tested on a laboratory basis in 1967. The first group consisted of a series of four cantilevered, rotating-roll picking units. Essentially, they consisted of adjacent pairs of counter-rotating rolls having their axis of rotation parallel to the row and mounted in an inclined position with their leading ends nearest the ground. The rolls were equipped with helical flights, giving them the appearance of modified conveyor screws. The rolls ranged in size from 19 mm (0.75 in) diameter with 10-mm-high (0.375 in) steel flights to 76-mm-diameter (3 in) rolls with 11-mm-high (0.4375 in) sponge rubber flights. In operation, the pointed, cantilevered ends of the rotating rolls would move through the plant foliage. Leaf stems and fruiting trusses would be guided into the space between adjacent rolls. As the unit moved down the row, the berries were stripped off the plants by the rotating rolls. Leaves and small berries passed between the rolls and remained attached to the plant. The helical flighting served as a conveyor for the harvested fruit. A set of smooth rolls 19 mm in diameter (0.75 in) was also tested.

The second group of picking units consisted of a series of 10 mm by 19 mm (0.375 in by 0.75 in) steel bars placed on the edge and inclined with respect to the ground. The distance between the parallel bars was controlled by means of spacers. As the unit moved down the row, the berries would slide up the inclined bars and be stripped from the plant. All units tested were capable of detaching fruit from the plants under certain conditions. All units were deficient in their ability to penetrate plant foliage and to pick up low-growing berries. The rotating-roll units were judged to be superior because there was less mechanical damage to the harvested fruit. None of the units, however, approached the harvesting effectiveness of the picking reels (Booster, 1968).

The Stripper had been designed to serve as a tool carrier to facilitate testing of other picking devices. In addition to the revised version of the original picking reels and the chain-bar unit mentioned, a floating-shoe unit and a mowing unit were field tested in 1969.

The floating-shoe unit was designed to see how effective a low-profile device following the contour of the ground would be in picking up fruit-bearing trusses. The forward travel of the harvester would cause the trusses to be lifted off the ground. When the trusses reached a predetermined position on the shoe, a suitable cutting device would detach the truss from the plant. A conveyor would then move the detached fruiting truss to an appropriate container for transport to the processing plant. On the units tested, an electrically powered hedge trimmer was used to detach the fruiting trusses and a series of travelling brushes was used to move the plant material from the point of detachment onto a conveyor belt. Field test results did not correspond to the findings of preliminary model studies and the floating-shoe unit was abandoned.

THE MOWING METHOD OF HARVEST

The mowing method of harvest has been under consideration for some time. It had been demonstrated at the 1966 Strawberry Harvester Field Day by using hand-operated hedge shears to cut off the strawberry plants. Prior to that, two Sublimity, Oregon, strawberry growers, Maurice and James Heater, had experimented with a mowing-type harvester. The primary deterrent to the mowing method of harvest at that time was lack of a mechanical method to separate the fruit from the large amount of vegetative material in the field-run machine-harvested product. Evaluations of various strawberry cappers, cherry- and grape-stemming devices, and ultimately, the development of a workable system for removing the vegetative material by Dale E. Kirk, Oregon State University Agricultural Engineering Department, renewed interest in the mowing method of harvest (Kirk, 1970).

Cutting Devices Tested

The unit constructed and tested in 1969 consisted of a cutting device and a wire mesh conveyor belt that transferred the detached material to the existing bucket elevator of the harvester. A number of reciprocating knives and cutting devices, including three electrically powered hedge trimmers, were field tested. One of the hedge trimmers was considered superior to the others because of its ability to handle heavy vegetative growth and thereby permit a greater speed of travel down the row. The unit had two reciprocating knives and no fixed guard. Two pea lifters, the type commonly used on grain combines, were attached to the cutter bar assembly to assist in lifting the fruit-bearing trusses off the ground ahead of the reciprocating knives. The forward motion of the harvester was not sufficient to prevent a buildup of detached plant material on the cutter bar. Consequently, it was necessary to provide mechanical assistance in moving the detached material from the cut-off point onto the conveyor belt. Although the 305-mm-wide (12 in) wire-mesh conveyor belt, the harvester's pneumatic cleaning system, and its bucket elevator proved to be inadequate to handle the large volume of vegetative material encountered, results of field tests were encouraging.

Field work on the mowing method of harvest continued after the regular strawberry season by utilizing plant material in the strawberry breeding program. This extended season made it possible to test other lifting and cutting devices. A mower having two reciprocating knives and no fixed guards, similar in configuration to the hedge trimmer used during the regular season except much larger, was among the devices tested. This machine, manufactured by J. A. Freeman and Son, a Portland, Oregon, agricultural equipment manufacturer, was chosen to be the cutting device for the future mowing-type harvester.

The Clipper Harvester

The Clipper harvester (Fig. 8), built in 1970, used the mowing method of harvest. It was a pull-type machine 4.11 m (13.5 ft) long and having a 2.13-m (84 in) wheel track. The cutting mechanism was a Freeman mower cutter bar reduced in length to provide a 610-m (24 in) width of cut. A 610-mm(24 in) wire-mesh belt was used to transfer the detached material from the cutter bar to the pneumatic cleaner. The harvested fruit was then transferred to plastic containers by means of two rubber-covered conveyor belts. The harvester components, with the exception of the cleaning fan, were hydraulically driven. A 13.42-kw (18 hp) gasoline engine was the prime mover for the hydraulic pump. A second 13.42-kw engine was directly connected to the cleaning fan.

The Clipper was field tested at the Lewis Brown Horticulture Farm, the North Willamette Experiment Station, and on five commercial farms in 1970. Results of some of these tests are summarized in Table 7.

Figure 8. Field testing the Clipper at the North Willamette Experiment Station, 1970.

Table 7. Picking effectiveness of the Clipper harvester, 1970 (Booster, 1971)

Berries	Northwest 11-plot average	Northwest Range	Hood 3-plot average	Hood Range
	%			
Picked and recovered	50	22-88	40	25-59
Picked but not recovered	27	9-38	35	31-38
Not picked	23	2-46	25	10-40

The harvested product from the Clipper is quite different from that of the Stripper. Cutting off the entire plant just above the ground results in much of the fruit still being attached to the main truss and there is a very high percentage of berries in clusters. The standard 12-hallock berry crate normally used when picking by hand was not suitable for the Clipper harvester because increased amounts of leaf and stem material were present. Consequently, a bulk handling system had to be devised. The initial attempt at bulk handling was to use plastic lug boxes with nest-stacking capabilities. This kind of container is also being used on strawberry harvesting machines in various parts of the country. Data collected during the 1970 season showed that, on a weight basis for Northwest strawberries, 81 percent of the material delivered from the pneumatic cleaner was fruit. The remaining 19 percent was leaf and stem material. Data collected from 10 years of field testing using the mowing method of harvest indicates that a weight division of 80 percent fruit and 20 percent nonfruit is a reasonable average for the mowing method of harvest regardless of the strawberry variety. Clipper-harvested fruit is shown in Figure 9.

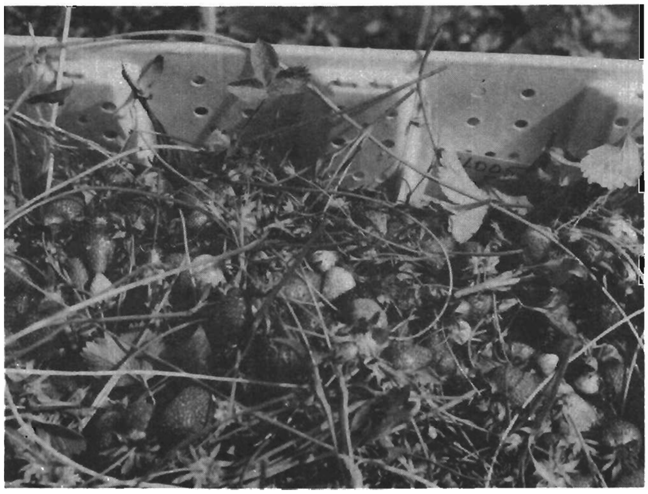

Figure 9. Large numbers of berry clusters are included in the field-run product from a mowing-type harvester.

The effectiveness of the Clipper was limited by performance of the gathering and pick-up mechanisms and by field conditions. Flat rows and a reliable lifting and gathering system are necessary for the successful operation of a mowing-type harvester. It became immediately apparent that the Clipper could operate at much higher ground speeds than the Stripper. The cleaning and conveying systems and the facilities for handling both empty and filled plastic lug boxes limited the maximum harvesting speed (Booster, 1971).

Stripper and Clipper compared

Evaluation of the 1970 field tests using the Stripper and the Clipper harvesters led to the conclusion that the mowing method of harvest had a greater potential for success than the stripping method. The mowing method was more versatile because it could be used on single-plant rows, on matter rows, or with bed-type cultural practices. The faster operating speeds would increase harvester field capacities. The quality of the fruit was as good or better than that harvested with the Stripper. In addition, substantial progress had been made in development of equipment for capping and stemming fruit from a mowing-type harvester. Consequently, further testing and development of the Stripper was discontinued.

Clipper development continued

During the ensuing years, the Clipper has undergone numerous modifications. A variety of lifting devices to assist in elevating the fruiting trusses over the cutter bar have been investigated. In 1971 alone, 11 different lifters involving modified half-sweep cultivator shovels, articulated fingers, and fixed fingers were tested. Ultimately, eight fixed-finger lifters were attached to the cutter bar and are currently in use. The four interior lifters are spaced 76 mm (3 in) apart while a 51 mm (2 in) spacing is used between the outer lifters. The lifters are approximately 152 mm (6 in) long.

The original gathering device consisted of a series of cam-positioned, tined bars carried between two strands of roller chain. The finger-studded bars produced a combing motion to help move the vegetative material over the cutter bar and onto the conveyor belt. This was replaced by the 610-mm-diameter (24 in), six-bar, tined pick-up reel (similar in configuration to those used on grain combines). See Figure 10.

Figure 10. The Clipper was one of the machines included in the Pacific Northwest Regional Commission Project field tests in 1978 and 1979.

Extra tines were added to the reel bars so that the tine spacing was reduced from the standard 102 mm (4 in) to 51 mm (2 in). No changes have been made in the double reciprocating knife Freeman mower cutter bar which has standard 76 mm (3 in) knife sections. The pneumatic cleaning system has undergone numerous modifications to increase its cleaning capacity. Changes had to be made in the materials handling system to accommodate faster harvester ground speeds. With the harvester operating at 0.80 km/hr (0.5 mph) on a (7 t/a) yield with 1.07-m (42 in) row spacings, lug boxes are filled at the rate of approximately four per minute. Leaf and stem removal capacity and handling of the harvested product are the primary machine-related factors that limit the harvesting rate.

Clipper use in the plant breeding program

The Clipper harvester has a role in Oregon's strawberry plant breeding program. It is the "standard machine" used to assist the plant breeder in evaluating plant and fruit characteristics to determine their suitability for mechanical harvesting. Experimental strawberry selections are propagated and grown at the North Willamette Experiment Station. Plots of those selections identified by the plant breeder as being worthy of further consideration are harvested with the Clipper. The machine-harvested fruit is then taken to the Food Science and Technology Department pilot plant for processing and quality evaluation. Some of the results obtained during the 1979 harvest season are shown in Table 8.

Pacific Northwest Regional Commission project

Strawberries have been mechanically harvested in Oregon since 1967. Progress has been made in developing strawberries with concentrated ripening and high-yield characteristics and in the development of field harvesting and processing plant equipment. But, for the most part, machine harvesting has been carried out on a rather limited scale. In 1978, a two-year project sponsored in part by the Pacific Northwest Regional Commission, was undertaken to demonstrate on a commercial scale the state of the art of strawberry mechanical harvesting and processing. Cooperators in the project included growers, processors, equipment manufacturers, the Oregon Department of Agriculture, and Oregon State University. The Clipper was one of three harvesters included in the project. Field tests in this project were conducted at the North Willamette Experiment Station and on two commercial farms. Machine-harvested lots of 'Benton,' 'Linn,' and 'Olympus' strawberries were delivered to two commercial plants for processing into consumer products.

OTHER STRAWBERRY HARVESTERS

The challenge of strawberry mechanical harvesting has stimulated the interest of numerous individuals and public institutions in the United States and in other parts of the world. Oregon has been a test site for several of the machines resulting from the acceptance of this challenge.

Table 8. Yields and damage percentages of strawberry selections harvested with the Clipper in 1979.

SELECT NUMBER	HARV DATE	TOT YIELD (LB/ACRE)	UNDERSIZED FRUIT (% OF TOT)	RIPE (LB/ACRE)	FRUIT (% OF TOT)	DAMAGED FRUIT (% OF RIPE) MECH.	OTHER	HARVEST RECOVERY (% OF TOT)	USABLE CAPPED RIPE FRUIT (LB/ACRE)
4951	6/25	31961.	25.7	20701.	64.7	7.5	7.9	57.5	12472.
4688	6/18	26236.	12.1	18981.	72.3	3.6	.6	61.8	11280.
4927	6/16	23796.	14.4	16842.	70.6	.6	.3	91.6	9779.
573-1	6/19	20361.	14.4	14656.	72.0	1.1	5.0	95.1	9160.
4474	6/18	23896.	12.1	17601.	73.7	3.6	.7	77.5	9122.
4442	6/18	19366.	10.6	11994.	61.9	2.9	1.0	85.1	8951.
4682	6/19	19614.	20.1	13448.	68.2	9.8	1.0	75.9	8134.
4930	6/19	18364.	19.8	12089.	65.4	7.7	1.1	83.7	8125.
4955	6/19	20610.	16.8	15309.	74.3	6.2	1.6	83.6	7386.
4357	6/18	23498.	16.7	16847.	71.5	11.5	1.0	89.3	7260.
4637(1)	6/21	23896.	7.8	18966.	79.2	10.3	4.0	76.3	7117.
4932	6/21	22801.	32.7	13265.	58.1	4.6	2.3	81.4	7030.
4681(2)	6/16	12740.	14.7	9109.	71.3	1.0	.7	68.3	6787.
4948	6/25	17972.	25.7	12486.	69.8	6.9	7.5	69.0	6568.
4681(1)	6/16	11623.	13.4	8768.	75.6	5.8	.9	84.9	6474.
4356	6/18	24593.	35.6	15029.	61.1	8.7	9.5	80.2	6397.
4637(2)*	6/25	19750.	18.9	14612.	74.0	13.7	7.3	48.9	6038.
4921	6/21	9658.	8.7	7972.	82.5	3.8	7.7	64.9	5595.
4826	6/19	15931.	8.1	12994.	81.5	8.3	.8	65.6	5164.
4937	6/16	32558.	15.2	19133.	58.7	2.3	.3	79.4	5144.
4348	6/18	28526.	6.3	22222.	78.0	2.4	1.9	94.8	5096.
5079	6/21	9770.	26.3	6538.	67.0	1.1	5.6	84.7	4775.
4428	6/19	14188.	41.2	7678.	53.8	13.8	1.4	89.5	4340.
701712(1)	6/16	9334.	7.5	8130.	87.1	4.5	2.1	93.0	3948.
4816	6/16	11533.	10.4	7549.	65.5	4.0	.4	69.2	3445.
4778	6/25	10405.	37.7	5693.	54.7	20.7	6.9	50.7	3435.
4821	6/25	17922.	44.2	9124.	50.9	14.9	3.6	91.7	3367.
4793	6/25	8563.	35.0	4909.	57.3	18.9	4.4	91.3	3218.
701712(2)	6/19	9155.	11.7	7789.	85.1	16.1	2.4	74.9	3138.
6027	6/21	13773.	14.9	9524.	69.1	3.1	1.5	75.5	3077.
4934	6/18	20560.	14.6	9572.	46.7	5.9	1.2	87.9	3059.
4825	6/21	24038.	13.4	17526.	72.7	7.3	2.1	89.5	2806.
4817	6/16	13753.	17.8	8009.	58.1	3.2	.3	80.5	2138.
701712(3)*	6/19	4718.	16.2	3729.	79.0	3.8	2.3	83.9	1158.
4681(3)*	6/21	3962.	24.0	2822.	72.0	25.0	1.9	76.4	950.
BENTON	6/19	-----	16.5	-----	71.2	8.2	.7	----	-----

Usable, capped, ripe fruit yields and fruit damage percentages were determined after the machine-harvested fruit had been processed once over the OSU capper-stemmer.

The numbers in parentheses indicate the times a particular selection or variety was machine harvested.

The unripe category of harvested fruit includes both green and over-ripe fruit.

The "other" damage category includes fruit with seedy tips, mold, rot, and insect damage.

Certain plots may have contained more total plants than shown, but values shown were adjusted to the percentages of harvested product processed by the Food Science and Technology Pilot Plant at OSU.

------- indicates missing data or data not separately evaluated this year.

* indicates plots hand-harvested once before the machanical harvest.

Iowa State University Harvester

A machine developed by Iowa State University was tested at the North Willamette Experiment Station in 1970. The picking mechanism consisted of a 510-mm-wide (20 in) row with plants 7.9 mm (0.4 in) apart. The 20-mm-long (8 in) rods were attached to an inclined frame so that the longitudinal axis of the rods was in a vertical plane parallel to the row. Four vertically inclined, pivoted arms connected the picking unit to the harvester's main frame. A crank mechanism caused the picking unit frame and attached fingers to oscillate with a motion parallel to the row. When in operation, the harvester stripped strawberries from the plants and, as a result of the oscillating motion, conveyed them toward the rear of the machine. A 16-mm (0.625 in) stroke at 16.67 hertz (1,000 cycles per minute) had been effective for fruit removal under Iowa conditions (Booster et al., 1969), but the machine was not successful in harvesting Oregon strawberry varieties. The large crowns and dense foliage of the Oregon berries caused serious plugging problems that rendered the picking unit ineffective.

University of Arkansas Harvester

A vacuum-assisted, stripper-type harvester developed at the Fayetteville campus of the University of Arkansas was field tested in several locations in Oregon in 1973. Steel fingers attached to bars carried between two strands of roller chain detach the berries from the plants. The picking unit is housed inside a metal duct which is open to the atmosphere at the lower end. High-velocity air entering the duct lifts the fruiting trusses off the ground so they are accessible to the stripping fingers. This machine is now made commercially by Blueberry Equipment, Inc., South Haven, Michigan, and is referred to as the BEI harvester more commonly. Two two-row BEI harvesters were operating in Oregon in 1979. A BEI harvester was included in the Pacific Northwest Regional Commission demonstration project.

SKH&S Harvester

Four Willamette Valley strawberry growers (SKH&S) pooled their ideas and resources and produced a mowing-type harvester that was first operated on a commercial scale in 1970. The first two machines were self-propelled. Experience gained in operating these machines led to design changes that were incorporated into the two pull-type harvesters used in 1979. Proper field preparation is essential for the successful operation of any mechanical harvester. SKH&S also developed row-shaping equipment for use in conjunction with its harvester. The SKH&S harvester was also included in the Pacific Northwest Regional Commission project.

CML Harvester

In 1977, Canners Machinery, Ltd. of Simcoe, Ontario, Canada, working cooperatively with Michigan State University, brought a mowing-type harvester to Oregon which had been developed in England. It was a tractor side-mounted unit operated from the tractor PTO. Further testing of the CML harvester has been carried out in Michigan.

Bush Bean Harvester

One enterprising Willamette Valley strawberry grower has been using his two-row Chisholm-Ryder bush bean harvester to pick strawberries on a clean-up operation basis when hand pickers are no longer available. Very few modifications were required for strawberries. The picking reel speed was reduced and the elevator was lowered to facilitate sorting and crate handling. The crew consisted of the operator, two sorters, and a crate handler. Approximately 25 acres were harvested in 1979. The machine-harvested fruit was used for juice and puree.

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POSTHARVEST HANDLING OF MECHANICALLY

HARVESTED STRAWBERRIES IN OREGON

Dale E. Kirk

Soon after the system of combing strawberries from the side of the plant row was tested in Oregon in 1967, a search was made for capping and stemming equipment that would work satisfactorily on mechanically harvested Oregon fruit. Several machines were found in Germany, Italy, Canada, and the United States. Also, patents were reviewed for many machines not now in production (3, 4, 10, 11, 12, 14, 15, 16, 17, 18, 19). Nearly all used some arrangement of smooth, counter-rotating, neoprene-covered rolls working together in pairs or in combination with stainless steel rolls having sharp edges resembling milling cutters. The roll sizes varied from 3/8 in (9.52 mm) to 5/8 in (15.88 mm) in diameter (Booster et al., 1969). None of these machines appeared to be more than 40 to 60 percent effective in removing caps and stems from the berry varieties grown in the Pacific Northwest at that time (6, 8).

Between 1968 and 1972, workers in California, Michigan, and Oregon tested various methods for orienting single berries so that the stem and sepal might be cut off by a high-speed knife or saw blade. Photo cells were used to identify the cap end and various means were used to reverse the fruit or reverse its movement toward a cutter as needed (9). Liquid flotation, air flotation, polarizing in high voltage fields, spinning, and sliding on various-shaped, inclined surfaces were all attempted without success. Workers in Oregon and Michigan investigated grasping the stem of single berries by counterrotating soft rubber rolls and passing the fruit across a high-speed cutting band to remove the cap and stem. This system was developed into commercial-sized machines and tested in Michigan (Ledebuhr et al., 1977).

Meanwhile, Oregon workers devised and tested a sharp-freeze system of cap and stem removal (6). Single berries or berries in cluster form from mechanical harvesters were frozen below the eutectic temperature and tumbled in a device resembling a lapidary rock tumbler. The brittle caps and stems were shattered without cracking the fruit. While this system could produce a packaged frozen product of high quality freezing the barriers before capping, stemming, and sorting involved a major change in existing practices of processing plants and was not readily accepted.

By 1970, Oregon plant scientists strongly emphasized easy cap and stem removal in their breeding program for cultivars especially adapted to mechanical harvesting. Since the accepted mechanical harvest system by OSU researchers was the mowing method (2), subsequent handling and processing systems were geared to handle fruit in cluster form after most of the leaves had been removed in the field. The machine that was developed in Oregon for removing fruit from the branched trusses now became a device which could remove stems and caps from the fruit if a proper abscission layer could be bred into the plant. This device consisted of counterrotating soft (29 Durameter) neoprene-covered rolls 1¼ in (3.18 cm) to 1-3/8 in (3.49 cm) in diameter. Clusters of fruit were carried onto the sloping bed of rollers by flume water. Overhead water jets were used to form a hydraulic dam for holding the clusters temporarily and for directing the stem ends into the pinch points of the rollers. If the berry had a natural weakened juncture between the fruit and the cap, the stem and cap would pull loose, leaving a clean, untorn fruit behind. This device has been used by the OSU Food Science and Technology Department since 1972 to evaluate the capping ease of all new breeding selections harvested and processed for examination as potential new commercial varieties. The capping ease must be bred in along with the other desired qualities of flavor, color, firmness, shape, yield, concentrated ripening, resistance to disease, virus and insects, and erect fruiting habits.

A vibrating bar screen placed in line with the rollers was used to drop out undersized fruit. Since most of the green fruit was undersized, the screen removed most green fruit from berry plants that displayed good concentrated ripening.

By 1976, Oregon and Washington plant scientists had progressed in their selective breeding program to where 40 to 75 promising test crosses were mechanically harvested and processed each year. Table 1 shows the capping success on 19 of the 65 breeding selections tested in 1976.

Table 1. Selections with best capping characteristics in 1976

Selection number	Capped usable fruit (t/ha)	Capped usable fruit (lb/acre)	Percent ripe fruit capped	Selection number	Capped usable fruit (t/ha)	Capped usable fruit (lb/acre)	Percent ripe fruit capped
4691	8.28	7,391	93.3	4692	15.11	13,480	85.9
4709	11.84	10,120	93.1	4700	13.01	11,610	84.9
3774	8.73	7,790	91.1	4690	10.16	9,060	83.9
4699	9.51	8,480	90.6	Linn	8.77	7,820	83.8
4600	7.24	6,460	90.4	4579	6.60	5,890	83.8
4697	11.01	9,820	89.3	4443	10.58	9,440	83.7
4695	10.84	9,670	87.9	Linn	3.79	3,380	83.3
4682	13.44	11,990	87.0	68-15-13	7.08	6,320	81.7
4640	8.37	7,470	86.2	4719	10.82	9,650	80.0
4688	11.95	10,660	86.1	--	--	--	--

Stem removal from the fruit was 98 to 100 percent for all 65 selections. Five selections showed 90 percent or better cap removal, and 19 selections showed better than 80 percent removal of caps. With the once-over mechanical harvest and process system, 9 of the 19 selections that were successful in capping yielded better than 10.312 t/ha (9,200 lb/acre) of capped usable fruit, the Oregon average for multiple hand harvest in 1976.

In 1977, 41 selections were tested. Table 2 shows that more than 80 percent of the fruit from 13 of these mechanically harvested selections was capped and stemmed mechanically. Seven of the 13 selections yielded more capped usable fruit from one mechanical harvest than the 1977 state average of 7.40 t/ha (6,600 lb/acre) for multiple hand picking.

Table 2. Selections with best capping characteristics in 1977

Selection number	Capped usable fruit (t/ha)	Capped usable fruit (lb/acre)	Percent ripe fruit capped	Selection number	Capped usable fruit (t/ha)	Capped usable fruit (lb/acre)	Percent ripe fruit capped
4916	8.82	7,866	92.5	4445 (2)	10.09	9,001	84.9
4690	8.09	7,219	90.7	4459 (2)	11.03	9,838	84.9
4697	7.25	6,472	88.9	4709	6.47	5,775	84.2
4512 (2)	1.51	1,351	88.7	4867	9.82	8,762	83.6
4512 (1)	7.68	6,854	88.2	4459 (1)	10.60	9,459	81.7
4831	7.07	6,306	86.5	4826	7.37	6,571	81.3
4445 (1)	6.06	5,410	85.8	--	--	--	--

In 1978, 52 selections were mechanically harvested and processed in 62 separate lots. As shown in Table 3, 15 lots from 10 of the selections capped and stemmed better than 80 percent. Three of the lots produced yields of more than 7.62 t/ha (6,800 lb/acre) of capped usable fruit, exceeding the Oregon 1978 average for multiple hand-picked fruit. Three of the lots had been hand picked one or two times prior to machine harvesting.

PACIFIC NORTHWEST REGIONAL COMMISSION PROJECT

Effective February 14, 1978, funding was authorized by the Pacific Northwest Regional Commission to "demonstrate, evaluate, and refine the technology of mechanical harvesting, handling, and pre-processing cleanup of strawberries...." This effort was to include field-scale mechanical harvesting tests on three strawberry varieties harvested by two commercial units and the OSU experimental harvester.

Table 3. Selections with best capping characteristics in 1978

Selection number	Capped usable fruit (t/ha)	Capped usable fruit (lb/acre)	Percent ripe fruit capped	Selection number	Capped usable fruit (t/ha)	Capped usable fruit (lb/acre)	Percent ripe fruit capped
4637 (3)*	3.60	3,211	89.5	4459 (2)	7.32	6,531	85.1
4637 (2)	5.52	4,925	88.8	4646	4.82	4,297	84.2
4619	5.19	4,634	88.8	4806	6.25	5,573	81.3
4823	6.41	5,723	88.4	4459 (1)	8.00	7,137	81.0
4696 (1)	4.85	4,331	87.2	4459 (3)*	6.62	5,905	80.6
4867	10.37	9,248	86.5	4696	2.54	2,266	80.2
**4459(4)	5.11	4,560	86.2	4695	5.75	5,128	80.1
4848	8.18	7,295	85.6	--	--	--	--

*Hand picked once prior to machine harvest.

**Hand picked twice prior to machine harvest.

Two new OSU capper-stemmer units, patterned after the unit used to test breeding selections for capping ease, were constructed and installed in two processing plants to operate beside industry-owned in-plant equipment for handling mechanically harvested fruit. Each of these machines provided a bed width of one foot (30.5 cm). One of these machines is shown in Figure 1. One of the processing plants was using clean-up equipment designed to remove dirt, loose stems, leaves, and other trash before the fruit was hand sorted and processed for puree or juice. Most of the mechanically harvested fruit received by this plant came from a vacuum-assisted stripping machine designed in Arkansas and manufactured in Michigan (Morris et al., 1978).

The other plant was equipped with two sets of capping and stemming rolls used in the same manner as those on the OSU equipment. However, instead of the rolls being soft and smooth, they were cut into a square-edged helical thread form from harder neoprene. Right-hand and the left-hand threaded rolls were matched to give a tight meshing of the threads as the rolls rotated. The meshed helical flights pulled the stems from the fruit and also provided a propelling action to move the stemmed fruit across the rolls. Water sprays were needed over the rolls for cleaning, but flume water was not required to move the product across the roll bed.

During the 1978 harvest season, 23 different runs were made on

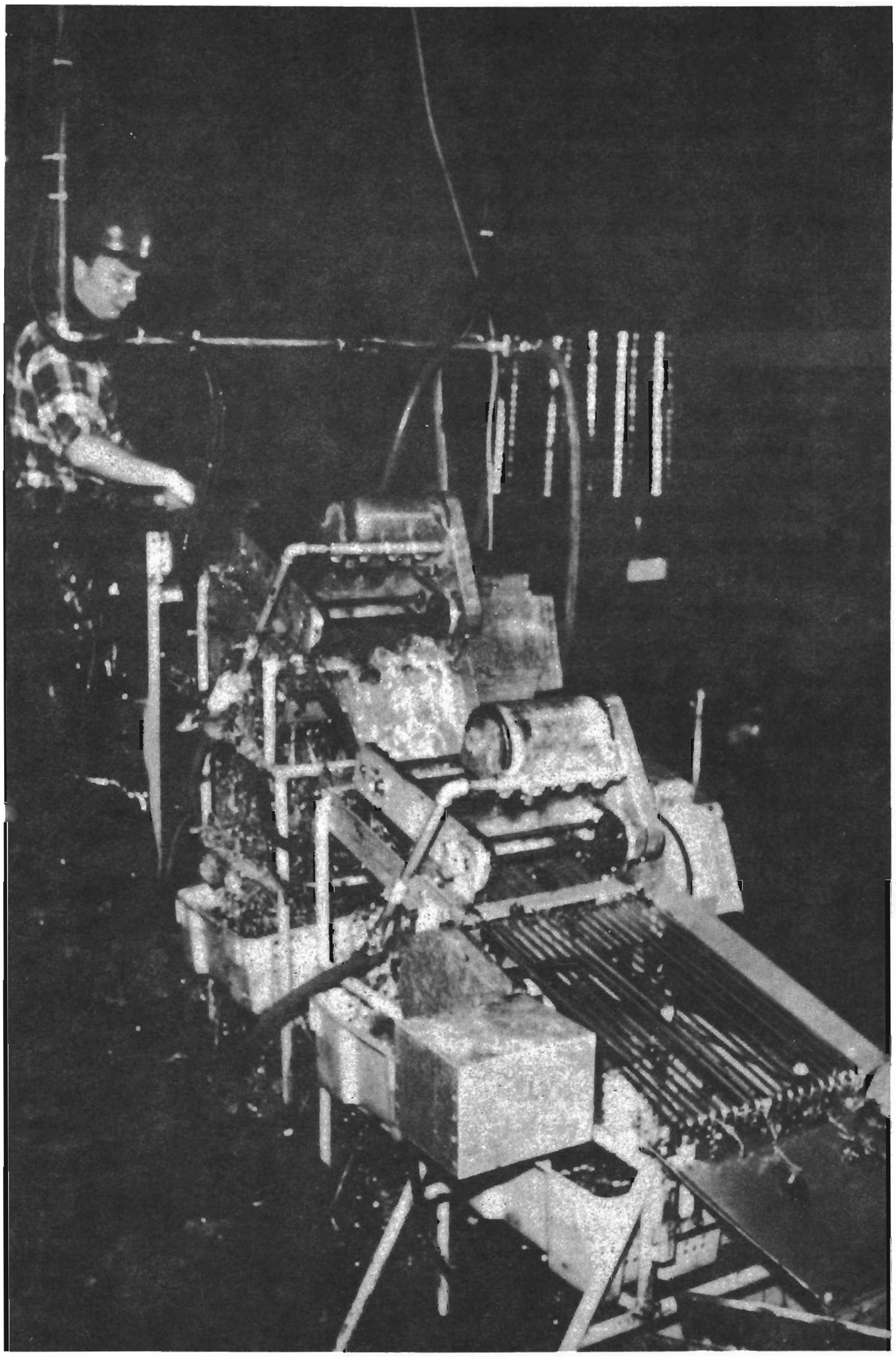

Figure 1. Tandem capper-stemmer units tested in commercial processing plants in 1978 and 1979.

mechanically harvested strawberries processed over various in-plant systems. Each run was planned to include one lot of approximately 454 kg (1,000 lb) of field product. Berry varieties involved were 'Linn,' 'Benton,' and 'Olympus.' These were harvested after no, one, or two hand pickings. The fruit was grown on four commercial farms in addition to the OSU North Willamette Agricultural Experiment Station. Three mechanical harvesters were used. One, developed at the University of Arkansas and manufactured by Blueberry Equipment, Inc. at South Haven, Michigan, utilized a vacuum-assisted stripping method of fruit removal (Booster et al., 1969). The other two machines both employed the mowing method of harvest. One was developed by Charles Hecht in Oregon and manufactured by the McNair Company at Chico, California. The other was the OSU machine, designed and built by the Agricultural Engineering Department.

Time studies, field efficiencies, and harvest rates were studied by representatives from the OSU Department of Agricultural and Resource Economics. Evaluations of in-plant processing equipment were made by representatives from the OSU Department of Food Science and Technology in cooperation with Clermont West Packing Co. and Stayton Canning Co. Overall coordination of the experiment and the logistics of handling the harvested fruit were under the direction of Lloyd Martin, OSU Horticulturist and Superintendent of the North Willamette Agricultural Experiment Station.

RESULTS

Harvest plot sizes were chosen in the field to yield approximately 454 kg (1,000 lb) of gross product. The length of the harvest season and limitations of equipment and manpower precluded making direct comparisons of all the individual variables in this study. Information was gathered on many of the variables, however, and it should be helpful in evaluating the necessary components to be synthesized into a practical, commercial, mechanical harvesting and processing system.

The actual processing line rates for each of the test lots for 1978 are given in Table 4. The gross product column indicates the rate in kilograms per hour at which the material from the field was put across the experimental plant processing line. The total fruit column indicates the kilograms of actual fruit per hour handled by each processing line. The total fruit includes small fruit and green fruit that are acceptable for puree or juice but would be sorted out for Grade 1 frozen pack.

Table 4. Line process rates, 1978

Plant equipment	Harvester	Cultivar	Location	Lot	Rates (kg/hr) Gross product	Total fruit
BEI	BEI	Linn	Clermont	1	1,408	--
BEI	BEI	Olympus	Clermont	2	1,312	--
BEI	BEI	Linn	Clermont	8	569	413
OSU	OSU	Linn	Clermont	3	290	236
OSU	OSU	Olympus	Clermont	4	349	300
OSU	BEI	Olympus	Clermont	7	372	291
OSU	OSU	Olympus	Stayton	31	246	184
OSU	OSU	Olympus	Stayton	32A	--	264
OSU	SKH&S	Olympus	Stayton	33A	--	254
OSU	SKH&S	Olympus	Stayton	34A	190	49
OSU	SKH&S	Linn	Stayton	40A	289	194
OSU	SKH&S	Benton	Stayton	41A	291	168
OSU	OSU	Benton	Stayton	52	477	301
OSU	OSU	Benton	Stayton	54	361	240
OSU	SKH&S	Benton	Stayton	55	367	213
Stayton	BEI	Olympus	Stayton	5	483	341
Stayton	SKH&S	Olympus	Stayton	30	411	315
Stayton	OSU	Olympus	Stayton	32B	--	299
Stayton	SKH&S	Olympus	Stayton	33B	--	237
Stayton	SKH&S	Olympus	Stayton	34B	271	73
Stayton	SKH&S	Linn	Stayton	40B	533	376
Stayton	SKH&S	Benton	Stayton	41B	446	267
Stayton	OSU	Benton	Stayton	53	160	66

The processing line rates for the 1979 test plots are shown in Tables 5A and 5B. Finished fruit in Tables 5A and 5B includes only the Grade 1 quality of individual quick frozen (IQF) material after the hand sorters have removed all unfit material including good fruit with caps or stems attached. No fruit containing caps or stems was returned to the finished fruit line.

Table 5A. 1979 line process rates for Benton and Olympus varieties

Plant equipment	Harvester	Cultivar	Location	Lot	Gross product rate lb/hr	Gross product rate kg/hr	Total fruit rate lb/hr	Total fruit rate kg/hr	Percent IQF grade 1 fruit
OSU	SKHS-A	Bent.	Stay.	1	648	294	522	237	--
OSU	SKHS-A	Bent.	Stay.	2	759	344	554	251	--
OSU	SKHS-B	Bent.	Stay.	27	545	247	398	181	54
OSU	SKHS-B	Bent.	Stay.	28	557	254	355	161	52
OSU	SKHS-B	Bent.	Stay.	29	761	345	614	279	48
OSU	OSU	Bent.	Stay.	21	604	274	330	150	--
OSU	OSU	Bent.	Stay.	22	725	329	453	206	53
OSU	OSU	Bent.	Stay.	23	666	303	421	191	48
Stay.	OSU	Bent.	Stay.	51	814	369	242	110	34
OSU	OSU	Bent.	Stay.	52	714	324	358	163	46
BEI	BEI	Bent.	Duyck	27	1,086	493	--	--	--
BEI	BEI	Bent.	Duyck	28	1,409	640	--	--	--
BEI	BEI	Bent.	Duyck	29	1,313	596	--	--	--
OSU	SKHS-A	Olym.	Stay.	12	680	309	559	254	--
OSU	SKHS-A	Olym.	Stay.	13	668	303	513	233	54
OSU	SKHS-A	Olym.	Stay.	14	952	432	378	172	47
OSU	SKHS-B	Olym.	Stay.	30	647	294	432	196	35
OSU	SKHS-B	Olym.	Stay.	31	633	287	420	191	38
OSU	SKHS-B	Olym.	Stay.	43	1,312	596	666	302	19
OSU	SKHS-B	Olym.	Stay.	44	774	351	310	141	21
OSU	SKHS-B	Olym.	Stay.	45	716	325	455	207	23
OSU	SKHS-B	Olym.	Stay.	46	794	360	289	131	27
OSU	OSU	Olym.	Stay.	18	907	412	740	336	--
OSU	OSU	Olym.	Stay.	19	757	344	603	274	--
OSU	OSU	Olym.	Stay.	39	776	352	457	207	39
OSU	OSU	Olym.	Stay.	40	1,211	550	782	355	40
OSU	OSU	Olym.	Stay.	41	789	358	408	185	27
OSU	OSU	Olym.	Stay.	42	912	414	258	117	28
Stay.	OSU	Olym.	Stay.	55	1,050	477	275	125	31
OSU	OSU	Olym.	Stay.	56	596	270	267	121	27

The BEI field harvester and in-plant processing equipment are designed to produce a puree or juice product. The OSU and SKH&S harvesters, in combination with the OSU or Stayton in-plant processing equipment are designed to produce either a puree or juice product or a Grade 1 frozen pack. When the cultivars demonstrate concentrated ripening and cap easily when the stem is pulled from the fruit, the mechanically harvested product can be readily upgraded to a frozen pack of USDA Grade 1 quality. Undersized fruit is readily removed by a mechanical size grader.

Table 5B. 1979 line process rates for Linn, Totem, and 70-17-12

Plant equip-ment	Har-vester	Cul-tivar	Loca-tion	Lot	Gross product rate lb/hr	Gross product rate kg/hr	Total fruit rate lb/hr	Total fruit rate kg/hr	Percent IQF grade 1 fruit
OSU	SKHS-A	Linn	Stay.	4	885	402	667	303	--
OSU	SKHS-A	Linn	Stay.	5	698	317	472	214	--
OSU	SKHS-A	Linn	Stay.	6	613	278	498	226	--
OSU	SKHS-B	Linn	Stay.	33	862	392	600	272	36
OSU	SKHS-B	Linn	Stay.	34	1,530	695	951	432	44
OSU	SKHS-B	Linn	Stay.	35	646	293	503	229	35
OSU	OSU	Linn	Stay.	24	953	433	671	305	46
OSU	OSU	Linn	Stay.	25	825	374	637	289	48
OSU	OSU	Linn	Stay.	26	687	312	462	210	42
OSU	SKHS-A	Totem	Stay.	9	861	391	704	319	--
OSU	SKHS-A	Totem	Stay.	10	756	343	609	277	--
OSU	SKHS-A	Totem	Stay.	11	763	347	620	282	--
OSU	OSU	Totem	Stay.	15	893	405	575	261	--
OSU	OSU	Totem	Stay.	16	766	348	615	279	--
OSU	OSU	Totem	Stay.	17	867	394	714	324	--
BEI	BEI	Totem	Duyck	50	1,204	540	--	--	--
OSU	SKHS-A	70-17-12	Stay.	7	648	294	497	225	--
OSU	SKHS-A	70-17-12	Stay.	8	644	292	471	214	--
OSU	SKHS-B	70-17-12	Stay.	36	1,179	535	916	416	44
OSU	OSU	70-17-12	Stay.	37	876	397	673	305	42
Stay.	OSU	70-17-12	Stay.	53	1,267	575	712	323	33
Stay.	OSU	70-17-12	Stay.	54	1,010	459	648	294	39

Near the end of the 1978 harvest season, three lots from the OSU and SKH&S harvesters were run over the OSU and Stayton processing lines to produce a Grade 1 frozen pack. The results are shown in Table 6.

Table 6. Fruit sorted, sliced, and sugared in 1978 frozen pack

Plant equipment	Lot	Harvester	Gross product	Total fruit	Size sortout	Hand sorted	Percent hand sorted
			kg				
Stayton	53	OSU	495	314	--	256	18.6
OSU	54	OSU	337	224	101	108	11.8
OSU	55	SKH&S	399	231	79	140	7.8

The OSU process line used a vibrating 1.91 cm (0.75 in) space bar screen to remove undersized berries before the fruit was sent over a sorting table. This screen dropped out much of the green fruit that otherwise might have required removal by hand sorting.

The hand sort-outs included all green, overripe, damaged, or soiled fruit, as well as any fruit still having a cap or stem attached. These three lots were all 'Benton' variety, which is considered to be a "fair capper." Other selections being tested in the breeding program are noted for giving up their caps and stem bases more readily when the fruit is pulled from the cluster by the stemming rolls.

SUMMARY AND CONCLUSIONS

The satisfactory performance of the mechanical harvesting and preprocessing system on berry selections bred especially for mechanical handling and on four new varieties developed early in the breeding program is attracting serious attention from growers and processors. Northwest processors have, in general, been reluctant to encourage field mechanization because of increased hand sorting and waste disposal problems that appeared inherent in the system change. While problems will arise in establishing equitable price structures for various field grades of mechanically harvested fruit, the in-plant handling systems have been demonstrated by taste panels to be adequate to upgrade the field product to a quality equal to or surpassing hand-picked fruit with a reasonable amount of in-plant labor. The mechanical systems will become increasingly attractive as more new breeding selections are released for commercial production.

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CLEANING AND GRADING OF MACHINE-
MARVESTED STRAWBERRIES

J. R. Morris and G. S. Nelson

Summary. A "continuous-flow" materials-handling system was developed that had a capacity of handling approximately 1.8 metric tons of fruit per hour (depending on time required for removing molded fruit). This unit did an excellent job of cleaning machine-harvested berries. Adjustment of the grading line for variation because of cultivar and harvest data allows for sorting fruit into maturities based on sizes. A finished product of high quality was obtained when the proper cultivars were harvested on the optimum date.

INTRODUCTION

During the development of the strawberry harvesting system at the University of Arkansas, we soon realized that industry was not going to use a harvesting system unless equipment could be developed that would clean and grade the fruit. Existing processing plants were not equipped to handle stems, leaf materials, and other debris that are present in mechanically harvested berries. Efforts were directed toward developing equipment for handling of mechanically harvested strawberries.

MATERIALS AND METHODS

Development of in-plant equipment

The first cleaning line tested for machine-harvested strawberries in Arkansas used air as a means to separate leaves and debris from fruit (6). This system adequately cleaned fruit of most Arkansas cultivars that were harvested as single fruits rather than clusters. However, we soon found when harvesting some cultivars in Arkansas, such as 'Cardinal,' and most cultivars in Oregon that a percentage of the fruit remained in clusters. Another problem with the air-cleaning system was that excessive damage occurred when the berries were dry-dumped onto a conveyor belt and spread out for air-cleaning.

Both of these problems were eliminated through development of a cleaning line that used a water dump-wash tank followed by a trash eliminator-cleaner and "cluster-buster." The water proved to be a much superior method of handling and conveying the fruit and provided the additional function of removing sand and loosening any dirt that might be present on berries that had contacted the soil.

The rollers on the trash eliminator grasp and pull stems and leaf material through the conveyor, leaving individual berries on the upper surface of the conveyor. Jets of water from fan-type nozzles positioned above the conveyor clean the rollers and also wash the fruit. The berries are then discharged from the trash eliminator-cleaner unit directly to a modified McLauchlan vibrating washer. After receiving a final wash in this unit, the clean berries pass over a tapered-finger sizing device attached to the McLauchlan washer (Fig. 1).

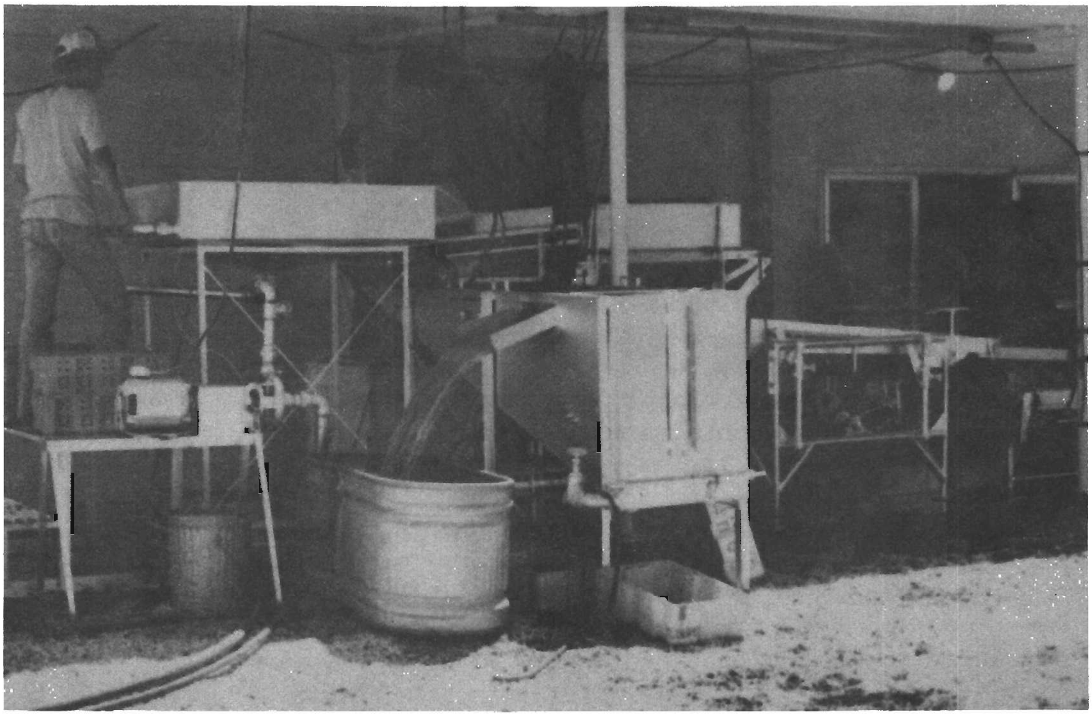

Figure 1. The 1976 model of the continuous-flow cleaning and grading line, showing from left to right: 1) dump-wash tank, 2) wire conveyor, 3) trash eliminator-cleaner, 4) McLauchlan vibrator-washer, and 5) tapered-finger continuous sizer.

The water-bath tray and sizing device are attached rigidly to a common vibrator unit that serves as a conveyor to move the fruit across the grading unit for sorting by maturity based on fruit size. An adjustable partition on the conveying belt collects fruits as they drop from the sizer, allowing for quick adjustment for proper sorting (Fig. 2).

Testing the cleaning system

In 1976 a study was conducted at the Arkansas Agricultural Experiment Station to evaluate the effectiveness of this unit in cleaning and grading cultivars harvested at three different dates.

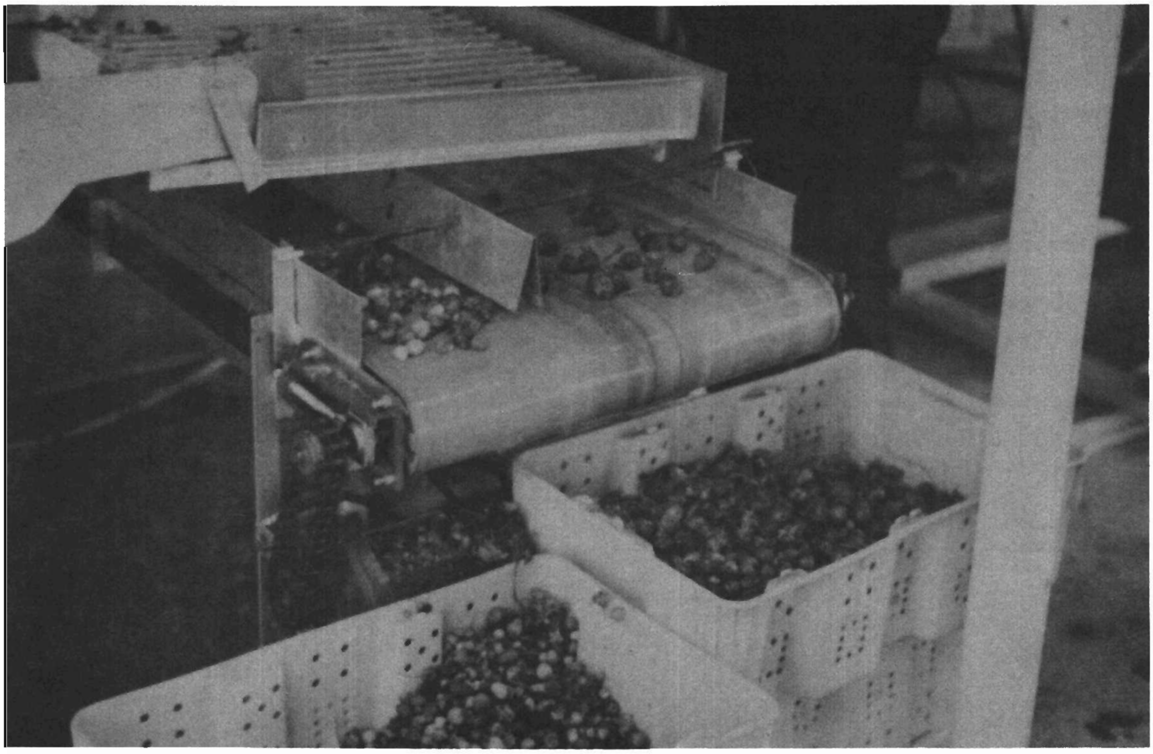

Figure 2. Tapered-finger continuous grader and adjustable divider for sizing. The small and large sizes are shown on the conveyor belt and in the lugs.

The 1973 commercial model of the University of Arkansas-BEI mechanical strawberry harvester was used to harvest berries for the study. The experimental design consisted of three cultivars and four Arkansas breeding lines, with three harvest dates at about 2-day intervals. The first harvest was made when about 60 percent of the fruit on each cultivar was in the ripe (large) stage. All plots were 4.6 m long, replicated eight times.

Collection of data and quality samples

Harvested fruit in each plot were weighed prior to washing, cleaning, and sizing. All trash and moldy fruit were removed during the cleaning operation, and the berries were sized into two categories: (1) small (mostly green and inception) and (2) large (mostly ripe). Fruit in each size category were weighed after washing, cleaning, and sizing. The amount (percent) of foliage material was calculated by subtracting the combined weights of the various sizes from the total machine-harvested yield for each plot. Fruits missed by machine harvesting were hand picked to determine harvester efficiency.

Samples for quality analysis were collected immediately after washing and sizing, sealed in 211 x 400 cans, and frozen. Quality determinations of Morris and others (5) were used. Shear was determined by use of an Allo Kramer shear-press on the fresh fruit, immediately after washing and sizing.

RESULTS

Yield components

'Cardinal' produced the highest yield of usable fruit, followed by 'Sunrise,' while A-5350 and A-5309 produced low yields (Table 1).

Table 1. Main effects of clone and harvest date on percent distribution of total yield, usable yield, and picking efficiency of mechanically harvested strawberries, 1976

	Distribution of total yield			Usable Yield			Machine
	Usable fruit	Decayed fruit	Foliage material	Metric tons/	Large fruit		picking efficiency
Treatment	(%)	(%)	(%)	ha	(%)	(g)	(%)
Clone							
Cardinal	88	4	8	17.4	75	11.5	96
Earlibelle	83	4	13	11.9	65	11.9	91
Sunrise	84	3	13	14.8	70	8.7	96
A-5344	84	7	9	11.2	58	8.4	95
A-5745	85	4	11	12.2	60	9.8	93
A-5350	85	4	11	9.4	65	10.3	91
A-5309	73	7	20	7.5	57	7.8	97
LSD @ 5%	2	1	3	1.4	3	0.7	NS
Harvest date							
Early	85	1	14	12.5	69	10.6	95
Mid	81	7	12	12.6	66	9.5	95
Late	82	7	11	11.1	58	9.3	92
LSD @ 5%	1	1	2	0.9	2	0.4	NS

The high percent of decayed fruit in A-5344 and A-5309 resulted from a "split fruit set," caused by the spring weather patterns, that allowed some early fruit to overmature before the majority were acceptable for harvest. 'Cardinal' and A-5344 had the lowest percent foliage material that had to be removed by the cleaning line.

Machine picking efficiency

The machine-picking efficiency in 1976, when means were pooled across three harvest dates and two plant populations, ranged from 91 to 97 percent, depending upon clone. 'Cardinal' produced the highest yields, had only 8 percent foliage material, and had a picking efficiency of 96 percent (Table 1). Researchers working with other types of mechanical strawberry harvesters report picking efficiencies ranging from 31 to 87 percent (4) with narrow rows and 24 to 92 percent with optimum conditions.

Damp foliage on the early harvest date in 1976 accounted for the increase in trash (Table 1). Under dry conditions the harvester eliminates more trash through its fan system. More recent models of the harvester do a better job of cleaning the fruit in the field. The 1975 model of the harvester (with an improved pneumatic system) was operated on a commercial basis in Oregon in 1976; the average amount of foliage material present in the harvested fruit and removed by the cleaning and grading line was only 4.1 percent (data not shown).

Date of harvest

Main effects show that a late harvest resulted in lower usable yields because of a reduction in percent large fruit, a decrease in berry weight, and an increase in percent decayed fruit in 1976 (Table 1). However, this reduction in usable yield at the late harvest date occurred only for A-5344, A-5745, and A-5309 (data not shown). Yield from the other clones tested was not significantly reduced by delaying harvest two or four days. Therefore, even though there was a reduction in usable yields for some of the clones tested, a minimum of a six-day harvest period exists for mechanical harvesting of most clones under Arkansas conditions.

Product quality

During the 1976 season, raw product quality was determined on both small and large fruit sizes. As expected, fruit in the small size category was consistently lower in percent soluble solids, Color Differences Meter (CDM) 'a-b' ratios, and visual color intensities and higher in titratable acidity (Table 2). Clones A-5344 and A-5309 produced small fruit with high CDM 'a-b' values and high visual color scores. Puree from the small fruit of these two clones was similar, in color to that of the large fruit of 'Sunrise.' A-5350 and A-5344 had the highest fruit firmness as determined by shear values. The seven clones ranged in shear values from a low of 15 kg/100 g for A-5309 to a high of 47 kg/100 g for A-5350. Large fruit from clones which had shear values less than the large fruit of 'Earlibelle' (35 kg/100g) did not handle well when passed through the cleaning and grading line.

The small fruit increased and the large fruit slightly decreased in soluble solids with a delay in harvest (Table 2). Titratable acidity

Table 2. Main effects of clone, plant population, and harvest date on raw product quality of mechanically harvested, cleaned, and graded strawberries, 1976

Treatment	Sol. solids (%)		Tit. acidity (ML)		CDM "a-b"		Visual color*		Shear	Viscosity
	Small	Large	Small	Large	Small	Large	Small	Large	(kg/100g)	(sec/25rev)
Clone										
Cardinal	4.7	6.2	5.9	5.7	1.8	2.6	4.4	10.0	38	4.5
Earlibelle	4.7	5.9	7.2	6.7	1.5	2.4	4.8	9.6	35	5.6
Sunrise	5.1	6.5	7.1	6.4	1.6	2.2	4.4	6.4	22	3.7
A-5344	4.8	5.7	5.9	5.4	2.2	2.6	7.4	9.2	44	4.8
A-5745	4.5	6.0	5.3	5.5	1.5	2.5	6.2	7.8	40	4.6
A-5350	4.9	6.0	6.7	6.4	1.3	2.6	4.8	9.6	47	6.1
A-5309	5.9	7.5	7.1	6.8	2.0	2.4	6.3	9.0	15	4.1
LSD @ 5%	0.2	0.2	0.2	0.3	0.2	0.1	0.6	0.4	3	0.4
Harvest date										
Early	4.8	6.5	6.6	6.4	1.2	2.5	3.6	9.0	40	4.8
Mid	4.9	6.0	6.4	6.0	1.8	2.5	5.6	8.4	33	4.7
Late	5.2	6.3	6.4	6.0	2.1	2.5	7.4	9.0	30	4.8
LSD @ 5%	0.2	0.2	0.1	0.2	0.1	NS	0.4	0.2	2	NS

*Ranked on a scale of 1-10, 10 = best.

in both small and large fruit was reduced after the first harvest date. This reduction in acidity in both the small and large fruit and the increase in soluble solids of small fruit with a delay in harvest was expected.

DISCUSSION

Total usable yields, firmness, concentration of fruit maturity, and acceptable processing quality are important clonal traits related to mechanical harvesting adaptability. In this study, 'Cardinal,' Arkansas breeding line A-5344, and 'Earlibelle' are well suited for once-over mechanical harvesting under Arkansas conditions when yield and quality factors are considered. Each cultivar has an optimum time of harvest, after which quality and/or usable yield will decrease. On the last harvest date in 1976, the small fruit from A-5344 and A-5309 were equal in color to the large fruit of these clones on the first harvest date. Once-over mechanical harvest could be delayed on clones that mature in this manner if the amount of molded fruit is not excessive. Clones A-5344 and A-5350 maintained fruit firmness throughout the harvest period and handled well when passed through the cleaning and grading lines. Mechanically harvested fruit from the majority of the clones tested had acceptable processed quality. Although delaying the harvest period reduced usable yields for some of the clones tested, a minimum harvest period of six days exists for mechanical harvesting under Arkansas conditions.

With the addition of a "continuous-flow" cleaning and grading line for handling mechanically harvested strawberries, production and handling of strawberries by the juice and puree industries can be totally mechanized. This cleaning line is capable of removing as much as 20 percent foliage from machine-harvested fruit and has a capacity of 1.8 metric tons of fruit per hour.

A modified version of this handling system is manufactured by Blueberry Equipment, Inc., and is used commercially in Arkansas, Oregon, and Michigan. These units have been installed at both grower and processing facilities.

Acknowledgments. The authors wish to thank J. N. Moore, Department of Horticulture and Forestry, University of Arkansas, for supplying plants of 'Cardinal' and the Arkansas breeding lines used in this study.

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IN-PLANT HANDLING OF MECHANICAL HARVESTED STRAWBERRIES

R. L. Ledebuhr and C. M. Hansen

Summary. Strawberries of the 'Midway II' variety were harvested by crop lifter-reel machines and processed. The "pack-out" was 36 percent of the field product. Additional singulating occurred in the plant prior to decapping. A round-belt sizer removed the small fruit, which was largely green, before the product was delivered to the sorting belt.

INTRODUCTION

Handling mechanically harvested fruit in the processing plant is a part of the total system of moving the fruit from the field to a merchantable product (1). The key machine in the processing plant is the decapper. The design of the strawberry harvester determines the kind of fruit that is available to the decapper. All of the operations, both on the harvester and on the feeding mechanism in the processing plant, should deliver fruit with a stem at least 2.54 cm (1 in) long to the decapper. The handling system is designed for stackable plastic boxes, having a capacity of about 9.0 kg (20 lb) and stored at 4.5 degrees Celsius (40°F) to remove field heat. Fruit with stems can be stored for a period of 48 hours before decapping without deleterious effects.

PROCESSING PLANT EQUIPMENT, 1979

The fruit enters the processing line by being dumped into a water boot of a flighted elevator that delivers it to a shaker pan (Fig. 1). Water flows across the shaker pan to assist in cleaning the fruit and moving it to a point of discharge. A series of small diameter rods, 90 cm (36 in) long, are attached to the discharge side of the pan. They are spaced 5 cm (2 in) on centers and descend 20 degrees below horizontal. A grid of fine wires about 12 cm (5 in) long is attached to the shaker pan between the rods to drain the water into a trough. The singulated fruits drop through the rods to a pan that carries them to the conveyor or decapper.

Fruit in clusters tends to straddle the rods and "rides" down to a shear bar, above which is a rotary shear. The shear cuts away the peduncles and trash above the rods. The pan below the rods carried the fruit to an elevator that feeds the decapper. The pan can be mounted to feed the decapper directly.

CML decapper

The CML decapper (2,3), based upon a Michigan State University research prototype, makes use of counterrotating, rubber-covered rods or rollers that travel up an incline (Figs. 2 and 3). Fruit that is caught

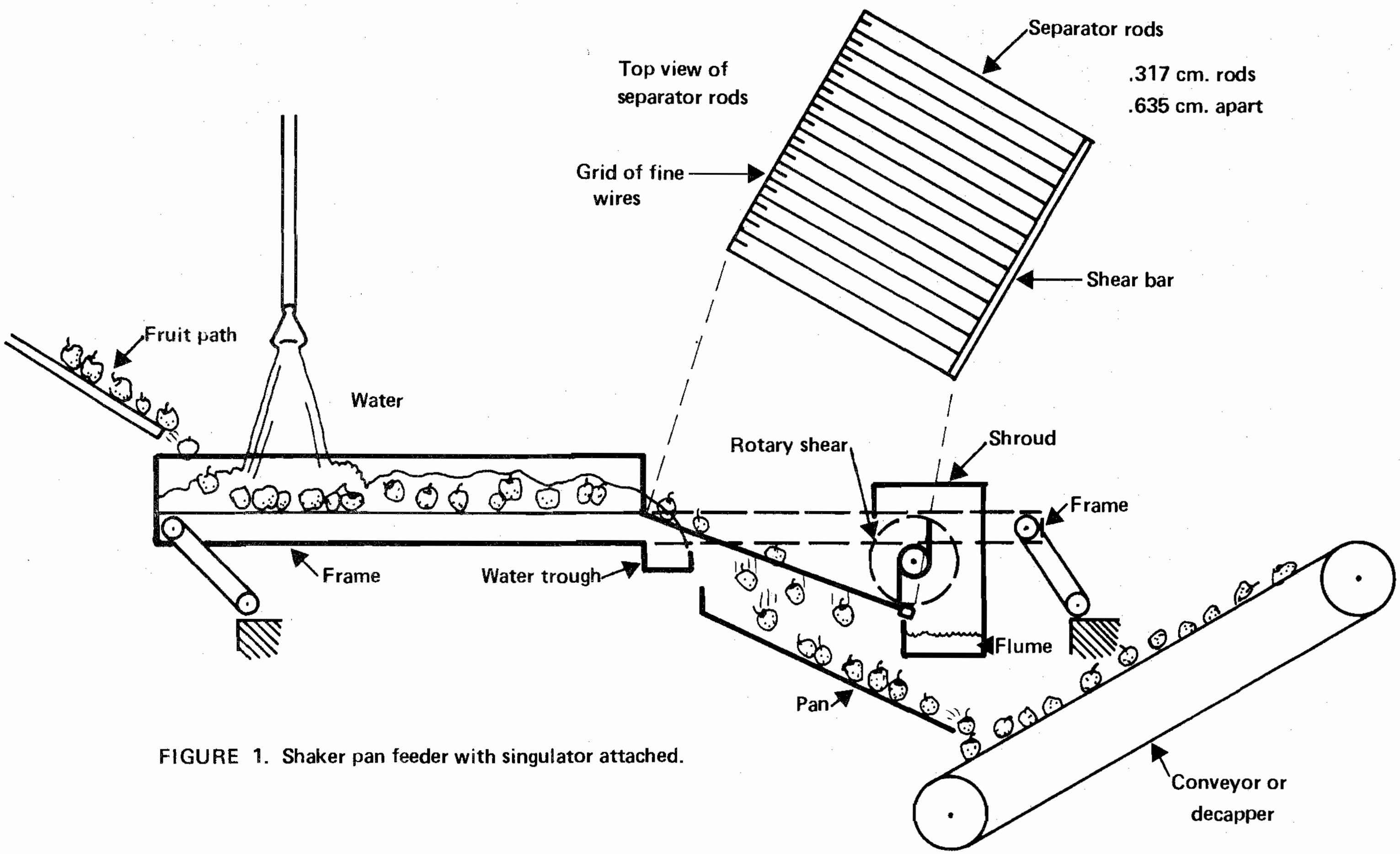

FIGURE 1. Shaker pan feeder with singulator attached.

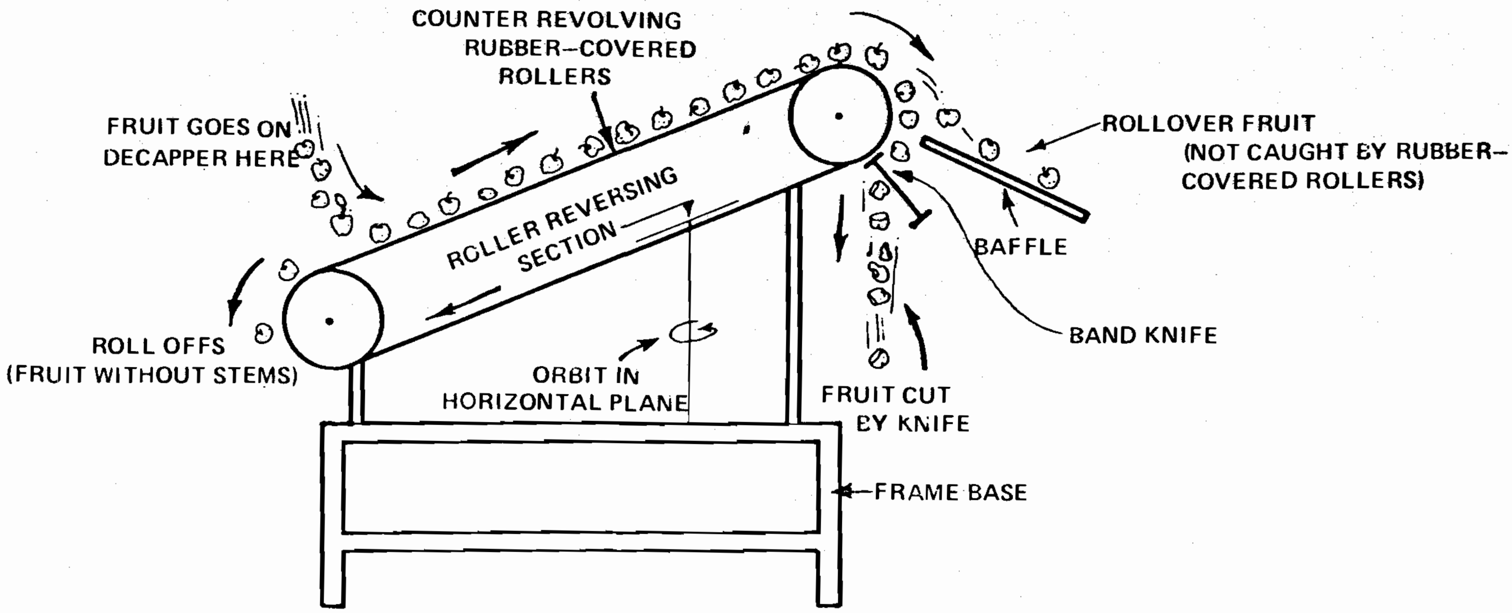

FIGURE 2. Schematic of the strawberry decapper.

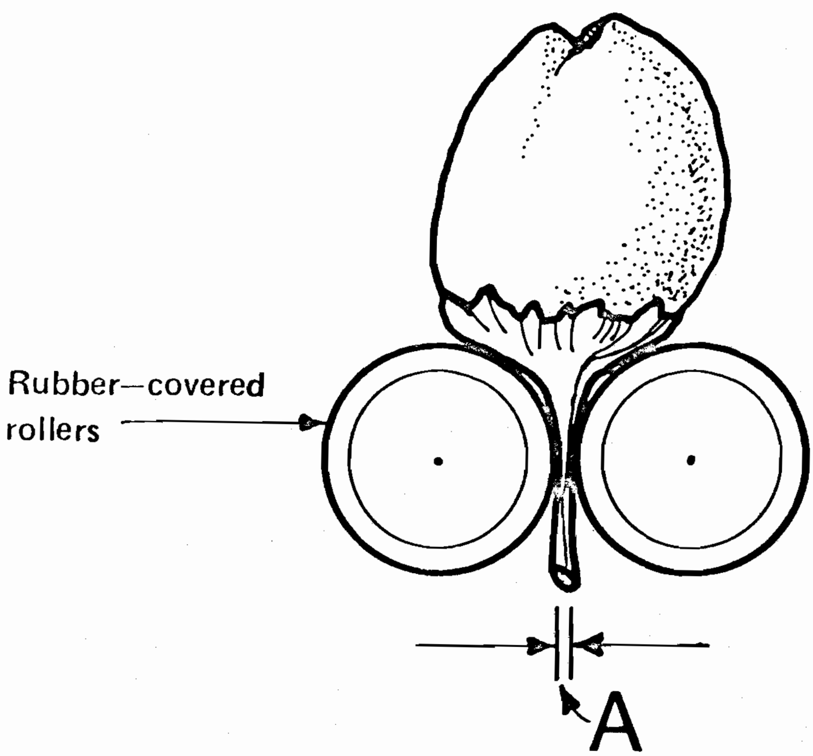

FIGURE 3. Strawberry decapper detail.

and held by the stems between the counter-turning, rubber-covered rollers is carried to a razor-edged band knife where the usable fruit flesh is cut from the calyx and stem. The functioning parts of the machine are orbited through a 1.9-cm (.750 in) circle in a horizontal plane to enhance the possibility of the rollers catching the stems. The band knife is mounted beneath the upper end of the rubber-covered roller conveyor. The fruit sliced from the stem and calyx falls into a flume or mesh conveyor to be carried to the fruit sizer.

A reversing rack that changes rotation of the rubber-covered rollers is mounted below the bed of the decapper to discharge stems that have been cut free from the fruit. This permits a continuous operation of the roller belt.

There are two other discharge ports on the decapper. Fruit which has not been trapped or caught by the counterrotating, rubber-covered rollers, either because the fruit does not have a stem or because the stem has been pulled free, is encouraged by the orbiting motion of the decapper to move down the incline of the bed. This fruit is usually used for juice or puree.

A third discharge point is located at the top of the incline of the bed of the decapper. The fruit that leaves the decapper at this point may have stems or be stem-free. This fruit is generally trapped or carried over the top of the incline by other fruit whose stems are firmly attached to the rubber-covered rollers.

In 1976 a CML decapper was shipped to England. Ivor Kemp, who was then with the National Institute of Agricultural Engineering at Silsoe, England, used it to process fruit which had been mechanically harvested. After the harvest season, he designed and built a decapper similar to the CML decapper with several modifications.

The primary changes consisted of increasing the diameter and length of the rubber-covered rollers and revising the orbiting suspension system. In so doing, Mr. Kemp was able to increase the capacity of the machine.

This decapper was shipped to California in September 1977 for testing. These tests will be discussed later in this paper.

Decappers used at Leelanau Fruit Plant at Suttons Bay, Michigan, were fabricated by CML and incorporated many of the Kemp modifications.

Fruit sizer

The fruit sizer consists of a series of .95-cm (.375 in) round urethane belts stretched over two 15.3 cm (6 in) rotating drums. Each drum has grooves spaced on 2.2-cm (.875 in) centers, leaving 1.27 cm (.5 in) between the belts. The drums may be grooved to give any desired spacing.

With judicious selection of spacing, the sizer will drop out small green and red fruit.

The sorting belt

The product that passes over the sizer is delivered to the sorting belt for final inspection to remove trash and defective fruit. The finished product is usually put into a pack which may be frozen.

DISCUSSION AND RESULTS

Some data were gathered during the 1878 season relative to the fruit as it passed through the processing line at Leelanau Fruit Plant (Table 1).

TABLE 1

Machine Harvested Strawberries, Midway II Variety

CML Harvester, owned by R. Kreiger

Stored for 4 hours at 10° C. (50° F.)

45.3 kilograms (100 pounds) as harvested

36.75% finished product

29.0% passed through sizer

13.9% rolled down incline of decapper

3.78% picked off sorting belt

16.57% cut off by band knife, pulled through the rollers (includes stems, leaves, etc.)

698 kilograms (1539 pounds) per hour of field products, rate of feed

Samples of fruit used in the tests weighed 45.3 kg (100 lb). The fruit had been harvested by the CML harvester owned by Kreiger.

Total raw product was processed as follows: 36.75 percent passed through the harvesting system into the pack; 29 percent dropped through the sizer (some of the soft fruit was removed by the sizer); 13.9 percent rolled down the inclined bed of the decapper and was used for puree and juice (95% of the fruit in this category was stemless, with the stems being removed either by the decapper or the harvester); 3.78 percent was picked off on the sorting belt as trash, green or soft fruit;

and 16.57 percent was cut off by the band knife or pulled through the rollers in the form of stems or leaves (tests have shown the loss of fruit flesh cut away by the band knife to be about 2.5%).

The decapper processed 697 kg (1,539 lb) of the field product per hour during these tests.

Table 2 gives the evaluation of fruit that passed through the sizer. Thirty percent of the fruit was usable product, with an average size of 3.19 g. This represents 8.7 percent of the field product.

TABLE 2

Strawberries and product which passed through sizer

Evaluation	Percent	Average weight (grams)
Good	30	3.19 (8.7% of field product)
Green	24	2.06
Trash	46	

The green fruit dropped out by the sizer weighed an average of 2.06 g each. This accounted for 24 percent of the product that passed through the sizer and 7 percent of the field product. Trash and overripe fruit accounted for 46 percent of the sizer discharge.

Table 3 shows the evaluation of fruit that passed over the sizer onto the sorting belt. The good product, the fruit with sepals attached, the green fruit, and the trash were evaluated at 75, 15, 3, and 7 percent, respectively.

TABLE 3

Strawberries and product which reached sorting belt

Evaluation	Percent	Average weight (grams)
Good	75	
Good with sepals attached	15	2.66
Green	3	4
Trash, stems, etc.	7	

California decapper trials, September 1977

The CML decapper, which was redesigned by Ivor Kemp of England, was shipped to California for evaluation. Tables 4 (p. 118) and 5 (p. 119) show the data collected during these tests. Several varieties were picked by hand with stems remaining on the fruit to determine their decapping characteristics. The number of fruits with stems are indicated for each test. The first 'Aiki' sample averaged 10.8 g per fruit. Only one strawberry was not decapped. By weight, 81 percent was usable fruit, with 18 percent being cut away by the decapper band knife (stem, calyx, and about 2.5% fruit flesh). The data shows varietal difference in decapping characteristics.

The data relative to tests conducted with large quantities of the same varieties of fruit mixed together are recorded in Table 5. This fruit was stored for 24 hours at 5° Celsius (40°F). The data show that if the decapper is fed beyond its capacity the efficiency will decrease. More tests are needed to determine optimum feed rates for each variety.

A new prototype decapper

Early in 1979 a new prototype decapper was designed and fabricated in the Michigan State University Agricultural Engineering Department. It was given limited tests in Michigan and California. This machine has rubber-covered rollers that are 1.6 cm (.625 in) in diameter and 70 cm (28 in) long. Only one roller design is used. The rollers are friction driven by rubber-covered wheels that come in contact with a pressure plate. This system differs from the rack and pinion drive used in earlier decappers.

The bank knife assembly also has been modified, and the sheet metal parts were designed to provide easy access for servicing the machine. Limited tests have shown that this machine has a capacity of about 1,360 kg (3,000 lb) per hour.

A FINAL COMMENT

The total system must be considered in mechanizing the harvest of the strawberry crop. The plant processing line must perform the most difficult task. To optimize stem and cap removal, the CML decapper must receive a high percentage of single fruit with stems at least 2.54 cm (1 in) long.

New technology has been required to handle mechanically harvested strawberries. We now have the expertise to deal with strawberries which have a large percentage of attached stems. The pack-out in the processing plant depends upon crop variety, condition of the harvested fruit, and the manner in which it is handled. The Michigan-grown 'Midway II' variety responds well to mechanization, but we must find new varieties that will increase the percentage of pack-out.

TABLE 4

Random sampling of decapper efficiency tests—California trials, 1977

Variety	Average weight per fruit (grams)	Number fruits per Sample	Percent Decapped [1]		Percent Stems,[2] Calyx, etc. by Weight	Percent Rolloff [3]		Percent Rollover [4]	
			Number	by Weight		Number	by Weight	Number	by Weight
Aiko	10.8	100	99	81	18	1	1	0	0
Aiko	9.8	100	98	77	21	0	0	2	2
Tufts	8.4	400	92.75	75	18	3.75	3.8	3.5	3.2
C–45	12.9	200	91	78	14	6.5	6	2.5	2
Tioga	7.7	200	80	61	20	14.5	14	5.5	5

1. Fruit suitable for fresh pack.
2. Product cut from each fruit by knife—about 2.5% is fruit flesh.
3. Fruit which rolled down the orbiting incline of the bed.
4. Fruit which was carried over the top of the decapper.

TABLE 5

Bulk Quantity Decapper Tests

Test No.	Decapped Percent	Kilograms per Hour	Pounds per Hour	Stems & Caps Percent	Rolloff Percent	Rollover Percent
1	80	590	1300	13	1	6
2	69	906	2000	16	1	13

Test 1 — Three mixed varieties (Tioga, Tufts, Aiko)
Test 2 — Four mixed varieties (Tioga, Tufts, Aiko, C—45)

Acknowledgments. The authors wish to express their appreciation to those who assisted with the work referred to in this paper. They include people associated with Canners Machinery, Inc., Simcoe, Ontario; Manistee-Benzie Horticulture Society; Leelanau Fruit Company; and National Institute of Agricultural Engineering, Silsoe, England.

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POSTHARVEST HOLDING OF MACHINE-HARVESTED STRAWBERRIES

J. R. Morris, D. L. Cawthon, and G. S. Nelson

Summary. Firm-fruited strawberries (*Fragaria* x *ananassa* Duch.) for processing can be mechanically harvested, properly handled, and then held for up to 48 hours at 24°C or for 7 days at 1.7°C without excessive quality loss. High mold count and a reduction in other quality attributes occur after 96 hours at 24°C.

INTRODUCTION

Considerable postharvest research on strawberries has been reported (1,2,4,6,8,9,12,16,17) and several reviews (3,13,14,15) are available on the subject. The importance of storage temperatures and time of holding periods, packaging, and fungal control on postharvest quality of hand-picked strawberries and other small fruits has been demonstrated (2,5,16); however, the response of mechanically harvested strawberries to postharvest handling techniques is a new area of investigation.

A preliminary test (7) indicated that immature machine-harvested strawberries could be ripened to acceptable color within 2 to 4 days at 24°C.

The purpose of this study was to determine the effect of length of holding period and fruit ripeness on the quality of machine-harvested strawberries.

MATERIALS AND METHODS

Fruit from the Arkansas breeding line A-5344 was mechanically harvested for the holding studies. This breeding line was selected because of its firm fruit characteristics. Large-sized A-5344 fruit averaged 44 kg/100 g on an Allo-Kramer shearpress as compared to 22 kg/100 g for large-sized 'Sunrise' fruit. Preliminary studies showed that with most commercial cultivars fruit firmness or holding capability was not sufficient for extended postharvest holding. The fruit was washed immediately after harvest and air-dried.

Ten kg of machine-harvested fruit were mechanically separated for ripeness by sizing into three categories: small (mostly green), medium (mostly inception), and large (mostly ripe).

Two 100-g samples were taken as intial (0 hour) samples from the three categories and frozen for later quality analysis. The remaining fruit in each category was separated into two lots and placed in open plastic containers. One lot was held at 24°C and after 48 to 96 hours, samples of each category were frozen for later analysis. The other lot of berries was held at 1.7°C for 7 days, transferred to 24°C; after 0, 48, and 96 hours at 24°C, samples of each category were frozen. Treatments were replicated twice. Quality determinations were those of Morris and others (10). Mold was determined by the Howard mold-counting technique and expressed as the percentage of positive fields (11).

In a separate study, ripe fruit of A-5344 was held for 24 and 48 hours. After each of the holdings periods the fruits were sliced and frozen with a fruit-to-sugar ratio of 4:1. The sensory attributes were rated from 1 (poor) to 10 (best) by a 10-member panel.

RESULTS AND DISCUSSION

More mature fruit averaged higher in soluble solids, lower in acidity, higher in CDM (Color Difference Meter) 'a' values, and had a higher mold content (Table 1). Green fruit was considerably more viscous than inception or ripe fruit. Small and medium-sized berries showed a greater reduction in titratable acidity during holding than did the large, ripe fruit. Color ('a' values) was lost during 96 hours, holding only for the inception and ripe fruits. The riper fruit had the greatest initial color and the greatest loss during holding. Viscosity of puree made from green fruit increased after 48 hours holding and then decreased. Holding fruit of the green category did not advance soluble solids or color to the level of the initial inception fruit, nor did the inception fruit advance in these quality attributes to the level of the initial ripe fruit.

Berries held at 1.7°C for 7 days before storage at 24°C had slightly higher soluble solids, lower titratable acidity, lower CDM 'a' values, and a higher percent mold count than fruit stored at 24°C without first being held at 1.7°C (Table 2). Although these treatments significantly differed in soluble solids, titratable acidity, and CDM 'a' values, the differences were not commercially important.

A significant interaction for storage method and holding time showed that the soluble solids in the berries held at 1.7°C for 7 days before storage at 24°C averaged slightly higher because of the higher soluble solids in these fruits on the last sampling. Although color 'a' values were best for fruit placed directly at 24°C, a drastic loss of color occurred after 96 hours and the color of these berries was not acceptable. Also, color scores of fruit stored first for 7 days at 1.7°C were not acceptable after 48 hours of storage at 24°C.

Commercial packers in the Ozark region believe that mold becomes a limiting factor any time the level consistently stays above 50 percent. The fruit held for 48 hours at 24°C after being stored for 7 days at 1.7°C was unacceptable.

Taste panel evaluation of ripe fruit of A-5344 (Table 3) showed that after 48 hours holding, all quality ratings, except color intensity, were lower. All ratings were within an acceptable level, but flavor was reaching the marginal limit of acceptability.

Table 1. Effects of ripeness and holding time at 24°C on quality of mechanically harvested A-5344 strawberries, 1975

Treatment	Sol. solids (%)	Tit. acidity* (ml)	Color CDM (a)	Color Visual** (1-10)	Viscosity (sec/25 rev)	Mold*** (%)
Ripeness						
Green	3.8	7.5	12	2.6	88.4	44
Inception	4.0	5.8	21	5.4	5.7	46
Ripe	4.8	5.0	23	6.4	4.6	70
LSD @ 5%	0.1	0.3	2	0.4	29.2	15
Ripeness x holding time @ 24°C						
Green						
0 hr	4.3	8.1	11	2.0	67.1	19
48 hr	3.8	8.2	13	3.0	161.5	22
96 hr	3.3	6.1	11	3.0	36.5	91
Inception						
0 hr	4.7	7.0	25	6.0	5.7	13
48 hr	4.1	5.3	23	6.0	6.5	39
96 hr	3.3	5.0	15	4.0	4.9	88
Ripe						
0 hr	5.3	5.0	28	8.0	5.1	37
48 hr	5.1	4.6	24	7.0	5.0	75
96 hr	3.9	5.3	17	4.0	3.7	98
LSD @ 5%	0.2	0.6	3	0.6	50.5	NS

*Ml of 0.1 N NaOH that were required to titrate 5 grams of puree to pH 7.

**Visual color was rated by a five-member panel on a scale of 1 to 10 (10 = best and 5 = acceptable).

***Mold was determined using the Howard mold-counting technique and reported as percentage of positive fields.

Table 2. Effects of storage method and holding time at 24°C on quality of mechanically harvested A-5344 strawberries, 1975

Treatment	Sol. solids (%)	Tit. acidity* (ml)	Color CDM (a)	Color Visual** (1-10)	Viscosity (sec/25rev)	Mold*** (%)
Storage method						
24°C	4.1	6.3	20	5.0	27.1	43
7 day @ 1.7°C, then @ 24°C	4.3	5.8	18	4.6	38.7	64
LSD @ 5%	0.1	0.3	1	NS	NS	12
Storage method x time @ 24°C						
Stored @ 24°C						
0 hr	4.7	6.8	23	6.0	23.8	13
48 hr	4.3	6.5	23	6.0	46.9	31
96 hr	3.2	5.6	13	3.2	10.4	84
Stored 7 days @ 1.7°C, then @ 24°C						
0 hr	4.7	6.6	20	6.0	28.1	32
48 hr	4.4	5.6	17	4.0	68.4	59
96 hr	3.8	5.3	16	4.0	19.7	100
LSD @ 5%	0.2	NS	2	0.6	NS	NS

*Ml of 0.1 N NaOH that were required to titrate 5 grams of puree to pH 7.

**Visual color was rated by a five-member panel on a scale of 1 to 10 (10 = best and 5 = acceptable).

***Mold was determined using the Howard mold-counting technique and reported as percentage of positive fields.

Table 3. Effects of holding time at 24°C on organoleptic quality of mechanically harvested A-5344 strawberries (ripe category)*

Variable	Wholeness	Flavor	Color intensity	Brownness	Texture	Gen. appear.
Holding time @ 24°C						
0 hr	8.5	7.1	7.6	8.3	7.9	7.8
48 hr	7.3	5.5	7.7	6.5	6.3	7.0
LSD @ 5%	0.5	0.5	NS	0.6	0.4	0.4

*Sliced and frozen strawberries rated by a ten-member panel on a scale of 1 to 19 (10 = best and 5 = acceptable).

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THE CONCEPT AND DESIGN OF AN ON-FARM CLEAN-UP SYSTEM FOR MECHANICALLY HARVESTED STRAWBERRIES

Dale E. Kirk

BACKGROUND

In response to a request from a group of growers who are developing a strawberry harvester in Oregon, a portable unit for washing, capping, stemming, and pre-sorting strawberries was constructed and operated briefly in 1979. The growers supplied the cost of all equipment and materials. The design time and construction labor were supported by a grant from the Pacific Northwest Region Commission.

REQUIREMENTS

Specifications for the unit indicated a required capacity to process 2,000 pounds (907 kg) per hour of raw product. The unit had to be portable and not require utility services beyond what might be expected to be available on a modern farmstead. Besides performing the capping, stemming, and washing operations, the unit was to provide opportunity for hand sorting and placing the fruit into various types of handling containers including field boxes or metal cans.

DESIGN

The pilot model of the OSU capper-stemmer unit (1,2) had a demonstrated capacity of 1,000 pounds (454 kg) per hour for a bed of rollers 1 foot (0.305 m) wide. To obtain the desired capacity, two of the OSU units, as illustrated in Figure 1, were used operating in parallel. Individual flotation and feed tanks were supplied to each line and the fruit was not combined until it had passed over the vibrating sizing screens. The fruit was collected by gravity from the two screens and elevated to a plastic-linked sorting belt. Containers were filled at the end of the sorting belt.

The equipment was mounted on an 8 foot by 23 foot (2.44 m by 7.01 m) flatbed implement trailer, as shown in Figure 2. A water catch basin was installed in the trailer bed, and part of the decking was replaced with expanded steel mesh, as shown in Figure 3, to facilitate catching the spray and flume water. Water for floating the berry clusters and fluming them over the roller beds was taken from the catch basin by a 3/4-inch (1.91 cm) centrifugal pump and piped to each feed tank.

Fresh water was supplied at 35 pounds per square inch (241.3 kPa) to each of the 16 fan spray jets. The spray jets served the triple purpose of (1) providing the hydraulic dam in the flume water to hold back

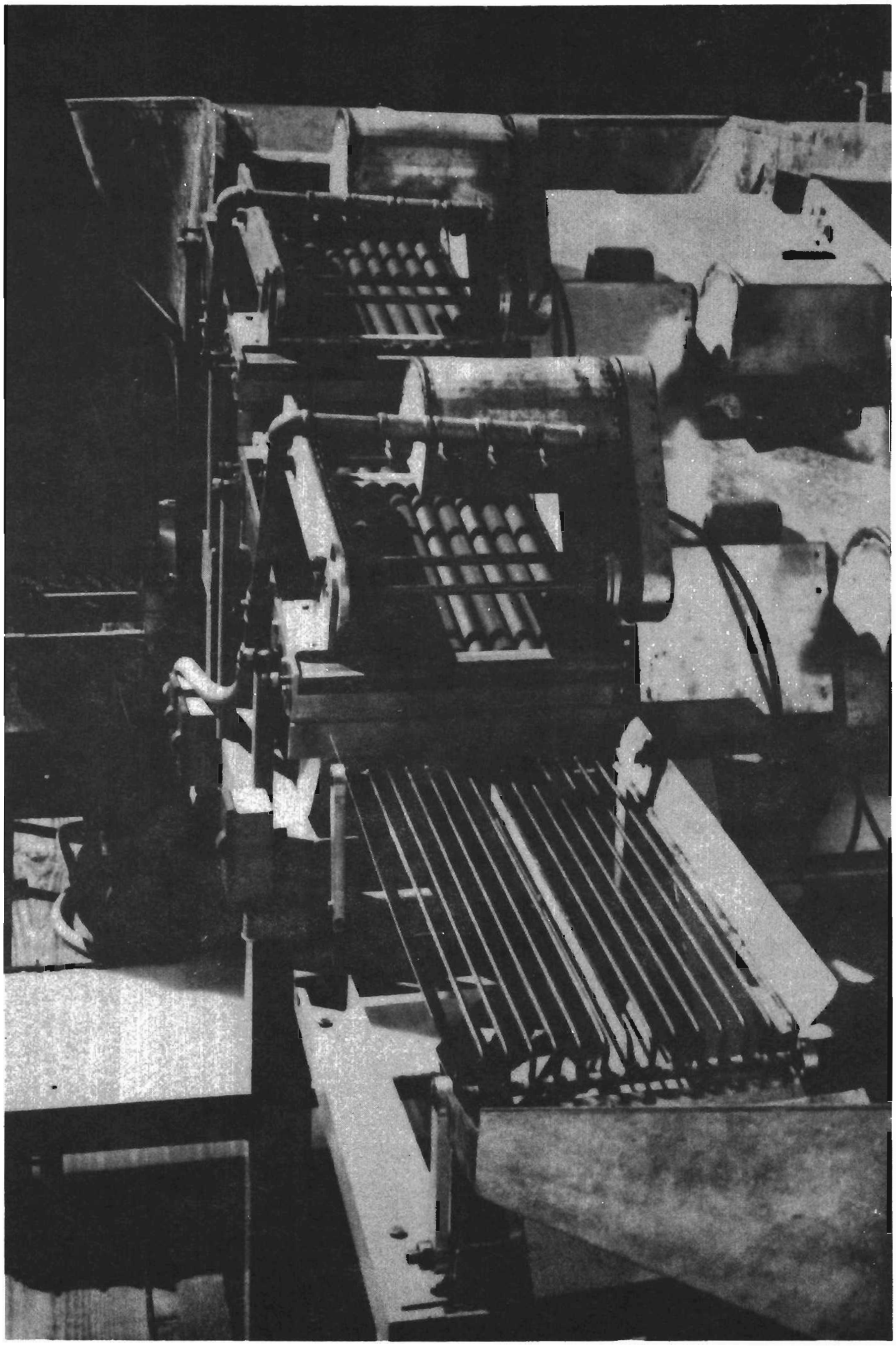

Figure 1. Tandem capper-stemmer roller beds with vibrating screen.

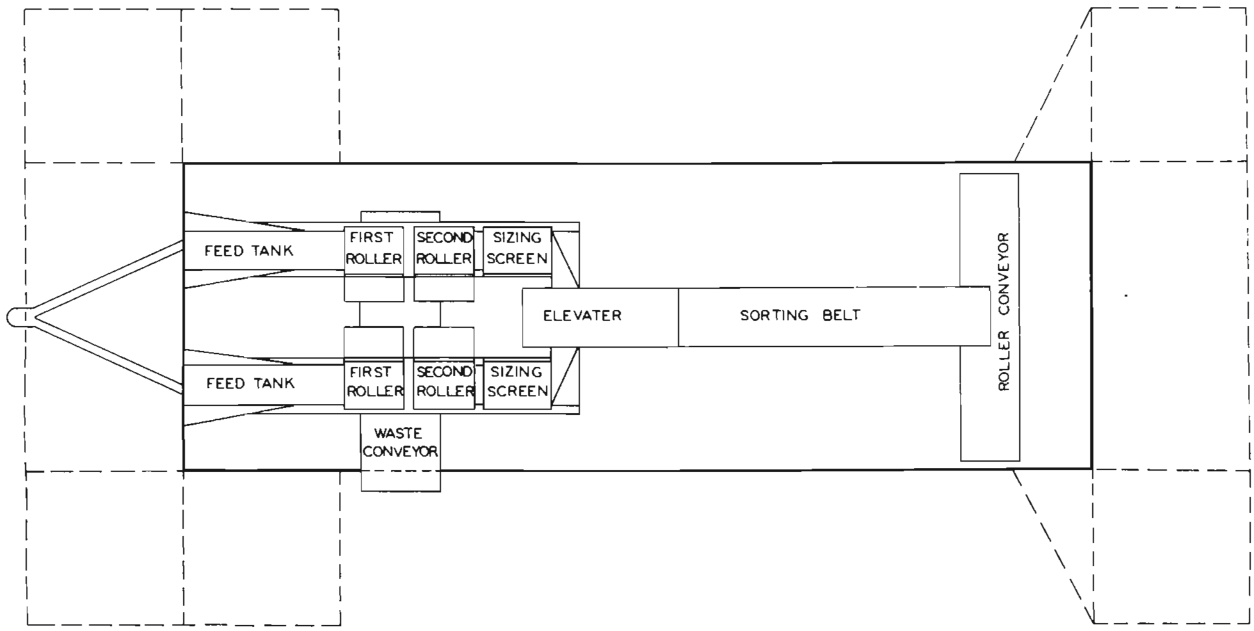

Figure 2. Layout of capping, stemming, and sorting equipment on implement trailer.

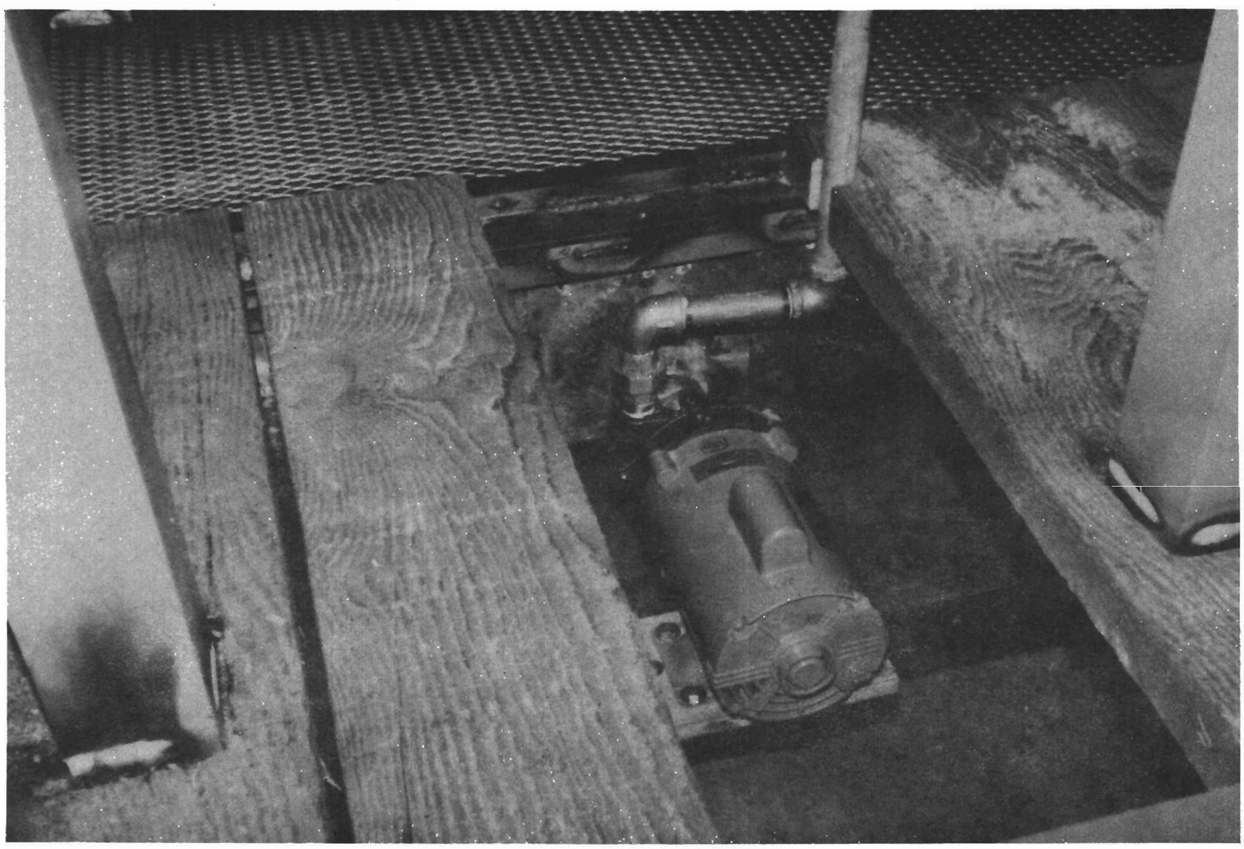

Figure 3. Expanded metal screen over trailer sump with circulating flume-water pump in foreground.

the berry clusters, (2) pushing the stem ends into the pinchpoints between the counterrotating soft neoprene rollers, and (3) washing any soil or other foreign matter from the berries. Each jet was rated at 1 gallon per minute (3.79 l/min), making a total make-up feed water requirement of 16 gallons per minute (60.62 l/min).

Power to the unit components was supplied through four one-tenth horsepower (0.0746 kw) motors, six three-fourth horsepower (0.5595 kw) motors, and one one-half horsepower (0.3730kw) motor. The total rated running current was approximately 30 amperes at 220 volts single phase.

Space for handling extra materials was provided by installing 4-foot-wide (1.22 m) fold-out platforms around the front and rear of the trailer, as shown in Figure 4. Folding leg supports gave the platforms sufficient strength and rigidity to permit setting pallet loads of unprocessed fruit on the front end and processed fruit on the rear end. When the platforms are folded into the vertical position, as shown in Figure 5, the trailer is restored to a maximum width of 8 feet (2.44 m) for convenient highway transport.

OPERATION

The unit was operated briefly on some overripe mechanically harvested fruit at the end of the 1979 season. It handled approximately 2,000 pounds per hour (907 kg/hr) of field-run product. No performance data on capping and stemming effectiveness were taken. A berry grower who observed the brief test has agreed to purchase the unit and plans to operate it on his farm during the 1980 season.

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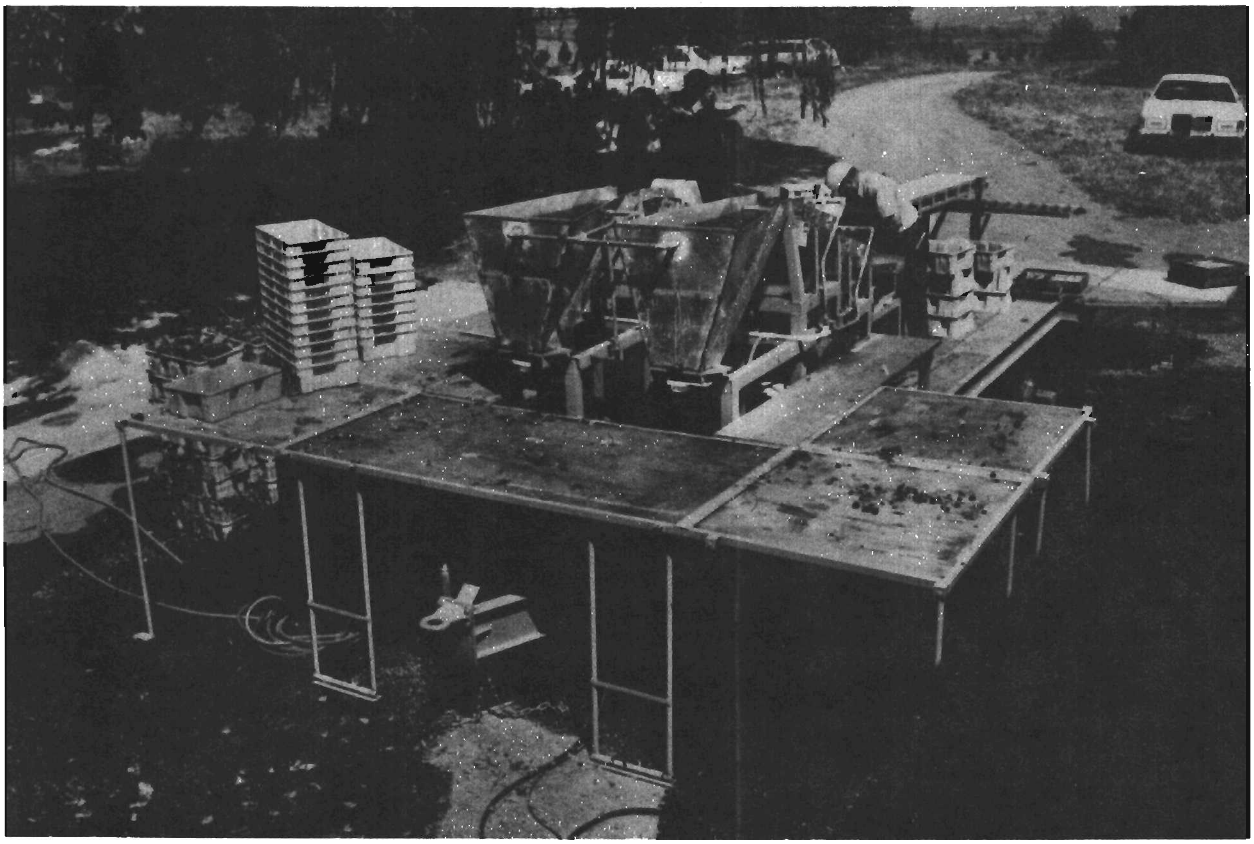

Figure 4. Platforms in folded-out position to provide added work space.

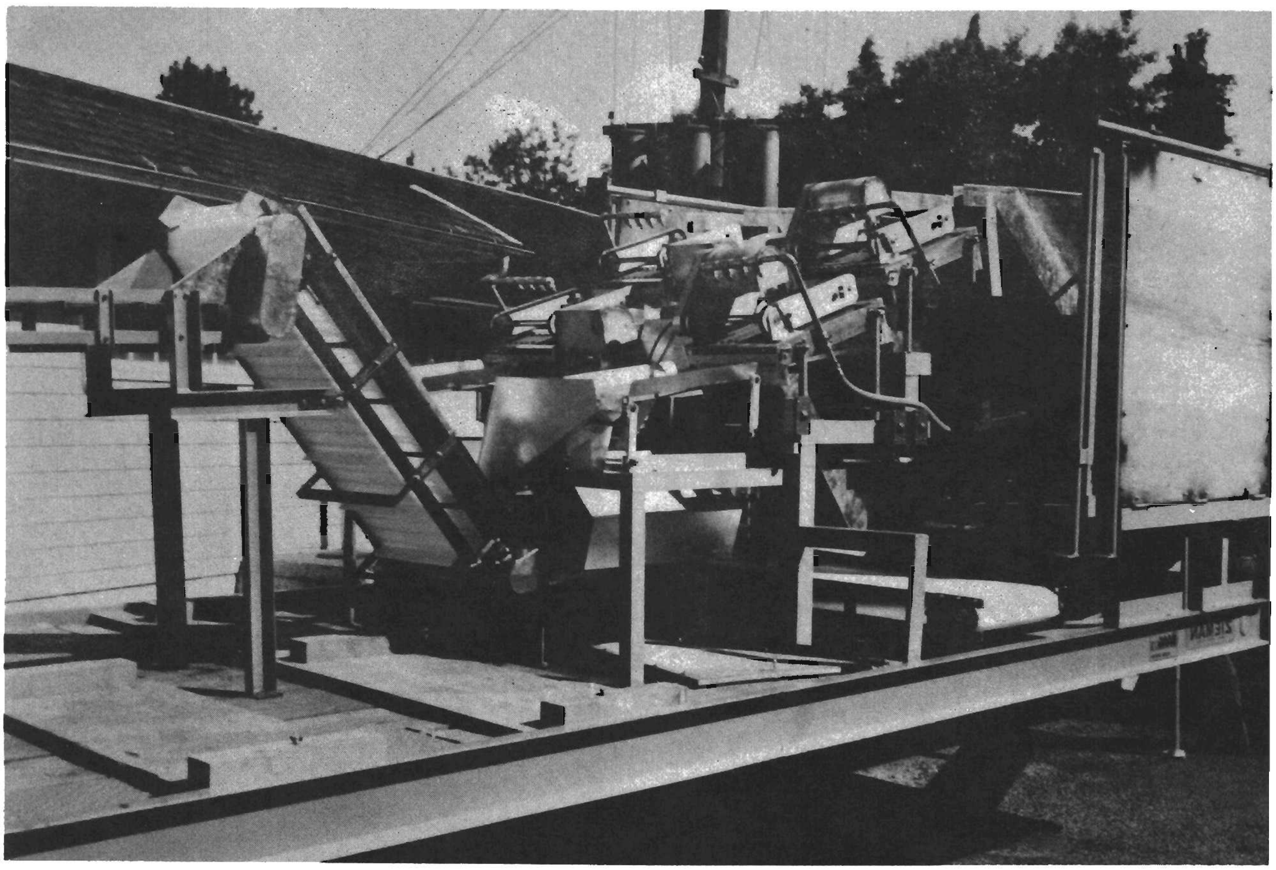

Figure 5. Platforms in folded-up position for highway transport.

EVALUATING STRAWBERRY SELECTIONS FOR MECHANIZATION AND HIGH QUALITY

W. A. Sistrunk and J. N. Moore

Summary. Cultivars and selections have been evaluated for quality and adaptation to mechanization over the past 15 years. Many physical, chemical, and sensory tests have been used to define quality of fresh and frozen sliced fruit. In the early part of the program, most of the nationally known cultivars were characterized for quality in comparison to new selections. Color was adequately defined by Color Difference Meter and total anthocyanins. The shearpress, viscosity, and ratings on slice wholeness and texture by the sensory panel were used to detect differences in firmness. 'Cardinal' and A-5344 performed well in all quality tests, and are adapted to mechanization.

INTRODUCTION

Strawberries have a consumer appeal that is unexcelled by other fruits because of their delicate flavor and dessert quality. The annual pack of frozen strawberries in the U.S. remained fairly constant at 200 to 300 million pounds between 1952 and 1969 (1). In the last 10 years the annual pack has fluctuated from 147 to 220 million pounds, being lowest in 1972 and highest in 1977. The 1978 pack declined 28 percent as compared to 1977. This decrease may be partly a result of change in available labor for harvesting.

The strawberry fruit is composed of cortical and medullar layers of cells that are loosely bound by short-chain pectins. Fibrovascular bundles radiate out from the center of the fruit and connect to the achenes at the cortex. Variations in fruit morphology range from a tough cortex and soft mealy medulla to a tender cortical layer and hard medulla, and these affect the quality of whole fruit during harvesting, handling, and washing. Subsequent slicing and mixing for freezing caused extensive breakage in soft strawberries, whereas firm selections showed very little breakage (22). Firmness and color of ripe fruit are perhaps the major quality attributes of cultivars mechanically harvested for processing. Chemical characteristics like acid content, soluble and total solids, ascorbic acids, pectins, cellulose, and phenolics are useful in defining the genotypes that are to be used in developing high-quality strawberries. Ascorbic acid and other nutrients may become more important in fruit breeding in the future than they have been in the past. Experience with chemical analysis of strawberry selections has shown us that we must understand the chemical nature of color, texture, and flavor if we are to make rapid progress in developing cultivars suitable for processing.

The development program on strawberries at the University of Arkansas was begun in 1964 and has included collecting genetic material, breeding, field testing, processing, sensory evaluation, chemical and physical measurements on fresh and frozen fruit, utilization studies on mechanically harvested fruit, and basic studies on pigment stability. The primary objective in evaluation of processing quality was to characterize quality attributes of cultivars and selections as they related to field variables in order to develop genotypes with consistently superior quality.

A number of factors such as cultivar, maturity, fertilizers, field temperature, harvest date, and rainfall have a significant effect on fruit firmness (6,7,11,13,19,21,22). Cultivars and selections with a tough cortex and firm medulla have the ability to resist adverse field variables. Softer fruited cultivars were more susceptible to mechanical injury and damage from fungi during handling (7,16). Thus heavy rainfall, high humidity, and heavy fertilization decreased firmness and total solids although fruit size was larger (6).

The delay of harvesting for mechanical picking did not affect mold counts, although incidence of moldy fruit was higher (12,15,23). The moldy fruit disintegrated during harvesting and was not recovered after washing. The picking interval did not affect mold count as much as the amount of rainfall (2). There was a lag period of 12 hours after inoculation with mold before the development of mycelium. One of the main problems of mechanization was the inefficiency of the harvester in the wet field after heavy rainfall (15). Delay in harvest beyond the date of optimum conditions caused lower yields and lower amounts of soluble solids and acids.

QUALITY ATTRIBUTES

Color

One of the principal quality attributes for strawberries is color. The Color Difference Meter (CDM) has proved to be a good method of measuring color (20,22). The DCM 'a' value measures redness, and is highly correlated with the color intensity of fresh and frozen strawberries. Shah and Worthington (20) demonstrated that 'L' value alone was sufficient to measure color of strawberries. Hue angle, which is calculated from the $\tan^{-1} a/b$ of the CDM, is another method of expressing color but it has been used less frequently (14). Another useful color expression for tomatoes was derived from data obtained by CDM, $2000 \cos \theta/L$ (27).

Texture

Internal and external structure of strawberries greatly influences the textural properties and resistance to breakage and disintegration during harvesting and handling. There is a wide range in these properties among different genotypes that must be recognized and defined early in a breeding program. A number of objective measurements have been utilized for testing texture of strawberries (3,4,5,17,25) by compression and puncture-type instruments. Three distinct firmness peaks were produced in strawberry cultivars and selections in curves with an Instron as follows: force to break the skin; nature of flesh and core area; and total resistance to shear (17). A wide range in firmness and skin toughness was obtained among 64 selections and cultivars. Firm-fleshed fruit decreased more in firmness with an increase in temperature than those that were soft-fleshed. A correlation of 0.76 was obtained between skin toughness and flesh firmness. Also, a wide range in firmness for cultivars at different ripeness levels was evident. Similar differences for cultivars and ripeness levels in strawberries was shown when a penetrometer was used to measure firmness (5).

Other textural characteristics or strength properties are directly related to composition of the cell wall and surrounding tissues. Changes in carbohydrates as the fruit ripens are important in regulating rigidity of the fruit. Szczesniak and Smith (25) demonstrated that the tissues became less firm in strawberries and juice was released during ripening. This change was attributed to the epidermal cell walls and subsequent enlargement of pith cells. The increased insolubility of pectic substances and cellulose during maturation, harvesting, handling, and processing was shown to be related to firmness, slice wholeness, and other textural properties (21,22,24).

Flavor

Flavor is especially important in strawberries because of the aroma and tantalizing flavor. Flavor is the most important single quality factor in processed foods (9), although it is almost impossible to separate flavor from other mouthfeel characteristics in fruit such as smoothness, softness, crispness, melting, and mealiness.

Although the volatile flavors in strawberries have been identified (8), there has been very little attempt to utilize the information for breeding selections rating high in flavor. Flavor has been shown to be related to color in strawberries (10,22). Flavor was correlated with acidity because of the desirability of an acceptable balance between acid and sweetness. Some of the precursors of flavor are necessary for development of anthocyanin pigments, so a relationship exists between color and flavor. Yamashita and others (26) demonstrated that alcohols were readily converted to esters in whole strawberries, whereas fewer esters were formed when berries were broken into small pieces.

Normally, when a strawberry selection has a good color with a good balance of acidity and sugars, the flavor is desirable. Some selections and cultivars with light color and a good balance of sugar and acid have good flavor, but these are not common among genotypes. 'Blakemore' and similar genotypes have a more exotic type of flavor than most cultivars of strawberries, yet this type of flavor has not been rated higher in sensory tests than the typical flavor found in other cultivars (Table 1).

Table 1. Main effects of cultivar and harvest on quality attributes of frozen strawberries

	CMD 'a'	Sensory*			Shear-press (kg/188g)	Viscosity (sec/100rev)	Percent mushy slices
		Color	Slice Wholeness	Flavor			
Cultivar							
Tenn. Beauty	23.2	6.2	4.1	5.3	58	17.7	36
Sunrise	23.5	3.4	3.9	4.2	47	18.9	31
Pocahontas	21.7	5.6	6.4	5.5	55	19.1	14
Albritton	24.5	5.5	4.8	5.3	42	22.2	25
Surecrop	23.3	5.2	4.0	5.2	40	24.2	27
Redglow	23.1	5.4	4.5	4.9	49	20.8	27
Midway	22.2	5.7	5.1	5.7	49	19.4	31
Blakemore	22.9	4.3	5.0	5.6	45	22.3	22
Stelemaster	21.2	3.9	4.5	5.0	55	34.6	16
Citation	22.8	6.0	5.7	5.1	51	27.3	15
Earlidawn	25.8	5.7	4.9	4.7	52	33.7	24
Dixieland	23.1	4.4	5.8	4.7	59	40.5	20
Midland	25.9	7.0	4.5	6.6	46	51.1	19
Earlibelle	27.7	7.3	6.5	5.2	69	60.9	10
Northwest	25.5	8.1	4.5	5.7	51	32.5	21
Md.U.S.2713	26.6	8.0	6.8	6.5	61	36.1	5
LSD @ 1%	1.6	1.4	1.7	NS	8	10.3	13
No. of harvests							
2	22.1	5.0	5.2	5.1	55	30.8	18
4	23.7	5.5	5.4	5.5	53	30.7	23
6	24.4	5.8	4.9	5.2	48	26.9	23
LSD @ 1%	0.8	0.4	NS	NS	3	NS	4

*Average ratings by a sensory panel on a scale of 1 (poor) to 10 (best).

The objectives of this research were to develop selections with optimum firmness, color, and flavor that were suitable for processing and for fresh market. High yield, adaptation to mechanization, and resistance to major diseases and insects were also included in field objectives.

MATERIALS AND METHODS

Strawberries were grown in individual or replicated plots at the

Main Experiment Station, Fayetteville, or at the strawberry branch station at Baldknob, Arkansas. The frozen sliced fruit was prepared and analyzed by methods described in earlier publications (22,23). Both the fresh fruit (after washing) and the thawed sliced frozen fruit were analyzed. Objective and sensory evaluation tests were performed to more clearly define quality attributes, but only a small part of the data are shown to illustrate the developments in the program.

RESULTS AND DISCUSSION

At the outset of the breeding program on strawberries in Arkansas, most of the cultivars grown commercially for processing in the U.S. were placed in trials and evaluated for yield and quality of frozen sliced fruit. Most of those tested were only fair in color as shown by lower 'a' values and color ratings (Table 1). Also, the frozen sliced fruit broke up badly after thawing, as indicated by the slice wholeness and percent mushy slices. In initial tests only 'Earlibelle' and Md. U.S. 2713 had an acceptable firmness in the frozen pack.

Some of the better selections in the first 4 years of the program were much better in color than the cultivars tested as shown by the higher 'a' values (Table 2).

Table 2. Quality determinations of better selections of fresh and frozen strawberries, 1969

Selections	CDM 'a'	Percent soluble solids	Percent acid as citric	Ascorbic acid (mg/100g)	Shearpress* (kg/188g)	Average rating**
A-5131	30.1	7.8	.93	45	44	8.2
A-5166	28.5	6.3	.62	54	51	7.6
A-5245	28.5	7.1	.80	60	64	7.8
A-5254	28.8	6.7	.88	48	49	7.6
A-5321	27.3	6.8	.72	62	68	7.9
A-5332	29.7	7.0	.98	48	46	7.6
A-5342	32.0	7.0	.85	50	48	8.5
A-5344	31.3	7.0	.91	44	98	9.1
A-5347	27.0	7.1	.90	46	52	7.6
A-5350	28.0	7.0	.85	51	78	8.0
A-5360	28.7	7.9	.75	57	45	7.6
A-5362	33.3	6.9	.94	59	57	8.4
Tenn. Beauty	27.2	6.8	.73	46	42	6.6
Surecrop	27.1	7.1	.92	44	39	6.4
Earlibelle	32.5	7.0	.99	57	59	8.0
LSD @ 5%	1.8	0.3	.08	7	16	0.5

*Shearpress values on thawed frozen slices (4+1 sugar).

**Average ratings by a sensory panel on a scale of 1 (poor) to 10 (best).

The average ratings for quality were much higher for selections than for 'Tennessee Beauty' and 'Surecrop' standard cultivars, grown commercially in the state at that time. Some of our earlier studies indicated that higher acidity was important for color stability. Most of the better selections contained 0.9 percent or higher acidity, which is considered to be a good range (23). A few selections were notably higher in soluble solids than the cultivars used as standards. The selection A-5344 stood out above all others on firmness, but others such as A-5245, A-5321, and A-5350 were firmer than the average selections in the program.

The development of the strawberry harvester had gained momentum by 1972 and the need for genotypes adapted to mechanization was evident. Fortunately, a few new selections in our program had firm fruit and relatively high yields. In an advanced trial in 1971 most of those selections, except 'Sunrise,' had higher yields than most cultivars (Table 3).

Table 3. Objective and sensory evaluation of certain strawberry selections, 1972

	Fresh						Frozen**		
Selection	Yield (T/A)	Percent soluble solids	Percent acids as citric	Ascorbic acid (mg/100g)	Shear-press (lb/200g)	PPO activity* (y/g)	Color	Slice wholeness	Flavor
5063	7.56	6.0	.83	52	80	55	6.1	6.4	6.1
5252	4.86	5.4	.78	55	80	51	5.0	6.0	6.0
5270	8.69	6.0	.69	44	79	58	5.5	6.6	6.6
5321	6.11	6.0	.69	35	130	60	6.4	7.3	7.1
5344	9.64	6.0	.65	48	167	48	7.6	8.6	6.1
5350	5.57	6.6	.91	30	138	48	7.8	8.8	7.5
5474	8.17	7.2	.79	79	93	62	4.8	7.0	5.7
5575	5.93	6.6	.74	45	109	140	5.1	7.6	6.6
5588	8.58	7.0	.69	57	63	48	6.7	6.3	6.2
5599	7.13	7.3	.86	55	66	54	3.5	5.2	6.3
5675	5.27	6.4	.79	43	69	76	7.2	6.5	7.0
5701	4.93	6.2	.81	61	138	79	7.1	8.6	7.5
5734	9.27	6.6	1.01	45	96	90	7.7	7.3	6.2
5736	6.51	6.8	.82	43	110	50	8.6	8.1	8.5
5744	12.33	6.4	.83	50	129	75	7.9	7.9	6.8
5745	9.12	6.6	.67	43	125	52	6.9	7.6	8.0
5756	5.95	7.0	.96	51	85	78	8.3	7.1	6.9
Earlibelle	5.65	7.5	.83	52	78	92	7.8	6.9	8.6

*Polyphenoloxidase.
**Rated on a scale of 1 (poor) to 10 (best) by a panel of 12 members.

The yield of 'Sunrise' was 12.07 tons per acre. Selections listed in the table were chosen from a larger group that was tested in 1972. Part of the selections were lower in soluble solids, acidity, ascorbic acid, and resistance to shear than 'Earlibelle.' Selections A-5344, A-5350, A-5701, A-5736, A-5744, and A-5756 were rated high in color and slice wholeness in the frozen sliced pack. Because of the high yields and desirable fruit characteristics, A-5744 was named 'Cardinal' in 1974. 'Cardinal' originated as a cross in 1967 and was first selected in 1969. Extensive testing was begun on 'Cardinal' in 1970 because of its productiveness, disease resistance, and high quality.

'Cardinal' was not as firm as A-5344, but it held up well under mechanized harvesting and handling. There was a wide range in polyphenoloxidase (PPO) activity and ascorbic acid among selections. Concurrent studies showed that PPO activity was important to color stability in strawberries (23). Selections with low acidity and high pH were especially vulnerable to pigment degradation unless PPO was inactivated. 'Earlibelle' rated high in color and flavor but its yield was low compared to 'Cardinal' (5744). The cultivar 'Earlibelle' emerged as the standard for comparison of selections because of its consistent quality, yet its firmness was only average.

A sister selection of 'Cardinal,' A-5734, was released in 1974 as a new cultivar, 'Comet.' It ripens earlier than 'Cardinal' but is consistently as high in quality except in firmness when harvested at optimum quality.

Progress has been made since 1974 in attaining resistance to red stele, a fungal disease. The selection A-6224 has shown the most resistance (Table 4). A sister selection, A-6225, has been rated exceptionally high in quality in trials since 1976, but it does not have disease resistance.

'Comet' has not shown the same firmness characteristics as 'Cardinal' and probably would be less suitable for mechanical harvesting. The cultivars 'Apollo' and 'Atlas,' which have been named in recent years, were comparable to 'Earlibelle' in quality. They were high in acidity and had good color and fairly good slice wholeness in the frozen sliced pack. 'Apollo' was low in soluble solids in 1978, while selections A-6718, A-6769, and 'Comet' were quite high (Table 4). We have not selected for soluble solids specifically; this characteristic might be worthy of consideration except there is no apparent relation to firmness. In 1978, selections A-6225, A-6583, and A-6775 were markedly firm in the sliced frozen fruit. Other selections such as A-6414, A-6565, and A-6568 were extremely firm, but their color was not comparable to 'Cardinal' or A-6224 (data not shown).

The test for total anthocyanins (TACY) has been very useful for determining total color of fresh fruit and color degradation during freezing and thawing. Selections A-6665 and A-6769 contained much more color than other selections, and this was reflected in the 'L' values and color scores. Too much color is considered objectionable by some panelists. Also, this may be a factor in mechanization when harvesting

Table 4. Objective and sensory evaluations of certain strawberry selections, 1978

Selections	Fresh: Percent Soluble solids	Percent acid as citric	Total anthocyanins* (OD/g)	Ascorbic acid (mg/100g)	CDM L	CDM 'a'	Frozen**: Color	Slice wholeness	Flavor
5745	6.2	.84	2.20	37	30.5	25.5	6.4	7.8	6.4
6086	5.3	.89	1.62	36	27.3	29.9	6.4	7.7	5.7
6224	5.8	.89	1.44	21	27.3	27.2	5.8	7.3	6.8
6225	6.2	1.07	2.21	40	24.4	29.0	9.1	8.8	6.8
6385	6.4	.83	2.01	40	21.9	26.1	7.8	6.7	7.3
6495	5.9	.94	2.48	47	23.8	30.7	7.9	6.2	6.8
6543	5.9	.94	1.68	50	22.7	27.6	6.5	6.1	7.2
6583	6.3	1.16	2.90	35	19.6	26.9	8.8	8.2	7.2
6665	6.7	.75	4.95	36	18.2	26.7	8.9	6.9	7.1
6673	7.0	.85	2.36	32	23.0	28.8	8.3	6.1	6.9
6675	5.5	.84	2.05	24	21.8	26.3	8.3	6.3	7.7
6679	6.1	.81	1.40	27	25.5	24.6	5.2	5.8	7.4
6718	8.3	.80	2.16	31	24.1	29.8	7.4	6.1	7.0
6725	5.7	.82	1.78	23	23.1	23.7	7.5	7.1	7.1
6769	7.5	.90	3.48	40	22.5	29.3	8.1	6.5	6.9
6775	6.0	.89	2.18	29	22.5	25.6	7.3	8.1	6.6
6791	6.0	.80	2.10	38	23.2	24.1	7.7	7.9	7.1
Apollo	4.8	1.08	2.44	40	24.0	30.5	7.4	6.4	6.3
Atlas	6.5	1.03	1.78	47	26.2	29.7	7.3	6.9	7.0
Cardinal	5.9	.85	2.95	27	18.9	24.7	9.1	7.9	7.4
Comet	8.2	.92	2.68	25	19.4	28.1	8.5	6.5	7.0
Earlibelle	5.9	1.15	2.52	42	23.6	31.5	7.5	6.9	6.7
Sunrise	6.3	1.08	1.64	42	28.8	28.5	4.6	5.2	6.1

*Total anthocyanins determined by extraction with acidified ethanol (Fuleki and Francis, 1971).

**Rated on a scale of 1 (poor) to 10 (best) by a panel of 12 members.

is delayed to obtain optimum yields with a once-over harvest. Picking the first one or two harvests by hand could alleviate the problem of excessive color intensity in late season picking by machine (15).

In conclusion, there are a number of physical and chemical tests that define selections of strawberries for adaptation to mechanical harvesting. The shearpress, percent broken slices, viscosity, slice wholeness, and other physical tests were used to evaluate firmness. Maturity affected firmness, but some of the firmer selections were consistently firm and resistant to handling even in advanced stages of maturity. Pectins and cellulose have been found to be useful for determining differences in selections at different maturities. Color was determined accurately by CDM and total anthocyanins. These tests appeared to be adequate for measuring color of fresh fruit and in predicting sensory color of frozen sliced fruit. PPO activity was important in predicting color stability during postharvest holding and during thawing of frozen sliced or whole fruit.

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QUALITY OF MECHANICALLY HARVESTED STRAWBERRIES FOR PROCESSING

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S. E. Spayd, and D. L. Cawthon

Summary. Strawberry cultivars which have raw product quality similar to 'Cardinal,' 'Earlibelle,' and A-5344 and have a concentrated ripening pattern should be suited to a once-over mechanical harvest.

An acceptable frozen sliced product can be prepared from the cleaned, sized, and capped large fruit of cultivars suited to mechanical harvest. Jam manufactured from puree containing as much as 50 percent small (mostly green fruit) of 'Cardinal,' 'Earlibelle,' and A-5344 resulted in products comparable in quality to jam of all-ripe fruit of 'Tioga.' Preliminary results indicate that the rate of loss of anthocyanins was not accelerated during storage by the presence of immature fruit.

Introduction

Overall success of harvest mechanization of the strawberry industry is dependent on developing a total system for the production, harvesting, handling, and utilization of the fruit maturity classes that result from a once-over harvest. We therefore undertook a study to: (1) determine the suitability of large-size, machine-harvested fruit for use as a sliced, sugar-packed product; and (2) determine the influence of cultivar, fruit-maturity mixtures, and storage time on quality attributes of jam made from machine-harvested fruit.

YIELD AND FROZEN PRODUCT QUALITY

Materials and methods

The 1975 commercial model of the strawberry harvester, which differs from the 1977 model in that it picks only one row at a time, was used in this study. The harvested (Fig. 1) performs three basic functions. Fruit is lifted by air and (1) stripped from the plants; (2) separated from the leaves and other foreign material; and (3) conveyed to transporting containers. The machine's basic functional components were described by Morris and others (1).

Twenty-four plots of three strawberry cultivars, 'Cardinal,' 'Earlibelle,' and A-5344, were produced on flat-shaped beds at the Main Experiment Station, Fayetteville, Arkansas. The average percentage of fruit produced in each plot picked by machine was 96 percent for 'Cardinal,' 92 percent for 'Earlibelle,' and 94 percent for A-5344. Details of this production system were described by Morris and others (1).

Field plots were 4.6 m long, with 4.6 m skips between plots within the row to allow the machine to stop and empty its load before harvesting the next plot. The first harvest (early) was made on May 21, 1975, for A-5344 and on May 22 for 'Cardinal' and 'Earlibelle.' Succeeding harvests (middle and late) were made at 2-day intervals for each cultivar. Yields for each cultivar were pooled across the three harvest dates.

The fruit from each plot was cleaned, size-graded into small (mostly green) and large (mostly ripe) categories, and weighed. Resistance to shear was determined immediately after washing and sizing, using an Allo-Kramer shearpress on a 100-g sample of fruit, and reported as an average of the three harvest dates.

Sample for organoleptic evaluation were selected from the middle harvest date for 'Cardinal,' 'Earlibelle,' and A-5344. Sliced samples of large fruit were packed with a fruit-to-sugar ratio of 4:1 and frozen at -18°C for 6 months. Sensory attributes of the frozen sliced fruit were rated by 10 panelists after storage.

Results and discussion

Of the three cultivars evaluated, 'Cardinal' produced the highest yields (Table 1). The Arkansas breeding line A-5344 was the firmest cultivar, as indicated by high shear values, followed by 'Cardinal.'

Table 1. Yield, shear force, and sensory evaluation of mechanically harvested, sugar-packed, large-size fruit of three cultivars, 1975*

Cultivar	Total yield (MT/ha)	Shear force (kg/100g)	Whole-ness**	Color inten-sity	Flavor	General appear-ance	Overall quality appeal***
Cardinal	12.7	38	6.6	8.9	6.6	7.1	29.1
Earlibelle	10.2	24	7.9	7.4	6.4	7.6	29.3
A-5344	11.2	55	8.0	7.4	6.1	7.7	29.2
LSD @ 5%	0.9	7	1.2	0.6	NS	NS	NS

*Sugar-packed (4+1).

**Attributes rated 1 to 10 by a ten-member panel (10 = excellent and 5 = acceptable).

***Total of sensory attributes.

The large fruit of all three cultivars had acceptable socres for the sensory attributes evaluated. 'Cardinal' had poorer wholeness but better color than the other two cultivars. There were no significant differences among the three cultivars for flavor, general appearance, or overall quality appeal.

JAM QUALITY STUDIES

Study 1

Materials and methods

Samples for jam manufacture were also selected from the middle harvest date for 'Cardinal,' 'Earlibelle,' and A-5344. After machine harvesting, both the large and small fruit were placed in heavy polyethylene bags (1.5-2 kg), immediately frozen, and stored for 4 months at -18°C until jam was made.

'Tioga' fruit obtained from a commercial field near Watsonville, California, was also used in the jam study. The end of the hand-harvesting season was approaching, and irrigation and hand harvesting were discontinued 10 days prior to the machine harvesting. The strawberries were machine harvested, washed, and sorted into ripe and green categories. The fruit was frozen in 30-pound tins which were then packed in styrofoam containers with dry ice and transported by air to our laboratory. No thawing of the fruit was observed during transport. Raw product quality was not determined on 'Tioga.'

The fruit was thawed for puree by heating in a steam-jacketed kettle to 80°C, then pulped in a laboratory pulper fitted with a 0.033-inch screen. Cap residue was removed along with a portion of the seeds. Products were formulated, on a weight basis, as follows: (1) 1/2 puree large (ripe=R) plus 1/2 puree small (green=G) fruit; (2) 3/4R plus 1/4G; and (3) 7/8R plus 1/8G.

Jam was prepared in the following method:

1. Cooking 1,500 g of fruit in a 19-liter steam-jacketed kettle for 3 minutes at 30 psi steam pressure.
2. Stirring in a mixture of 8 g of 150 commercial rapid-set pectin and 100 g sugar and bringing to a boil.
3. Adding 1,500 g more sugar and bringing back to a gentle boil.
4. Turning off steam and adjusting batch to 68-69 percent soluble solids by adding water or by rapid heating.
5. Adding 10 ml citric acid; and
6. Pouring batch into 211 x 304 enamel-lined cans.

After cooling in tap water, the jam was held overnight prior to being analyzed.

Jam samples were presented in coded lots to a taste panel of 10 members before storage and after 9 months of storage at 21°C. Flavor, color acceptance, and color intensity were rated. Total anthocyanins (TAcy) was measured by extracting a 2-g sample of jam blended with 18 ml of EtOH-HCl at pH 1.0 and allowing the extract to set for one hour. The flocculate was filtered off by a single layer of facial tissue, and the absorbance was read at 500 nanometers on a Spectronic 20 spectrophotometer. The dilution factor x the absorbance was recorded as TAcy. A relative index of discoloration for the jam stored at 21°C for 9 months was determined by calculating the ratio of the absorbance of the filtrate at 520 nanometers to the absorbance at 430 nanometers (A_{520}/A_{430}).

To determine the ascorbic acid content, a 12.5-g sample was blended with 50 ml of 1 percent oxalic acid and filtered twice through Whatman No. 1 filter paper. Then 2 ml of 2,6-dichloroindophenol dye and 2 ml of filtrate were combined, and absorbance at 520 nanometers was determined within 15-20 seconds. Distilled water was used as a blank.

Results and discussion

Results of the tests are shown in Table 2. Organoleptic evaluation of jam made from the various maturity mixtures of the mechanically harvested fruit indicated that jam quality increased as the amount of green fruit decreased. However, as much as 50 percent of green fruit could be used in jam prepared from 'Cardinal,' 'Earlibelle,' and A-5344 to produce a product acceptable to the panel. Jam prepared from up to 50 percent green fruit of these three cultivars (all with high levels of total Acy) yielded products that were comparable in quality to jam prepared from 100 percent ripe fruit of 'Tioga.' Taste panel evaluation indicated that all products prepared from 'Cardinal,' 'Earlibelle,' and A-5344 were still acceptable after storing 9 months at 21°C. Because of the high total anthocyanin content of ripe 'Cardinal,' 'Earlibelle,' and A-5344 berries, it was possible to prepare a jam of acceptable color intensity even when large quantities of immature fruit were used.

As the percentage of green fruit increased in A-5344 and 'Tioga' jam, there was a tendency for more discoloration (lower A_{520}/A_{430}) after 9 months of storage. As expected, storage resulted in a major reduction in the ascorbic content of the jam, and ascorbic acid content was influenced more by storage time than by fruit maturity. Storage of the jam at 21°C for 9 months resulted in greater quality differences than did fruit maturity mixtures in the highly colored cultivars.

Study 2

Materials and methods

Fruit of 'Cardinal' and A-5344 for this study were collected the same way as in the previous study. Prior to pureeing, the small and large fruits were thawed for 12 or 24 hours at about 30°C. Puree combinations were (a) 25 percent ripe plus 75 percent green fruit, (b) 50 percent ripe plus 50 percent green, (c) 75 percent ripe plus 25 percent green, and (d) 100 percent ripe.

Table 2. Effects of cultivar and fruit maturity mixtures on sensory evaluation, total anthocyanins, reduced ascorbic acid, and discoloration of jam made from mechanically harvested strawberries (initially and after 9 months at 21°C), 1975

	Color intensity*		Color acceptance*		Flavor*		Total Acy (mg/100g)		Ascorbic acid (mg/100g)		Discoloration (A_{520}/A_{430})
	0	9 mo	0	9 mo	0	9 mo	0	9 mo	0	9 mo	9 mo
Cardinal											
R1/2 G1/2**	7.5	6.2	7.5	6.5	8.2	7.1	12.1	4.7	9.40	4.65	1.195
R3/4 G1/4	8.6	7.3	8.2	6.4	8.1	7.2	13.2	5.6	9.80	5.55	1.147
R7/8 G1/8	8.7	7.2	8.7	6.5	8.2	8.4	15.0	6.5	10.48	4.95	1.245
Earlibelle											
R1/2 G1/2	7.2	7.3	7.4	6.1	6.5	6.9	11.0	5.3	9.05	5.25	1.375
R3/4 G1/4	8.0	7.2	8.4	6.0	8.0	7.4	15.0	8.6	13.15	8.63	1.432
R7/8 G1/8	8.8	8.4	8.9	6.0	8.1	7.7	17.2	9.0	13.33	9.00	1.361
A-5344											
R1/2 G1/2	7.7	6.7	7.1	5.2	7.2	7.2	9.9	5.6	8.90	5.55	1.178
R3/4 G1/4	7.9	7.3	8.3	5.6	7.9	7.4	11.2	5.6	8.90	5.55	1.205
R7/8 G1/8	8.5	7.2	8.5	6.2	8.2	7.4	13.0	5.9	11.30	5.85	1.390
Tioga											
R1/2 G1/2	3.3	5.0	4.5	4.0	5.3	6.0	3.7	2.6	8.95	2.60	.787
R3/4 G1/4	3.8	5.5	5.5	4.4	6.0	6.1	4.4	3.4	7.75	3.40	.889
R7/8 G1/8	4.8	5.3	6.3	4.2	7.4	7.6	5.3	4.7	7.90	4.65	.931
R1 G0	5/0	6.0	6.8	5.7	7.9	7.3	6.3	6.2	12.18	6.20	1.120

*Attributes rated 1 to 10 by a ten-member panel with 10 = excellent and 5 = acceptable.

**R = large, ripe fruit; G = small, green fruit. Fractions indicate the proportion of the maturity used to prepare product.

Jam preparation was the same as in the first study, with the exception that two different levels of malic acid (0.75% and 1.50% based on puree weight) were added to the jam prior to filling cans. Samples were initially analyzed and the remaining samples were then stored at 2°C, 25°C, or 35°C for 6 months. Total anthocyanin (TAcy) content and discoloration index were determined. Organoleptic evaluations were made by panelists familiar with strawberry products. Ratings of color intensity, color acceptability, lack of discoloration, flavor, and overall product acceptability were made on a scale of 1 to 10, with 10 = excellent and 5 = acceptable.

Results and discussion

Preliminary results show that jam prepared from 'Cardinal' had higher TAcy and was less discolored than jam prepared from A-5344, when pooled across two replications and all other variables. Organoleptic evaluations showed 'Cardinal' to be superior to A-5344 in all attributes. Thawing for 24 hours at 30°C resulted in jam with lower TAcy and more discoloration (lower discoloration index), but the organoleptic scores showed no differences in sensory quality. Acidification had no effect on objective color measurements, but the sensory panel observed a slight reduction in discoloration at the higher acid level. However, flavor and product acceptability were reduced at the high acid level.

As the percentage of ripe fruit increased, there was a corresponding increase in TAcy and a reduction in discoloration; sensory scores followed a similar trend of improvement. Initial samples of the jam were of similar objective and organoleptic quality to the samples stored for 6 months at 2°C, while quality reductions resulted from storage at 25°C and 30°C. Preliminary results indicated that during storage the loss rate of TAcy was not accelerated by the presence of immature fruit, rather it was more related to the initial amount of TAcy.

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EFFECTS OF MECHANIZATION ON PRODUCT QUALITY AND UTILIZATION OF STRAWBERRIES

W. A. Sistrunk, JoNelle Nunek, and J. R. Morris

Summary. Experiments were conducted on mechanically harvested strawberries to determine the suitability of different cultivars for strawberry products. Quality was defined by carbohydrate composition, total anthocyanins, ascorbic acid, phenolics, Color Difference Meter, individual pigments, and sensory tests. 'Cardinal' and A-5344 were more suitable for mechanization than other cultivars. Both green and ripe fruit were acceptable when manufactured into preserves and jams. Increasing the storage time and temperature decreased quality of the product, but percentage of green fruit did not markedly affect quality. Fruit quality was stabilized during frozen storage either by heating to 82°C or by adding 1.25 percent citric acid.

INTRODUCTION

The quality of strawberries is important to producers and processors alike because acceptance by the consumer is the key to success. Strawberries vary widely in characteristics such as size, shape, internal structure, pigments, acids, phenolics, and enzymes. Field conditions, cultivar, and maturity of fruit probably have more influence on injury to fruit during harvesting and handling than the method of harvesting. Nevertheless, wet fields, condition of the strawberry beds, and adjustment of the harvester have a significant influence on mechanical damage during harvest.

The harvested strawberries vary from clean, hand-picked fruit to trashy, bruised, muddy fruit. These conditions could also occur in hand harvesting, except for excess trash. Firmness is much more important in mechanically harvested than in hand-harvested fruit. Color is equally important since significant quantities of pigment may be lost during handling, washing, and preparation for freezing. Generally, a more thorough washing system is required to remove grit and sand embedded in mechanically harvested fruit, so firm fruit is less subject to bruising and leaching of color than soft fruit.

Time of harvest did not have as much effect on color and firmness as cultivar, maturity, and weather conditions (9,15). During periods of rain and warmer weather, color and acids were leached out, resulting in more oxidation of pigment and darker, oxidized color (15). In some cultivars, color degraded more rapidly after freezing and thawing.

Under ideal conditions many named cultivars produce frozen strawberries of acceptable quality (15). However, by subjecting fruit to realistic conditions in the field and in postharvest handling, we can separate cultivars that are outstanding for mechanization. Certain

Arkansas selections have been shown to withstand mechanical harvesting and rough handling without a great loss in quality (9,10,15). Such characteristics as color, soluble and total solids, acidity, firmness, fiscosity, toughness of cortex, and shearpress values are used to define differences in quality of selections (14,15).

The delay in harvesting for mechanization, as compared to picking two or three times a week for hand harvesting, caused a decrease in firmness and darkening of fruit regardless of cultivar (9,10,11,14,15). Time and temperature of storage of strawberry products had a significant effect on loss of pigment and development of browning (4,6,7,16). Little (4) described this browning as a polymer-anthocyanin complex in which the bond was broken with time, giving a much lighter brown color. Hussen and others (3) discussed a total approach to mechanical harvesting of strawberries from both economical and quality viewpoints, in which all cultivars and selections in the Oregon program were evluated for desirable characteristics in the field as well as in processed fruit.

The objectives of the separate experiments were to evaluate the suitability for processing and to quantitate differences in quality that occurred in mechanically harvested strawberries during harvesting, handling, frozen storage, processing, and manufacture into products.

MATERIALS AND METHODS

Strawberries were grown on the Main Arkansas Agricultural Experiment Station at Fayetteville by methods described previously (9,10,11) and harvested by a commercial machine (9,10). The 1976 fruit were separated into sizes after washing, placed in 211 x 400 enamel-lined cans, sealed, and frozen without sugar. After 3 months' storage the fruit were capped without thawing, and samples were weighed for ascorbic acid determination by the Morell (8) method. The remainder of the fruit was blended and analyzed for phenols, anthocyanins, sugars, pectins, cellulose, and dry matter by methods described earlier (14,15).

The 1975-76 fruit for manufacture was harvested, handled, and frozen according to the method of Morris and others (11). Green and ripe fruit were separated and frozen in approximately 2-kg lots. Preserves and jam were prepared from three cultivars, 'Earlibelle,' 'Cardinal,' and A-5344, by methods described previously (16). The preserves and jams were standardized to a soluble solids content of 68 percent and a pH of 3.1. The product was sealed in 211 x 304 enamel-lined cans, cooled, and stored at 2°C, 24°C, and 35°C.

In 1977, a third study was conducted on two cultivars, 'Cardinal' and A-5344, that had been mechanically harvested and cleaned by the same procedure above. Fruit were divided into three categories: small and essentially all green fruit; large or ripe fruit; and a combination of the two. The cultivar 'Cardinal' had 84 percent ripe fruit and A-5344 had 88 percent. Small, large, and combined samples were divided into two lots; one lot was heated to 82°C and the other was not heated. Half of each sublot was then passed through a laboratory-sized finisher fitted with a .033 mesh screen. Whole and pureed fruit were then divided into two sublots, one of which was acidified with 1.25 percent citric acid (w/w). Samples were placed in 211 x 400 enamel-lined cans, sealed, and frozen at -18°C for later analysis.

Analytical

Ascorbic acid was determined by the method described previously. Total anthocyanins were analyzed by the two following methods: extracting pigment from pureed samples with acidified ethanol, filtering, diluting, and reading optical density (OD) at 500 nanometers; and the pH difference method described by Fuleki and Francis (2).

Anthocyanin pigment separation was conducted on 25-g samples of large and composite fruit. Samples were freeze-dried, extracted with one percent HCl-methanol (3 ml HCl:97 ml absolute methanol) and filtered through Whatman No. 1 filter paper by the Roush method (12). Filtrate was evaporated in a rotary evaporator maintained at 40°C by a water bath to a volume of 10 ml. Samples were streaked on 2.5-inch strips by Whatman 3MM chromatography paper with drip tips. Pigments were separated by descending chromatography, using the top layer of a butanol:acetic acid:water (BAW 4:1:5) solvent system. Bands were cut into small strips and eluted with one percent HCl:methanol. Optical densities for pigments were obtained at the maximum wavelength (λ max) for each pigment. The extinction coefficient used for cyanidin (C-3-G) computation was 4.89×10^4, while for pelargonidin (P-3-G) the value was 2.908×10^4. Flow rates (R_f) for isolated pigments were determined after subjecting strawberry extracts to ascending chromatography for 15 hours in a BAW 4:1:5 solvent system.

RESULTS AND DISCUSSION

The field performance of the seven cultivars and selections in the 1976 studies have been discussed by Morris and others (9). 'Cardinal' was the leading cultivar in yield and one of the highest in picking efficiency. The total sugars and dry matter were highest on A-5309, while 'Earlibelle' and A-5344 were lowest in dry matter (Table 1). Quality attributes and yield distribution of fresh fruit have been recorded by Morris and others (9). 'Cardinal,' A-5344, A-5745, and A-5350 were highest in shearpress values. These same cultivars were highest in cellulose in the present study (Table 1). Ascorbic acid varied among cultivars, but A-5309 was highest and A-5745 was lowest. Lundergan and Moore (5) found that ascorbic acid could be controlled by selection of parent genotypes. Total sugars and anthocyanins were higher in the late harvest as compared to the early harvest. Cellulose and ascorbic acid values declined in the later harvest. Total sugars, anthocyanins, and ascorbic acid were higher in the large fruit, while cellulose and total pectin were higher in the small sizes. There was no significant difference in composition due to plant density in the field (data not shown).

Color was rated higher on 'Cardinal,' 'Earlibelle,' and A-5350 (9), which agrees with the data for concentration of anthocyanins for the cultivars (Table 1).

Table 1. Main effects of cultivar and selection, harvest, and size on composition of mechanically harvested strawberries, 1976

	Percent total sugars	Percent total pectins	Percent cellulose	Total* antho-cyanins	Ascorbic acid (mg/100g)	Percent dry matter
Cultivar						
Sunrise	2.41	.412	.457	1.08	26.0	7.29
Earlibelle	2.61	.434	.550	2.47	28.3	6.96
Cardinal	2.77	.413	.680	2.33	27.0	7.15
A-5350	2.57	.481	.675	2.14	25.7	7.95
A-5344	2.26	.432	.656	1.98	26.5	6.85
A-5309	3.47	.383	.553	1.94	30.5	8.14
A-5745	2.82	.401	.671	1.70	21.6	7.55
LSD @ 5%**	.32	.024	.064	.36	1.9	.27
Harvest						
Early	2.67	.432	.684	1.62	29.7	7.24
Middle	2.56	.423	.611	1.71	25.4	7.36
Late	2.87	.412	.566	2.51	24.4	7.64
LSD @ 5%	.23	NS	.043	.26	1.0	.17
Size						
Small	2.46	.412	.688	1.41	24.6	7.45
Medium	2.58	.441	.624	1.82	26.0	7.42
Large	3.02	.407	.557	2.51	28.5	7.34
Combined	2.74	.429	.611	2.05	27.0	7.44
LSD @ 5%	.25	.019	.049	.27	1.1	NS

*Determined on 1-g samples diluted with 9 ml of 1% HCl-methanol.

**LSD = least significant difference at 5% level; NS = not significant.

In the 1975 and 1976 studies on use of green and ripe fruit for preserves and jams, all cultivars performed equally well (Table 2). 'Cardinal' was darker red in color, as shown by lower 'L' values and higher 'a' values and total anthocyanins. The preserves and jams made from the 50 percent green fruit were lighter in color in most instances, but the 'L' and 'a' values, total anthocyanins, and sensory ratings did not always reflect the differences (Tables 2 and 3). Green fruit changed to a light pink color when cooked, so the dilution of color by 50 percent green fruit was not very great. Since the percentage of green fruit was usually less than 25 percent, green fruit did not have a marked effect on preserve and jam color. While scores for the jams and preserves made from 50 percent green fruit were rated lower on the product in 1975, the ratings were still quite acceptable (Table 3).

Table 2. Effects of cultivars, treatments, storage temperature, and storage time on quality of strawberry preserves and jams

	Color Difference Meter				Total anthocyanins	
	'L'		'a'			
	1975	1976	1975	1976	1975	1976
Cultivar						
Earlibelle	8.6b*	11.8a	6.6b	5.1c	9.0b	5.3c
Cardinal	8.4c	10.0c	6.8a	7.6a	9.4a	7.7a
A-5344	8.9a	10.8b	6.3c	6.2b	8.5c	7.3b
Treatments**						
Preserves						
W-1/2 P-1/2	9.0a	11.0b	7.9a	6.0d	8.8a	6.1c
W-1/4 P-3/4	8.7bc	10.7cd	6.6b	6.1d	8.4b	7.2b
W-1/8 P-7/8	8.6c	10.8c	6.7b	6.0d	8.5b	7.6a
Jam						
R-1/2 G-1/2	8.8b	11.4a	5.4c	6.9a	8.0c	6.5b
R-3/4 G-1/4	8.3d	10.6d	5.8b	6.5b	9.4b	6.7a
R-7/8 G-1/8	8.3d	10.8c	6.9a	6.3c	10.7a	6.6ab
Storage temperature (C)						
2°	8.7a	10.6b	8.6a	7.8a	12.6a	8.5a
24°	8.5b	11.0a	6.6b	5.9b	8.3b	6.3b
35°	8.6bc	11.1a	4.5c	5.2c	6.0c	5.6c
Storage time (months)						
0	8.2c	9.6c	7.7a	7.7a	12.4a	9.0a
4	9.1a	11.2b	6.4b	6.7b	7.8b	5.9b
9	8.5b	11.7a	5.6c	4.6c	6.7c	5.4c

*Mean separation in columns within variables by Duncan's multiple range test, 5%.

**W = whole sliced ripe fruit; P = mixed green and ripe fruit puree; R = ripe fruit puree; G = green fruit puree.

Storage temperature and time had the greatest effect on color and overall quality ratings (Tables 2 and 3). All combinations and cultivars rated high in quality, even after storage for 9 months at 2°C, but the quality was poor at 4 months when fruit was stored at 35°C. Samples stored for 9 months at 24°C were acceptable in color and flavor as compared to commercial samples purchased at a supermarket.

Table 3. Effects of cultivars, treatments, storage temperature, and storage time on sensory quality of strawberry preserves and jams

	Color intensity		Color acceptance		Flavor	
	1975	1976	1975	1976	1975	1976
Cultivar						
Earlibelle	7.5a*	7.3b	7.0a	7.7a	7.2a	7.4a
Cardinal	7.4a	7.5ab	7.0a	7.0b	7.3a	7.1b
A-5344	7.4a	7.7a	6.8b	7.9a	7.1a	7.4a
Treatments**						
Preserves						
W-1/2 P-1/2	7.3b	7.4a	6.6c	7.5a	7.1c	6.9c
W-1/4 P-3/4	7.7a	7.5a	7.1ab	7.5a	7.4ab	7.1bc
W-1/8 P-7/8	7.7a	7.6a	7.4a	7.5a	7.5a	7.2b
Jams						
R-1/2 G-1/2	7.0c	7.4a	6.4c	7.6a	6.8d	7.6a
R-3/4 G-1/4	7.4b	7.5a	6.9b	7.6a	7.1c	7.5a
R-7/8 G-1/8	7.7a	7.5a	7.3a	7.5a	7.2bc	7.6a
Storage temperature (C)						
2°	8.4a	9.0a	8.4a	9.0a	8.3a	8.5a
24°	7.7b	7.2b	7.4b	7.3b	7.5b	7.1b
35°	6.3c	6.3c	5.1c	6.2c	5.7c	6.3c
Storage time (months)						
0	8.2a	9.0a	8.2a	9.7a	8.8a	8.6a
4	6.9c	7.2b	6.9b	7.2b	7.1b	7.2b
9	7.2b	6.3c	5.6c	6.3c	5.6c	6.1c

*Mean separation in columns within variables by Duncan's multiple range test, 5%.

**W = whole sliced ripe fruit; P = mixed green and ripe fruit puree; R = ripe fruit puree; G = green fruit puree.

For mechanically harvested strawberries it would be convenient to clean, wash, and freeze uncapped fruit for manufacture into puree, juice, and concentrate during the off-season. Sistrunk and Moore (15) have shown that color degradation during storage was attributed to polyphenoloxidase (PPO). Certain chemical treatments were found to inhibit the changes in color. The 1977 study demonstrated that unsugared fruit decreased significantly in color during one year of storage (Table 4).

Table 4. Relationship of cultivar, fruit, size, and processing variables to quality of mechanically harvested strawberries during frozen storage

Main effects	Color difference 'L'	Color difference 'a'	Main effects	Color difference 'L'	Color difference 'a'
<u>Cultivar</u>			<u>Heat treatment</u>		
Cardinal	26.2	22.0	No heat	27.6	22.4
A-5344	31.7	23.9	82°C	30.3	23.5
LSD @ 5%*	0.5	0.3	LSD @ 5%	0.5	0.3
<u>Form</u>			<u>Size</u>		
Whole	30.3	24.5	Small	35.0	11.1
Puree	27.6	21.4	Large	25.7	30.2
			Combined	26.2	27.5
LSD @ 5%	0.5	0.3	LSD @ 5%	0.7	0.4
<u>Acidity</u>			<u>Storage</u>		
No acid added	28.9	21.7	Initial (1 week)	31.8	26.3
1.25% citric	28.9	24.2	1 year	26.1	19.6
LSD @ 5%	NS	0.3	LSD @ 5%	0.5	0.3

*Least significant difference at 5% level.

Both 'L' and 'a' values decreased, indicating a darkening in color and loss of redness, respectively. Either the addition of 1.25 percent citric acid or heating to 82°C prevented loss of redness. Decreasing the pH to 3.0 or below has been shown to inhibit PPO activity (13). Small or green fruit discolored more during storage than large or ripe fruit (data not shown).

The disadvantage of preparing puree by passing fruit through a pulper (.033-inch screen) was the loss of ascorbic acid (Table 5). However, total anthocyanins were higher in the puree form, and there was less loss during storage. Heating to 82°C preserved more ascorbic acid but total anthocyanins were not affected. Large fruit retained more ascorbic acid than small or combined fruit during storage, possibly because of the effects of the higher enzyme activity in small fruit. Although acidification increased redness, as shown by higher 'a' values (Table 4), the total anthocyanins were not significantly different between acidified and non-acidified lots (Table 5). There was a loss in anthocyanins during storage in all sizes of fruit, the percentage of loss being approximately the same. 'Cardinal' was higher in ascorbic acid and anthocyanins than A-5344, but both cultivars reacted similarly to treatment.

Table 5. Relationship of cultivar, fruit size, and processing variables to quality of mechanically harvested strawberries during frozen storage

Cultivar	Ascorbic acid mg/100g initial	Ascorbic acid mg/100g 1 year	Total anthocyanins mg/100g (fresh weight) initial	Total anthocyanins mg/100g (fresh weight) 1 year
Cardinal	32.5	23.4	31.0	23.4
A-5344	28.9	20.1	23.1	20.1
LSD @ 5%	1.4		2.1	
Form				
Whole	36.3	26.3	26.8	20.0
Puree	25.0	14.3	27.3	23.5
LSD @ 5%	1.4		2.1	
Acidity				
No acid	30.2	19.8	27.5	21.4
1.25%	31.2	20.8	26.6	22.1
LSD @ 5%	1.4		NS	
Heat				
No heat	26.5	16.1	26.6	22.1
82°C	34.8	24.5	27.5	21.4
LSD @ 5%	1.4		NS	
Size				
Small	29.2	17.0	6.3	4.5
Large	29.9	22.4	43.3	34.4
Combined	32.9	21.4	31.5	26.3
LSD @ 5%	1.1		3.5	

*Least significant difference at 5% level.

The pigments were separated into five bands by chromatography, but only two are shown (Table 6). Pelargonidin-3-glucoside (P-3-G) was the predominant pigment, and Cyanidin-3-glucoside (C-3-G) represented approximately 4 percent of the total pigment. 'Cardinal' was significantly higher in C-3-G, and large fruit were higher in P-3-G. Earlier studies demonstrated the importance of pigment concentration and type of pigment to color in strawberries (1). The pureed fruit was higher than whole fruit in both pigments, possibly because of the greater effectiveness of the treatments in the puree. Neither heat nor acidification showed a difference in either C-3-G or P-3-G bands. 'Cardinal' was higher in bands 4 and 5 than A-5344 (data no shown).

Table 6. Main effects of cultivar, fruit size, heat treatment, acidification, and fruit form on the pelargonidin-3-G and cyanidin-3-G content of frozen strawberries (mg/100 gfw).

	Pelargonidin-3-G	Cyanidin-3-G	Total P-3-G and C-3-G
Cultivar			
Cardinal	26.44	1.35	27.79
A-5344	25.05	0.49	25.37
LSD @ 5%*	NS	.12	1.81
Size			
Large	28.51	0.94	29.42
Composite	22.98	0.90	23.73
LSD @ 5%	1.61	NS	1.81
Heat			
Fresh	26.52	0.88	27.26
Heated (82°C)	24.98	0.96	25.90
LSD @ 5%	NS	NS	NS
Acidification			
No acid	26.35	0.94	27.17
Acidified (1.25% w/w)	25.15	0.90	25.98
LSD @ 5%	NS	NS	NS
Form			
Whole	24.15	0.86	24.90
Pureed	27.35	0.98	28.26
LSD @ 5%	1.61	.12	1.81

*Least significant difference at 5% level.

In conclusion, 'Cardinal' and A-5344 strawberries appeared to be well adapted to mechanical harvesting and handling for processing. Both green and ripe fruit of all cultivars tested in the studies were manufactured into preserves and jams after cleaning and washing. The products containing as high as 50 percent green fruit rated high in quality in storage tests. The stability of frozen strawberries during storage was improved either by heating to 82°C or by acidification, especially when the fruit was in the form of puree.

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MACHINE HARVESTING AND IN-PROCESS HANDLING EFFECTS ON PACIFIC NORTHWEST STRAWBERRY QUALITY

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Summary. The effects of the mechanical harvester and in-plant processing equipment on strawberry quality and quality composition of mechanically treated lots during a 2-year field study are presented. Stemmed and capped whole strawberries resulting from the three types of mechanical in-plant equipment available in the study contained up to 60 percent grade A quality fruit. Further removal of nonusable fruit by sizing and manual sorting resulted in a whole product that was suitable for grade A frozen sliced strawberry pack. Sensory quality of the frozen sliced product from mechanically handled berries was judged equal in quality to the conventional pack containing hand-harvested fruit. Removal of cull fruit from machine-harvested and capped strawberries shows good potential.

INTRODUCTION

The continued success of commercial strawberry production in the Pacific Northwest is currently clouded by increasing production costs, particularly harvesting costs. While similar harvest problems in other small fruit crops were being alleviated by development of mechanical systems for harvest and handling of the crop, the plant structure and delicate nature of the strawberry caused a deferral in development of machine harvester technology in the Pacific Northwest until the rapidly diminishing harvest labor supply in the late 1960's moved the Oregon strawberry industry to demand that high priority be given to mechanical harvesting research by the Oregon Agricultural Experiment Station. Since that time, research at Oregon State University has led to several designs for a mechanical harvester of strawberries. Effects of the machine prototypes on fruit quality have been monitored (1), and many new strawberry clones selected for machine-harvest potential have been characterized (2).

During 1978 and 1979, a 2-year study was carried on by a research task group at Oregon State University and by industry cooperators to develop information on mechanical systems currently available for harvesting and handling strawberries on a commercial scale.

The objectives of the study were: (1) to evaluate the current commercial-scale systems for mechanical harvesting and in-process handling of strawberries, (2) assess the quality characteristics of mechanically harvested strawberries and consumer acceptance of the processed products, and (3) analyze economic factors involved in the mechanical system for harvesting, handling, and processing of strawberries. This paper will deal with the fruit quality assessment phase of the project.

METHODS AND MATERIALS

1978 study

Fruit quality and lot composition data were gathered on 25 mechanically harvested field lots representing three harvesting machines, four grower locations, three cultivars with varying numbers of prior hand harvests, and three processing lines located at two processor sites. Time and equipment limitations prevented a direct comparison of all of the mentioned variables in the study; therefore, a complete identification of the variables represented by each of the 25 lots was made to provide quality assessment information to be grouped under common treatment but not compared statistically.

Two samples of at least 2.3 kg (5 lb) were drawn randomly from each mechanically harvested raw product lot of 400 to 600 kg in weight when received at the processing site. Berries were removed by hand from nonfruit parts in the raw product sample, and individual berries were segregated into the following categories: (1) Undersize (under 1.6 cm in diameter); (2) Ripe-50 (50 to 80% of the berry surface colored red); (3) Ripe-80 (at least 80% of the berry surface colored red); (4) Nonripe (less than 50% of surface colored red or overripe). Weights of berries placed in the undersize and maturity categories were recorded. Fruit in the Ripe-80 fraction was further segregated into undamaged, mechanically damaged by other causes (disease, insects or birds, weather). The weights of mechanically damaged fruit were reported separately in order to assess damage caused by the harvester. The undersize, nonripe, and damaged categories were combined and total weight reported as culls.

Three lines of cleaning, stemming, and capping equipment, designed by Blueberry Equipment, Inc. (BEI), Oregon State University (OSU), and Stayton Canning Company (SCC) respectively were available for study in 1978. As strawberries from each field lot moved through one of the in-plant lines, the whole berry was sampled for quality (after the stemmer-capper operation but before any manual sorting). At least one sample of 2.3 kg was drawn from the line and segregated for Undersize, Ripe-80, and No. 1 Usable (undamaged Ripe-80 fruit, 1.6 cm or larger in diameter, without caps). Fraction weights were reported as a percentage of the total fruit sample. The Ripe-80 fruit was analyzed for the percent of mechanical damage, other types of damage, and fruit with caps still attached. The occurrence of soil on the fruit after washing and stemming operations was determined visually by count in samples of 25 ripe usable berries.

Most mechanically harvested lots included in the 1978 study were used to produce juice stock. However, three lots were given a final manual inspection and the sorted fruit was sliced and frozen with a fruit-to-sugar ratio of 4:1. The frozen sliced products were evaluated against a hand-harvested control sample for sensory quality by a 20-member panel using a scale of 1 (poorest) to 9 (best).

1979 study

In the second year of the study, the number of field locations was reduced to two and the number of cultivars was increased to five. Harvester operation for a given location, date, and cultivar was replicated to provide more information on variability within treatment. Procedures for sampling and analyzing lot quality were similar to those used in 1978. Soil content in the raw product was determined on a larger separate sample (20 to 30 kg) to overcome low sensitivity in smaller samples.

A significant number of the 1979 mechanically harvested lots were prepared for sliced frozen pack by capping, sizing, and manually sorting the whole berries. Samples were evaluated for quality composition, and lot data related to percentage of cull removed by sizing and sorting were collected. Six sample lots of frozen sliced berries were identified for later quality evaluation by a small panel and consumer test methods.

A CYPRO Andromat II electronic color sorter was installed at one processor site to test the capacity of the sorter in separating nonripe and color-differentiated defective fruit from a continuous stream of mechanically stemmed strawberries.

RESULTS AND DISCUSSION

Raw product quality

Total fruit percentages for mechnically harvested strawberries by cultivar and year (Table 1) represent raw product lots harvested by mower-type harvesters, such as the SKHS harvester (Charles Hecht and Associates) or the OSU harvester (Agricultural Engineering Department, Oregon State University) that remove strawberries from the plant in clusters, or by the BEI (Blueberry Equipment, Inc.) machine that strips the fruit from the plant. When the crop has not been previously picked by hand, the mower-type machines will produce a raw product containing up to 20 percent non-fruit material in once-over harvest. This compares with a level approximating 10 percent non-fruit material in the crop harvested by the BEI machine. Fruit content and fruit size both declined substantially (Table 1) for machine-harvested lots of 'Benton' or 'Olympus' cultivars following one or two hand pickings. However, the percentage of nonripe fruit was lowest in those lots harvested by the machine after one hand harvest, and increased strongly after two hand harvests.

Mechanical damage (major damage to fruit caused by crushing, tearing, dissection, puncture, or severe abrasion) was normally present in some degree in the ripe fruit of all mechanically harvested strawberries, and was attributed to the harvester operation. Amounts of mechanical damage recorded in the raw product with respect to cultivar (Table 1) varied from 1 to 8 percent of the Ripe-80 fruit weight, according to the characteristic berry firmness of the cultivar.

Table 1. Quality of mechanically harvested (once-over) strawberries, grouped by cultivar and number of prior hand picking[a]

Cultivar	Prior hand picking	No. of samples	Percent total fruit[b]	Percent under-size[c]	Percent nonripe[c]	Percent mech. damage[d]
1978 STUDY						
Benton	0	4	82.0	10.1	33.8	5.4
	1	3	76.3	13.4	30.5	6.7
	2	2	63.2	22.7	37.9	4.8
Linn	0	3	84.6	11.5	53.8	2.5
	1	1	93.2	16.6	40.3	1.5
	2	1	89.1	23.1	67.2	3.1
Olympus	0	5	83.2	13.1	40.8	2.5
	1	2	72.3	13.0	36.6	4.7
	2	2	67.0	35.7	54.8	3.4
1979 STUDY						
Benton	0	9	81.2	15.5	31.7	6.9
Linn	0	10	87.2	6.6	28.8	4.2
Olympus	0	15	82.7	16.0	38.0	7.7
	2	2	77.5	41.4	59.4	4.7
Totem	0	6	87.6	6.6	29.5	4.4
BC 70-17-12	0	4	86.9	8.3	25.5	2.5

[a]Data pertain to SKHS (Charles Hecht and Associates) and OSU (Ag. Engineering, OSU) harvesters.

[b]Percent of raw product sample weight.

[c]Undersize: fruit passing a 1.6-cm riddle (percent of total fruit); nonripe fruit: less than 80% of surface color red (percent of total fruit).

[d]Mechanical damage: crushed, partial, torn fruit; percent of Ripe-80.

Soil content in the raw product varied from 0 to 1 percent through the 1979 season, although a level of 20 percent was recorded for one lot received from a poorly prepared field. The three in-plant lines operating during the 1979 study included a deep-water dump tank that effectively removed any soil aggregate from the plant material.

Stemmed product quality

The quality of mechanically harvested strawberries after a stemming-capping treatment on in-plant line during 1978 is summarized (Table 2) by cultivar and by combination of harvester and in-plant equipment. A sizing riddle installed in the OSU line to eliminate undersize fruit (below 1.6 cm diameter) was responsible for the 10 to 20 percent improvement in the amount of Ripe-80 and No. 1 Usable fruit produced by the OSU line and other lines in the study. Approximately 20 percent of the 'Olympus' fruit and 15 percent of 'Linn' and 'Benton' berries harvested by the mower-type machines were not capped when processed on the SKHS or OSU line equipment. However, neither the BEI (Blueberry Equipment, Inc.) nor OSU equipment was more than 50 percent effective in cap removal from 'Olympus' berries harvested by the BEI stripper.

Mechanical damage varied by cultivar, approaching 10 percent of Ripe-80 weight in the case of 'Olympus.' Other damage (nonmechanical), as may be expected, varied with the incidence of rot and mold in the field.

The record of cultivar, harvester, and stemmer-capper contributions to mechanical damage in Ripe-80 fruit (Table 3) indicates that generally higher levels of damage occurred in the 1979 season. The higher prevailing temperatures in the 1979 season may account for this difference; however, comparative differences within each major effect should be considered more meaningful than seasonal levels.

The three stemmer-capper lines tested in 1978 caused 1.5 and 3 percent damage to the fruit. Frequent back-up of fruit on the stemmer rolls of the SCC (Stayton Canning Company) line accounted for the higher amount of damage for this equipment in both years. Coupling the CML (Canners Machinery, Ltd.) capper to the Stayton stemmer-capper line caused increased damage to the ripe fruit. Mechanical damage levels for the five cultivars tested in the study (Table 3) were directly proportional to the firmness of the cultivar. The characteristic firmness of 'Linn' and 'Totem' resulted in these cultivars receiving much less damage than the softer lines.

During the 1979 season, berries from a series of lots harvested by the OSU or SKHS machines were prepared for grade A sliced pack by subsequent sizing and inspection belt sorting for removal of cull fruit. The record of sort-out removal for four representative lots (Table 4) indicates that 10 to 15 percent of the total fruit was removed by the sizing riddle in the form of undersize, mostly green berries. After removal of nonusable fruit at the inspection table, the sorted material for the sliced frozen pack represented 32 to 40 percent of the original total fruit in the lot.

Table 2. Quality of mechanically harvested, stemmed, and capped strawberries, grouped by harvester and plant equipment, 1978

Harvester[a]	Plant equip.[a]	No. of samples	Percent of total sample: Ripe-80[b]	Percent of total sample: No. 1 Usable[c]	Percent of Ripe-80 fruit: Mech. damage[d]	Percent of Ripe-80 fruit: Other damage[d]	Percent of Ripe-80 fruit: Fruit w/caps
				BENTON			
SKHS	SCC	3	65.3	46.9	8.0	8.4	11.6
SKHS	OSU[e]	4	83.6	60.3	5.5	9.7	13.0
OSU	OSU	2	86.6	53.3	7.0	8.3	13.6
				LINN			
SKHS	SCC	1	65.0	52.7	2.3	7.6	9.1
SKHS	OSU	1	77.8	61.8	1.2	4.7	14.6
OSU	OSU	1	72.0	34.6	0.7	38.4	12.5
BEI	BEI	1	75.0	17.8	0.9	35.8	42.4
BEI	OSU	1	69.6	26.2	1.4	14.4	46.5
				OLYMPUS			
SKHS	SCC	2	57.2	37.4	5.8	8.0	21.6
SKHS	OSU	1	70.4	41.7	10.5	5.5	24.9
OSU	OSU	3	74.0	47.4	5.3	11.7	19.4
BEI	BEI	1	53.0	6.0	7.6	12.5	68.7

[a]BEI: Blueberry Equipment, Inc., South Haven, Michigan; OSU: Department of Agricultural Engineering, Oregon State University; SKHS: Charles Hecht and Associates, Stayton, Oregon; SCC: Stayton Canning Company, Stayton, Oregon.

[b]Ripe-80: fruit with at least 80% of surface color red.

[c]No. 1 usable: undamaged Ripe-80 fruit at least 1.6 cm in diameter, ree of caps.

[d]Mechanical damage: crushed, partial, torn fruit; other damage: rot, mold, insect, undeveloped, sun damage.

[e]OSU plant line equipped with a sizing riddle to remove undersize (< 1.6 cm) fruit; other lines not so equipped.

Table 3. Mechanical damage in Ripe-80 strawberries: cultivar, machine harvester, and stemmer-capper effects[a]

		1978		1979	
Effect	Identity[a]	No. of samples	Percent mech. damage	No. of samples	Percent mech. damage
Cultivar[b]	Benton	11	6.1	11	15.6
	Linn	4	1.8	10	5.1
	Olympus	12	7.2	15	10.5
	Totem	--	--	6	4.4
	BC 70-17-12	--	--	6	7.8
Harvester[c]	BEI	4	2.9	--	--
	OSU	7	1.9	18	5.3
	SKHS	8	4.5	27	3.6
Stemmer-capper[d]	BEI	2	1.5	--	--
	OSU	14	1.9	45	4.0
	SCC	11	3.1	3	12.0
	SCC-CML	--	--	3	19.1

[a]BEI: Blueberry Equipment, Inc., South Haven, Michigan; OSU: Department of Agricultural Engineering, Oregon State University; SCC: Stayton Canning Company, Stayton, Oregon; SKHS: Charles Hecht and Associates, Stayton, Oregon; CML: Canners Machinery, Ltd., Simcoe, Ontario, Canada.

[b]Percent damaged Ripe-80 fruit by weight determined after stemming.

[c]Percent damaged Ripe-80 fruit in raw product samples.

[d]Percent damage estimated as average difference between corresponding values of Ripe-80 fruit in raw product and stemmed-capped samples.

Table 4. Sort-out fruit removal from mechanically harvested strawberries intended for grade A sliced frozen product, 1979[a]

			Sort-outs				
Cultivar	Raw product[b] (kg)	Total fruit[c] (kg)	1.6 cm size riddle[d] (%)	Manual[d] (%)	Sorted fruit[d] (kg)	Sorted fruit[d] (%)	Culls in sorted fruit[e] (%)
Benton	447	280	23	25	148	53	14
Benton	401	293	23	24	155	53	9
Olympus	690	553	26	13	292	53	20
Linn	611	438	12	40	212	48	11

[a]SKHS or OSU harvesters; OSU in-plant equipment.

[b]Total weight of fruit and plant material collected by the harvester.

[c]Fruit separated from plant material by processing equipment.

[d]Percent of total fruit weight before sorting.

[e]Percent of sorted fruit weight.

Frozen product evaluation

Sensory evaluation of the frozen sliced product from mechanically harvested strawberries in both 1978 and 1979 studies (Table 5) shows that mechanization of harvest and capping operations did not adversely affect sensory quality of the finished product when compared with the conventional hand-harvested sample. Quality scores for all samples were at the acceptable level.

Cull removal by electronic color sorter

Results of the experimental use of the CYPRO Andromat II color sorter to remove nonripe or defective whole strawberries from the machanically harvested lot indicate (Table 6) the sorter removed 60 to 80 percent of the underripe (green) fruit in the 'light' response phase. A similar removal rate of overripe fruit, capped fruit, and nonmechanically damaged fruit occurred when the sorter was in the 'dark' response phase. At a continuous feed rate of 400 kg/hr, lot quality was upgraded from approximately 50 percent usable (grade A quality) to 70 percent usable in one pass through the sorter (rejection of light fruit) and to 80 percent usable after a second pass through the sorter (rejection of dark or defective fruit).

Table 5. Sensory evaluation of sliced frozen strawberries from mechanically harvested (MH) or hand-harvested (HH) fruit, 1978 and 1979[a]

Sample identity	Cultivar	Panel mean score[b]			
		Color	Appear.	Texture	Flavor
		1978 Study (20-member panel)			
MH 53	Benton	5.7	6.4	5.5	6.1
MH 54	Benton	5.9	6.7	5.3	6.2
MH 55	Benton	5.8	6.7	5.2	6.2
HH	Benton	5.2	5.8	5.8	5.4
LSD @ 5%		NS	0.8	NS	NS
		1979 Study (11-member panel)			
MH 47	Benton	6.0	5.3	5.2	6.4
MH 1	Benton	5.0	5.3	5.2	5.5
MH 44	Olympus	6.5	5.1	5.0	5.9
HH 2	Olympus	5.5	5.4	5.5	5.7
LSD @ 5%		0.96	NS	NS	NS

[a]No. 1 Usable fruit from OSU in-plant line; manually sorted.

[b]Nine-point preference scale where 9 = excellent, 5 = acceptable, 1 = very poor.

Table 6. Effect of an electronic color sorter[a] on quality of mechanically harvested, capped, and sized strawberries, 1969

Cultivar (and lot)	Process rate[b] (kg/hr)	Sorter reject response	Quality of whole fruit (% by count)					
					Ripe			
			Under-ripe	Over-ripe	w/caps	Mech. damage	Other damage	Usable
Benton (40)	370	*	19	3	14	7	3	54
		Light	7	2	12	5	3	71
		Light or dark	6	0	4	6	1	83
Olympus (44)	435	*	26	6	17	4	2	45
		Light	5	2	18	5	2	68
		Light or dark	6	1	10	5	0	78
Hood (9166)	--	*	24	6	17	4	2.	47
		Light	11	4	14	3	3	65
		Light or dark	5	3	5	5	1	81
Hood (9166 - sort-outs)	--	Light	63	10	13	3	0	11
		Dark	12	16	60	1	1	10

[a]CYPRO Andromat II, Cypro Corporation, Grand Rapids, Michigan.

[b]Process flow rate estimated from trials of 5- to 10-minute duration.

*Indicates initial quality composition of the lot.

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PRELIMINARY STUDY OF PEROXIDASE AND POLYPHENOLOXIDASE ACTIVITY IN STRAWBERRY FRUITS

Sara E. Spayd and Justin R. Morris

Summary. Polyphenoloxidase and peroxidase activities of extracts from five maturity categories of strawberries ranging from small green to processing ripe fruit were measured. Clonal differences exist and activity of both enzymes decreased from the small and green stage to inception. Frozen fruit had lower enzyme activity than fresh fruit.

INTRODUCTION

Anthocyanin stability in foods is influenced by many factors. Markakis (1974) has reviewed this area of product quality. Factors which were reported to degrade anthocyanins in foods or model systems included enzymes, temperature of processing and storage, oxygen, ascorbic acid, pH extremes, metals, sugar and sugar degradation products, light, and sulfur dioxide (7). Some of these factors, such as pH changes and ascorbic acid, may have an influence on the behavior of strawberry products containing green fruit. During the maturation of strawberry fruit, percent soluble solids, ph, color, and ascorbic acid increase while acidity decreases (11). The two major anthocyanin pigments in strawberries are pelargonidin-3-monoglucoside and cyanidin-3-monoglucoside (1). Of the two pigments, pelargonidin-3-monoglucoside is the most abundant and the least stable (1). Lukton and others (1956) reported that the rate of strawberry anthocyanin oxidation was directly dependent on the percentage of the pseudobase form. It was theorized that pigment precipitants might be formed from the pseudobase of the oxonium salt of the glucoside (6).

Enzymatic degradation of anthocyanins has been studied to some extent. Crude fungal enzyme preparations have been shown to decolorize chrysanthemin chloride, the primary anthocyanin in blackberries (5). Grommeck and Markakis (1965), using a model system containing cyanidin-3-gentiobioside, cyanidin-3-rhamnoglucoside, and pelargonidin-3-glucoside with horseradish peroxidase, found that peroxidase does degrade anthocyanins. Optimum conditions for anthocyanin degradation by peroxidase were a pH in the range of 4.5 to 5.5, a hydrogen peroxide concentration of 10^{-4} to 10^{-5}M, and temperature of 60°C to 70°C (4). The presence of hydrogen peroxide in strawberry juice has not been demonstrated, but if present, hydrogen peroxide could be responsible for some color loss (13, 14). Peng and Markakis (1966) found that the cyanidin types of anthocyanin were poor phenolase substrates. Sakamura and others (1965) reported that delphinidin-3-(p-coumarylrutinoside)-5-glucoside (the primary anthocyanin in eggplant) was degraded in a model system by polyphenol oxidase which had been extracted from mushrooms, potatoes, and eggplant flesh tissue. Degradation was accelerated by chlorogenic acid and retarded by ascorbic acid when added to the enzyme system (10). In a model system, Goodman and Markakis (1965) showed that SO_2 inhibited phenolase degradation of cyanidin-3-gentiobioside. Less SO_2 was needed for inhibition as pH decreased (3). When Cash and Sistrunk (1971) found that commercially prepared polyphenol oxidase increased the rate of decolorization of strawberry puree, it was concluded that the enzyme was specific for anthocyanins (2). This study was designed to determine the nature of this enzyme system in strawberries.

MATERIALS AND METHODS

Fruits were obtained from matted-row plantings of 'Cardinal' and Arkansas breeding-line 5344 at the Main Experiment Station, Fayetteville. 'Cardinal' and A-5344 were used since both of these clones have traits suited to machine harvest and good raw product quality while having different fruit-ripening patterns (8). 'Cardinal' has an uneven fruit-ripening pattern (8), and when ripe, the berries develop high levels of anthocyanins (12). A-5344 concentrates fruit ripening and the berries are very firm when ripe (8).

Berries were hand stripped to simulate a once-over machine harvest. Fruits were then visually sorted into five maturity categories within a given clone: (1) small green, (2) large green, (3) inception (first appearance of color to 50 percent or less of full color), (4) firm ripe, and (5) processing ripe. Berries were frozen overnight on trays, about 200 g sealed in plastic liners in 303 cans that had been flushed for 10 seconds with nitrogen gas, and stored at -15°C until analyzed.

Enzyme extraction techniques were those of Cash and Sistrunk (pers. comm.). A 50-g sample of capped berries was ground for two minutes at high speed in a Waring blender using 100 ml of cold (2°C) 0.1M Tris (hydroxymethyl) aminoethane buffer (pH 9.5). The homogenate was filtered through four layers of grade 50 cheesecloth, and proteins were precipitated from the filtrate with two volumes of acetone (-15°C) for 30 minutes. The mixture was filtered through fine mesh nylon cloth. The protein-pectin mass was dried at -2°C for 2 hours and suspended in a minimal amount (20-30 ml) of cold (-2°C) 0.1M sodium acetate buffer (pH 6.2). To precipitate pectins, calcium chloride (1M) was added to a final concentration of 0.05M in the solution, and the pH was adjusted to 7.2 with 0.1N NaOH. The mixture was allowed to precipitate 30 minutes, centrifuged for 15 minutes at 4400 x g and the supernatant retained.

Polyphenoloxidase activity was measured as the change in optical density at 420 nanometers, using an assay mixture of 8.5 ml of 0.1M sodium acetate buffer (pH 5.4), 1 ml 0.3M catechol, and 0.5 ml of enzyme extract. The reaction mixture was equilibrated at 35 ± 1°C for 5 minutes prior to addition of the enzyme extract. Catechol plus 9 ml of acetate buffer was used as the blank. Changes in optical density were followed over a 30-minute period at 5-minute intervals. Peroxidase activity was measured as the change in optical density at 460 nanometers, using a substrate mixture of 0.01M O-dianisidine-0.03 percent H_2O_2 in 0.1M sodium phosphate buffer (pH 5.4). The reaction was followed over a 2-minute period at 15-second intervals. Enzyme activity was calculated and expressed as the change in optical density-minute-gram fresh weight.

RESULTS

Preliminary results showed clonal differences in polyphenoloxidase and peroxidase activity. With advancing fruit maturity, there was a reduction in the activity of both enzymes from the small and large green fruit to the inception stages.

Freshly harvested strawberries had higher levels of enzyme activity than fruits that were frozen under N_2 atmosphere for 20 weeks. In general, peroxidase activity is approximately 100 times higher than polyphenoloxidase activity.

Although polyphenoloxidase and peroxidase activity was found in extracts, the maintenance of activity in strawberry puree and the influence of the enzymes on color loss in strawberry puree have yet to be demonstrated. Research is being continued in this area.

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ECONOMIC FEASIBILITY TO OREGON GROWERS OF MECHANICALLY HARVESTED STRAWBERRIES

Chong S. Kim, William G. Brown, and R. Donald Langmo

Summary. Production costs and net revenues are compared for hand-picked versus mechanically harvested strawberries for two harvesters and one capper-stemmer. Results indicate that mechanical harvesting may be profitable to growers in some cases, if harvesting takes place on the appropriate dates. Also, mechanical harvesting compared more favorably to hand picking with relatively lower strawberry prices. Net revenues computed in this paper are based on the assumption of no difficulty in procuring labor for hand picking. Considering the difficulty and uncertainty in procuring labor and the improving efficiency of mechanical harvesters and capper-stemmers, mechanical harvesting may be helpful in solving some of the problems facing the Oregon strawberry industry.

INTRODUCTION

The demand for processed strawberries has been increasing in the U.S. as consumers' income increases. However, in all strawberry-producing states except California and Florida, strawberry production for processing has been declining. California has been increasing both strawberry acreages and yield. Yield per acre has also been increasing in Oregon.

Acreage for strawberry production has declined in Oregon since 1965, even though yield per acre has increased and net profits per acre are supposedly greater than for some other crops, such as snap beans or sweet corn. In 1975, for example, the net profit to growers was estimated to be $130 per acre ($321/ha)[1] for producing strawberries in Oregon compared to net profits of about $34 per acre ($84.02/ha)[2] for sweet corn or $48 per acre ($118.61/ha) for snap beans.[3]

Oregon strawberry acreage reached its lowest level, 5,000 acres (2,023.4 ha), in 1978 as compared to 14,000 acres (5,665.6 ha) in 1967. Part of this decline may have resulted from increased production of

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[1]Based on Enterprise Data Sheets, Commodity Data Sheets, Extension Service, Oregon State University, 1975. Figures vary, depending on the farm prices of the crops and the skill and efficiency of the individual grower.

[2]Ibid. [3]Ibid.

strawberries in California and increasing imports from Mexico. However, Hussen[4] hypothesized that increased picking costs without an offsetting increase in the farm price of strawberries was the main reason for the continuing decline of the strawberry industry in Oregon. Even though picking and handling costs have increased, another important factor in the decline of Oregon strawberry acreage is the difficulty in obtaining enough pickers.

In 1978 the picker shortage was made worse by hot weather that hastened ripening, contributing to the estimated 25 percent of strawberries that rotted in the field.[5] In summary, rising production costs and lack of labor to pick strawberries (with the associated uncertainty in procuring pickers) are thought to be the main reasons for the declining acreage in strawberry production in Oregon.

To find a satisfactory solution to the problems of declining strawberry acreage, Oregon has put time and money into mechanical strawberry harvesting since 1967. If mechanizing strawberry harvesting is profitable, it will alleviate harvesting costs, and the difficulties in obtaining labor, and therefore induce growers to increase acreages in strawberry production. The purpose of this paper is to assess the profitability of mechanical strawberry harvesting to the Oregon growers.

PERFORMANCE OF MECHANICAL HARVESTERS AND PROCESSING EQUIPMENT

Two types of harvesters, the OSU and SKH&S machines, were tested on experimental plots during the 1978 season in Oregon. Seventeen field experiments with mechanical harvesting were conducted. Among these, eight experiments were on plots with no previous hand pickings, six on plots with one previous hand picking, and three on plots with two previous hand pickings. Three strawberry varieties ('Benton,' 'Olympus,' and 'Linn') were used in the experiments.

Many people believe that the mechanical harvester can be used as a clean-up operation after one or two hand pickings, but analysis of 1978 data indicate that net profit to the grower from mechanical harvesting is decreased when the number of previous hand pickings is increased, and that losses may be incurred. The reason is that growers must incur the costs of mechanization regardless of the amount of fruit harvested, and the amount of mechanically harvested fruit decreases as the number of previous hand harvests increases.

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[4]A. M. Hussen, Economic feasibility of mechanical strawberry harvesting in Oregon, Ph.D. dissertation, Oregon State University, Corvallis, May 1978.

[5]Charles Holzhauer, Oregon Farmer-Stockman, March 1979.

Forty-eight field experiments were conducted on plots without previous hand picking in 1979. Three harvesters, including two SKH&S machines and the OSU harvester, were tested with five strawberry varieties: 'Benton,' 'Olympus,' 'Linn,' 'Totem,' and 70-17-12.

The two SKH&S harvesters were nearly the same, except that one machine had an engine as a power source. To find whether those two SKH&S harvesters operated identically, relevant hypotheses were tested by factorial experimental design. Statistical tests indicate no significant difference in the operation of the two SKH&S harvesters.

Harvesting and processing data collected during the 1978 and 1979 seasons are presented in Tables 1 through 9.

Table 1. Efficiency of the mechanical harvesters, 1978[a]

Harvesters	Varieties			
	Benton	Olympus	Linn	Average
OSU	65.2	78.0	81.3	74.8
SKH&S	59.5	76.8	--	68.2

[a] $\text{Efficiency} = \frac{\text{Total fruit}}{\text{Gross raw product}} \times 100$

Table 2. Efficiency of the mechanical harvesters, 1979[a]

Harvesters	Varieties					Average
	Benton	Olympus	Linn	Totem	70-17-12	
OSU	53.78	80.55	71.78	75.82	66.56	69.70
SKH&S	74.63	76.22	71.89	81.25	76.24	76.05

[a] $\text{Efficiency} = \frac{\text{Total fruit}}{\text{Gross raw product}} \times 100$

Table 3. Efficiency of the OSU Capper-Stemmer, 1978

Variety	Percent undersize[a] (5/8")	Percent sorted out by hand[b]	Grade No. 1[c] (Percent of total fruit)
Benton	29.54	4.52	64.64
Olympus	23.67	3.67	71.36
Average	26.61	4.10	68.00

[a](Undersize/total fruit) x 100.

[b](Fruit sorted out/total fruit) x 100. (Most of this fruit is used for juice, jam, and puree.)

[c]Grade No. 1 is defined as "Standard" quality and computed by subtracting an average spillage of 1.3 percent.

Table 4. Efficiency of the OSU Capper-Stemmer, 1979.

Variety	Percent undersize[a] (5/8")	Percent sorted out by hand[b]	Spillage	Grade No. 1[c] (Per-
Benton	24.01	22.54	2.81	50.64
Olympus	20.97	29.63	2.10	47.30
Linn	12.00	43.16	2.36	42.48
Totem	14.18	32.11	1.90	51.81
70-17-12	11.50	39.91	2.35	46.24
Average	16.53	33.47	2.30	47.70

[a](Undersize/total fruit) x 100.

[b](Fruit sorted out/total fruit) x 100. (Most of this fruit is used for juice, jam, and puree.)

[c]Grade No. 1 is defined as "Standard" quality and is composed of large, ripe berries.

Table 5. Percent molded strawberries in total fruit, 1979[a]

Harvester	Benton	Olympus	Linn	Totem	70-17-12	Average
	Varieties					
	(%)	(%)	(%)	(%)	(%)	(%)
OSU	6.13	5.42	3.79	9.60	4.45	5.88
SKH&S	5.34	8.38	10.55	18.98	10.38	10.73

[a]This table is based upon 5-pound samples.

Table 6. Percent grade No. 1 and grade No. 5 in total fruit, 1978[a]

Variety	Grade No. 1	Grade No. 5
	(%)	(%)
Benton	64.64	33.22
Olympus	71.36	26.66
Average	68.00	29.94

[a]Grade No. 1 is defined as "Standard" quality and is composed of large, ripe berries; grade No. 5 is defined as berries for juice, jam, and puree, and is composed of undersized, misshaped, or underripe berries. All moldy or rotten berries are discarded. (Grade No. 2 is also defined as hand-picked berries for juice, jam, and puree. However, there is a price differentiation between grade No. 2 and grade No. 5 as noted in a later section.)

Table 7. Percent grade No. 1 and grade No. 5 in total fruit, 1979[a]

Variety	Grade No. 1	Grade No. 5
	(%)	(%)
Benton	50.64	41.59
Olympus	47.30	44.16
Linn	42.48	48.36
Totem	51.81	32.80
70-17-12	46.24	43.30

[a]Grade No. 1 is defined as "Standard" quality and is composed of large, ripe berries. Grade No. 5 is defined as berries for juice, jam, and puree, and is composed of undersized, misshaped, or underripe berries.

Table 8. Percent of usable fruit in total raw product, 1978[α]

Harvester	Grade No. 1	Grade No. 5
	(%)	(%)
OSU	50.86	22.40
SKH&S	46.38	20.42
Average	48.62	21.41

[α]Usable fruit is defined as the sum of grade No. 1 and grade No. 5.

Table 9. Percent usable fruit in total raw product, 1979[α]

	OSU harvester		SKH&S harvester	
Variety	Grade No. 1	Grade No. 5	Grade No. 1	Grade No. 5
	(%)	(%)	(%)	(%)
Benton	27.23	22.37	37.79	31.04
Olympus	38.10	35.57	36.05	33.66
Linn	30.49	34.71	30.54	34.77
Totem	38.69	24.87	41.46	26.65
70-17-12	30.78	31.42	35.25	33.01
Average	33.06	29.79	36.22	31.83

[α]Usable fruit is defined as the sum of grade No. 1 and grade No. 5.

ESTIMATED MECHANICAL HARVESTING AND PROCESSING COSTS

Machinery costs estimated in this section are based on the following assumptions:

(1) The owner of the mechanical harvester has 20 acres of strawberries on his 200-acre (80.9 ha) farm (farm size affects production costs).

(2) The expected useful mechanical life of the harvester is around 1,500 hours, and the annual use of the mechanical harvester is 214 hours, which is needed to harvest the owner's 20 acres (8.1 ha) plus 37 acres (14.97 ha) of custom harvest, at a field speed of 0.63 mph (1.01 km/hr) (based upon actual running time and a 20 percent allowance for non-operating needs).

(3) The list price of the harvester is $15,000.

Machinery costs include variable and fixed costs. Variable (operating) costs include fuel, lubrication, repair, and labor costs, while fixed costs are those costs not affected much by the amount of annual use. Fixed costs include depreciation, taxes, housing, interest, and insurance.

The OSU and SKH&S harvesters are very similar in operation, size, and estimated price. The cost figures obtained in this section are based on the OSU harvester.

Variable costs for the mechanical harvester

Fuel. The amount of fuel used per hour depends upon the horsepower of a harvester and the type of fuel it uses. The OSU harvester with two 18-hp gasoline engines was estimated to consume 2.4 gal (9.08 l) of gasoline per hour. The gasoline was assumed to be delivered to the farm at 85.4¢/gal (22.56¢/l) (all cost figures were computed on an August 1979 basis). An 11¢/gal (2.91¢/l) tax refund, which includes state and federal taxes, should be deducted. Therefore, fuel cost for the OSU harvester was computed to be $1.79/hr, i.e., 2.4 gal/hr x $(0.854-0.11)/gal = $1.79/hr.

Lubrication. The lubrication costs, including oil, grease, and oil filters are commonly estimated by multiplying 15 percent of the fuel costs, giving $0.27/hr for lubrication.

Repair costs. Repair costs[6] generally increase as a machine gets older (since the amount of wear and, therefore, the amount spent for repairs is proportional to use). Therefore, it was assumed that repair costs reach a high level early, then slowly and continuously increase. The following formula is used to estimate repair costs:

$$TAR = C \times RC1 \times RC2 \times L^{RC3}$$

where TAR = total accumulated repair costs as measured at "L,"
L = percent of the designated lifetime hours of the machine that have been used up at point where accumulated repairs are to be measured,
C = initial list price,
RCI = a constant that is actually a ratio of TAR to C as measured at 100 percent of life, assuming no inflation, and RC2 and RC3 are repair cost constants that indicate the general shape of the accumulated repair cost curve (Fig. 1).

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[6] W. Bowers, Modern Concepts of Farm Machinery Management (Champaign, Ill.: Stipes Publishing Company, 1970).

For the OSU harvester, 1, 0.00251, and 1.3 are used in this study for RC1, RC2, and RC3, respectively. After estimating repair costs for the machine's expected lifetime, an average repair cost of $10.01/hr is used in this study. The results are shown in Table 10.

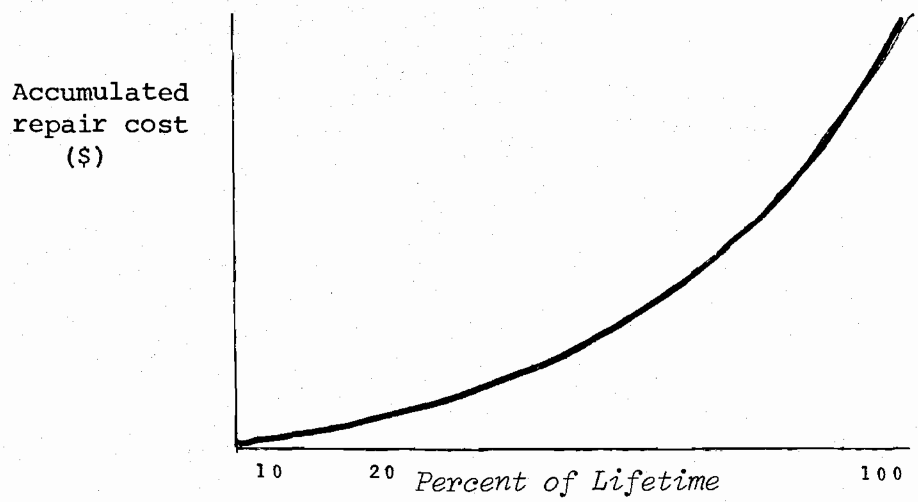

Figure 1. Relationship between accumulated repair cost and the percent of a machine's estimated useful life

Table 10. Repair costs per hour for the OSU harvester

	Age (years)							
	1	2	3	4	5	6	7	Average
Repair cost per hour ($)	5.54	8.21	9.54	10.56	11.39	12.10	12.72	10.01

Labor. The OSU and SKH&S harvesters are pulled by tractors with approximately 35 hp. A crew of three workers is necessary for the OSU or SKH&S harvester, one operating the tractor and the other two assisting on the harvester.

To estimate labor costs, $8/hr for the tractor operator and $5/hr for the harvester assistants are assumed. Therefore, $18/hr is used as the labor cost.

Total variable costs per hour, including fuel, lubrication, repair, and labor costs, is $30.07/hr.

Fixed costs for the mechanical harvester

Fixed costs include depreciation, taxes, housing, insurance, and interest on investment.

Depreciation. The declining balance method is employed to estimate depreciation for the harvester. This method depreciates at a constant percentage of the remaining value each year and gives approximately 10 percent of list price as a salvage value. The declining balance is represented by the following formula:[7]

$$V = C \text{ x } (1_x - R/L)^y$$

where
- V = remaining value,
- C = initial list price,
- R = ratio of depreciation rate used to straight-line rate (R=2 is used in this study),
- L = estimated service life in years (L=7 in this study, and the expected life is 1,498 hours with an annual use of 214 hours), and
- y = an exponent that is equal to the year in question.

Results are shown in Table 11.

Table 11. Fixed costs for mechanical harvester

Age	Depreciation per hour	Tax and housing per hour	Insurance per hour	Interest per hour	Total fixed cost/hour
	($)	($)	($)	($)	($)
1	20.03	1.50	0.15	7.71	29.39
2	14.30	1.07	0.11	5.51	20.99
3	10.22	0.77	0.08	3.93	15.00
4	7.30	0.55	0.06	2.81	10.72
5	5.21	0.39	0.04	2.01	7.65
6	3.72	0.28	0.03	1.43	5.46
7	2.66	0.20	0.02	1.02	3.90
Average	9.06	0.68	0.07	3.49	13.30

Taxes, housing, and insurance. Taxes and housing costs are each assumed to be 1.5 percent of the remaining value, and insurance is assumed to be 0.3 percent of remaining value. (In Oregon, property tax on farm machinery is being eliminated after 1979.)

Interest on investment. Interest payment is estimated at 11 percent of the remaining value of the machine. Estimated interest and other fixed costs are shown in Table 11, and total fixed costs are $13.30/hr, on the average.

[7] Ibid.

The OSU harvester can be pulled by a diesel tractor greater than 20 hp. Since most farmers have 35-hp tractors rather than 20-hp tractors, it is assumed that the OSU harvester is pulled by a 35-hp diesel tractor that comsumes 1.7 gal (6.44 l) of diesel fuel per hour. To compute fuel consumption, $0.75/gal (%0.20/l) is used as the cost per gallon. The cost of lubrication is assumed to be 15 percent of fuel cost. This figure gives a fuel and lubrication cost for the tractor of $1.47 per hour.

The list price of a 35-hp diesel tractor is assumed to be $9,000, with expected life of 12 years and usage of 500 hours per year. Using Table 11, the repair cost was computed to be $0.74/hr.[8] Therefore, the total variable cost of using the tractor was $2.21/hr.

The total cost, including the variable cost for the tractor and variable cost plus fixed cost for the harvester, was computed to be $45.58/hr.

ADDITIONAL COSTS FOR OPERATING THE CAPPER-STEMMER

The strawberries from 52 field experiments were processed by the OSU capper-stemmer to separate the undersized berries. It is assumed that the total raw product harvested is processed through the OSU capper-stemmer. Additional assumptions on cost estimation are as follows:

(1) The expected life is 10 years.

(2) Annual use is 260 hours. This figure varies, depending upon the amount of raw product harvested (this figure was estimated as follows: processing machine-picked strawberries at the plant could run 3 to 3.5 weeks. Therefore, 3.25 weeks x 5 days/week x 16 hours/day = 260 hours). However, different amounts of raw product will vary the number of capper-stemmers needed.

(3) List price is estimated to be $8,000 for one 4-foot-long (1.22 m) capper-stemmer. In previous experiments, only the 1-foot-long (0.3 m) capper-stemmer was available. However, for large-scale use, the capper-stemmer would be extended in size to operate efficiently at the 4-foot (1.22 m) length.

Variable costs and fixed costs for the OSU capper-stemmer can be estimated by the same procedures used in estimating costs for the mechanical harvester. Only the differences and results will be given in this section.

Electricity

The 4-foot-long OSU capper-stemmer would be equipped with a 7.5-hp motor that would consume 6 kw of electricity per hour. Each processing line at the processing company has two conveyor belts, each belt having

[8] Ibid.

a 0.5-hp motor. The two conveyor belts are estimated to consume 1 kw per hour. A charge of 1.716¢ per kw is used for electricity.[9]

Repair costs

In estimating repair costs, 0.000251 and 1.8 are used for RC2 and RC3.

Labor cost

For each capper-stemmer, a dumper, a feeder, and sorters are required for processing. However, no feeder is required for processing hand-picked strawberries. The number of sorters varies, depending upon the amount of fruit. The total fruit per acre by mechanical harvesting is less than the fruit per acre by hand harvesting and, therefore, some savings in cost of sorting would occur. This is explained in detail in a later section.

To simplify estimation, only the additional costs are computed. For example, one dumper is needed for the capper-stemmer, but a dumper is also required for processing hand-picked berries, so this is not counted as an additional cost. Results for additional variable costs and fixed costs are as follows:

Additional variable costs[a]	
Electricity	12.01¢/hr
Lubrication	1.5 ¢/hr
Repair cost	$ 3.07 /hr
Labor (feeder) cost	$ 4.72 /hr
Total	$ 7.93 /hr
Additional fixed costs	
Depreciation	$ 2.75 /hr
Tax, insurance, housing	$ 0.20 /hr
Interest (11%)	$ 1.51 /hr
Total	$ 4.46 /hr
Additional total cost[a]	$12.39 /hr

[a]Does not include the savings in sorting costs.

Speed of the mechanical harvester

The speed of the harvester affects operating costs and the amount of fruit harvested. In 1978, speeds in the field ranged from 0.31 mph

[9]This charge is based on "Schedule 25," General Service, Pacific Power and Light Company, Portland, Oregon.

(0.50 km/hr) to 0.56 mph (0.90 km/hr) for the OSU harvester and from 0.45 mph (0.72 km/hr) to 0164 mph (1.03 km/hr) for the SKH&S harvester. Simple regression equations were estimated to find the relationships between the amount of fruit harvested per acre and the speed of harvester. Statistical results failed to show a significant effect of speed upon amount of fruit, but the analysis indicated a slight positive relation between speed and amount of fruit harvested per acre (at lower speeds, more berries are lost by rolling forward off the cutter bar).

In 1969, speeds in the field ranged between 0.52 mph (0.84 km/hr) and 1.02 mph (1.64 km/hr) for the OSU harvester and between 0.52 mph (0.84 km/hr) and 1.13 mph (1.82 km/hr) for the SKH&S harvester. Statistical results for the 1979 experiments indicated that speed of harvester and total amount of fruit harvested per acre were inversely related. According to Dean Booster, Department of Agricultural Engineering at OSU, total fruit per acre harvested with the OSU harvester is positively related to speeds up to 0.75 mph (1.21 km/hr) under current technology. Therefore, a speed of 0.75 mph (1.21 km/hr) is chosen for the OSU and SKH&S harvesters (based on running time only). Therefore, this figure is readjusted by allowing 20 percent for non-operating needs.

MACHINERY COST PER ACRE FOR MECHANICALLY HARVESTING STRAWBERRIES

The field capacity of the harvester is estimated by determining the hours necessary to harvest one acre of strawberries.

$$\text{Field capacity} = \frac{\text{Acres covered}}{\text{Time required (hours)}} = \text{acres/hour}$$

where time required (hours) includes both running time and an allowance of 20 percent for non-operating needs.

Using the estimated field capacity, hours necessary to harvest the strawberries on one acre can be derived, and the result is that 3.77 hours are required to harvest one acre with 0.63 adjusted mph (1.01 km/hr). With this result, machinery cost per acre for harvester was computed to be $171.84. That is, $45.58 per hour x 3.77 hours per acre = $171.84 per acre.

Machinery cost for harvesting is not affected by the amount of raw product. The growers must bear the machinery cost of the harvester regardless of yield. However, the amount of raw product harvested affects processing cost. This will be studied in the next section.

ESTIMATION OF NUMBER OF CAPPER-STEMMERS

The greatest difficulty lies in determining how many capper-stemmers the processing company would need. The processing rates[10] were estimated to range from 2,200 pounds (997.9 kg) to 5,200 pounds (2,358.7 kg) per hour, averaging 3,400 pounds (1,542.2 kg) per hour.

The following assumptions were made to determine the number of capper-stemmers required to process mechanically harvested strawberries:

(1) Eighteen thousand crates (15 lb/crate) or 135 tons (122.47 MT) of hand-picked strawberries are processed per day by the processing company. (This quantity was an average amount of hand-picked strawberries processed daily at the participating processing company.)

(2) All growers harvest berries with mechanical harvesters.

(3) A yield of 4 tons (3.63 MT) by hand picking would be averaged per acre.

(4) All of the raw product harvested is processed by the OSU capper-stemmer.

(5) The processing capacity of the OSU capper-stemmer is 3,500 lb/hr (1,587.57 kg/hr).

It is assumed that 18,000 crates (122.47 MT) of hand-picked strawberries are processed per day at a participating processing company during the 6- to 7-week season. These 18,000 crates would require 33.75 acres (13.66 ha) if 4 tons (3.63 MT) of strawberries were produced per acre. That is,

$$\frac{18{,}000 \text{ crates x } 15 \text{ lb/crate}}{4 \text{ t/a x } 2{,}000 \text{ lbs}} = 33.75 \text{ acres.}$$

The weight of the mechanically harvested raw product is about equal to the weight of hand-picked strawberries (Table 13). However, data collected in 1978 showed that the amount of raw product harvested accounted for around 90 percent of the amount of hand-picked strawberries (Table 12). Therefore, both situations will be considered.

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[10] Processing rate is defined as amount of raw product processed per hour.

Table 12. Gross raw product harvested and amount of hand-picked strawberries, 1978

Harvester	Benton (No. Willamette Expt. Sta.)	Olympus (Keudell Farm)
	(t/a)	(t/a)
OSU	9.12	4.57
SKH&S	9.92	6.08
Handpicked[a]	10.57	6.13

[a]Based on commercial picking. (Experiment Station yields are usually much higher than farm yields.)

Table 13. Gross raw product harvested at the North Willamette Experiment Station and amount of hand-picked strawberries, 1979

Harvester	Variety				
	Benton	Olympus	Linn	Totem	70-17-12
OSU	5.10	8.89	8.22	4.75	6.41
SKH&S	6.20	9.30	7.87	4.18	6.91
Handpicked[a]	7.41	11.98	7.13	4.68	4.31

[a]Based on commercial picking.

Case A: The amount of raw product harvested is equivalent to the amount of hand-picked strawberries.

Since weight of the mechanically harvested raw product is assumed to be equal to the weight of hand-picked strawberries, the company should be able to process 135 tons (122.47 MT) of product per 8-hour day (i.e., 33.75 acres x 4 tons/acre = 135 tons/day). However, the processing hours can be extended to 16 hours per day during the harvesting season. Therefore, the company should be able to process the raw product from 67.5 acres per day.

The capacity of the OSU capper-stemmer is 3,500 lbs/hr, so nine capper-stemmer lines are needed to process the raw product harvested from 67.5 acres. This is,

$$\frac{270 \text{ tons/day} \times 2{,}000 \text{ lbs/ton}}{3{,}500 \text{ lbs/hr} \times 16 \text{ hrs/day}} = 9.6$$

(To make it more realistic, it is assumed that the processing company is equipped with nine capper-stemmers, by truncating the decimal point.)

Case B: The amount of raw product harvested accounts for 90 percent of the amount hand picked.

The company should now be able to process 243 tons of raw product per 16-hr day (i.e., 67.5 acres x 4 t/a x 90% - 243 tons/day), and eight capper-stemmers are required to process the raw product harvested from 67.5 acres. That is,

$$\frac{243 \text{ tons/day} \times 2{,}000 \text{ lbs/ton}}{3{,}500 \text{ lbs/hr} \times 16 \text{ hrs/day}} = 8.6$$

(It is assumed that the processing company is equipped with eight capper-stemmers, by truncating the decimal point.)

ESTIMATED NUMBER OF SORTERS NEEDED

The participating processing company presently is equipped with seven processing lines for hand-picked strawberries. According to company information, seven sorters would be needed in each line to obtain the qualities shown in Tables 15 and 16.

Also, it is assumed that 18,000 crates (15 lbs/crate) of hand-picked strawberries are processed per day. Therefore, about 4,821 pounds (2,186.96 kg) of hand-picked strawberries could be processed per hour per line. That is,

$$\frac{18{,}000 \text{ crates} \times 15 \text{ lbs/crate}}{8 \text{ hrs/day} \times 7 \text{ line}} = 4{,}821.43 \text{ lbs/hr/line}$$

This amount of strawberries could be handled by seven sorters, assuming each sorter handled 688.78 lbs (312.43 kg) of hand-picked strawberries per hour.

However, the number of sorters needed varies, depending not only on quantity, but also quality of strawberries. According to company information, nine sorters would be required in each line for an equivalent quantity of mechanically harvested strawberries. Therefore, each sorter is assumed to handle 535.71 lbs (242.99 kg) of machinery-harvested strawberries per hour. That is,

$$\frac{4{,}821.43 \text{ lbs/hr/line}}{9 \text{ sorters/line}} = 535.71 \text{ lbs/hr/sorter}$$

The amount of fruit accounts for 76.05 percent of gross raw product harvested by SKH&S harvester (Table 2). Undersized strawberries and spillage account for 17.80 and 2.30 percent, on the average, of the total fruit, respectively (Table 4). Therefore, only 60.8 percent of the gross raw product would be handled by hand sorters. That is, 76.05% x (100-17.80-2.30)% = 60.8%.

The capacity of the OSU capper-stemmer is assumed to be 3,500 lbs/hr (1,587.57 kg/hr). Therefore, only 2,128 pounds (965.24 kg) of strawberries would be handled by hand sorters. That is, 3,500 lbs/hr x 60.8% = 2,128 lbs/hr. Also, each sorter is estimated to handle 535.71 lbs (242.99 kg) of mechanically harvested strawberries per hour. Therefore, these 2,128 lbs (965.24 kg) of strawberries could be handled by four sorters in one hour. That is,

$$\frac{2{,}128 \text{ lbs/hr}}{535.71 \text{ lbs/hr}} = 3.97 \text{ sorters (4 sorters)}$$

ESTIMATION OF THE NET PROCESSING COST

The additional cost for operating the capper-stemmer is $12.39 per hour.[11] It is estimated the 4.74 hours are required to process hand-picked strawberries from 20 acres (8.1 ha). That is,

$$\frac{4 \text{ t/a x } 2{,}000 \text{ lbs/t x } 20 \text{ a x } 8 \text{ hrs/day}}{18{,}000 \text{ crates/day x } 15 \text{ lbs/crate}} = 4.74 \text{ hrs}$$

Therefore, $1,096.27 would be paid to sorters for hand-picked strawberries from 20 acres (8.1 ha). That is, 4.74 hrs x 7 lines x 7 sorters/line x $4.72/hr - $1,096.27.[12]

As explained in the preceding section, the number of capper-stemmers needed varies, depending upon the amount of raw product harvested. Therefore, the number of sorters needed to process raw product harvested will also vary.

Case A: The amount of mechanically harvested raw product is equal to the amount of hand-picked strawberries.

Since there is an equivalent weight of mechanically harvested raw product to hand-picked berries, it is estimated that 5.08 hours are required to process the raw product harvested from 20 acres (8.1 ha) of strawberries. That is,

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[11] Does not include the savings in sorting cost.

[12] This figure was obtained from a participating processing company, and it includes all fringe benefits.

$$\frac{4 \text{ t/a} \times 2{,}000 \text{ lbs/t}}{3{,}500 \text{ lbs/line} \times 9 \text{ lines}} = 0.25 \text{ hrs/acre and } \$12.39\text{/hr} \times 0.25 \text{ hr} \times$$

0 lines = $27.88.

Therefore, there is a net additional processing cost of $16.23 per acre ($40.11/ha) in processing the mechanically harvested raw product ($27.88-$11.65/a = $16.23/a).

Case B: The amount of mechanically harvested raw product accounts for 90 percent of the amount of hand-picked strawberries.

Since less raw product is harvested, it will reduce processing time and the number of processing lines needed. It is estimated that 5.14 hours are required to process the raw products harvested from 20 acres of strawberries with eight capper-stemmers. That is,

$$\frac{4 \text{ t/a} \times 0.9 \times 20 \text{ a} \times 2{,}000 \text{ lbs/t}}{3{,}500 \text{ lbs/line} \times 8 \text{ lines}} = 5.14 \text{ hrs}$$

The total amount paid to sorters would be $776.35 for raw product harvested from 20 acres, and the saving in cost of sorting is $319.91/20 acres or $16.00 per acre. That is, 5.14 hrs x 8 lines x 4 sorters/line x $4.72/hr - $776.35, and $1,096.27-$776.35 - $319.92/20 acres or $319.92/20 - $16.00 per acre. To process raw products harvested from an acre, 0.26 hour is needed, and therefore, the additional cost for operating the capper-stemmer would be $25.77/acre. That is,

$$\frac{(4 \text{ t/a} \times 0.9 \times 2{,}000 \text{ lbs/t}}{3{,}500 \text{ lbs/line} \times 8 \text{ lines}} = 0.26 \text{ hrs, and } \$12.39\text{/hr} \times 0.26 \text{ hr/a}$$

x 8 lines = $25.77/a).

Therefore, there is a net additional processing cost of $9.77/a ($24.14/ha) in processing the mechanically harvested raw product, i.e., $25.77-$16.00 = $9.77/a.

	Net additional processing cost ($/acre)
Case A:	$ 16.23
Case B:	9.77

ESTIMATION OF TOTAL USABLE FRUIT OF MECHANICALLY HARVESTED BERRIES[13]

The date of harvest affects not only the amount of usable fruit, but also the proportion of grade No. 1 and grade No. 5 in total usable fruit. In 1979, the harvesting season in Oregon came earlier than expected, and berries were over-ripe when mechanically harvested. Missing the appropriate dates for mechanical harvesting resulted in an increased proportion of grade No. 5 relative to grade No. 1 in total usable fruit harvested.

Statistical results from estimated regression equations showed a significant negative effect from late mechanical harvesting on June 27 and 28 upon total fruit harvested, and even though the regressions failed to show a significant effect of mechanical harvesting between June 11 and 19, there was an indication of a slight negative impact on the amount of fruit harvested.

Economic analyses are based on the data for SKH&S in 1979 and for the OSU harvester in 1978 (Table 14).

Table 14. Percent grade No. 1 and grade No. 5, on average for all varieties, of machine-harvested gross raw product

Harvester	Grade No. 1	Grade No. 5
	(%)	(%)
OSU (1978)	50.86	22.40
SKH&S (1979)	36.22	31.83

Case A: The amount of gross mechanically harvested raw product is equal to the amount of hand-picked strawberries

SKH&S	Grade No. 1: 4 t/a x 36.22% =	2,897.6 lbs/a (3,247.78 kg/ha)
	Grade No. 5: 4 t/a x 31.83% =	2,546.4 lbs/a (2,854.14 kg/ha)
	Usable fruit:	5,444 lbs/a (6,101.92 kg/ha)
OSU	Grade No. 1: 4 t/a x 50.86% =	4,068.8 lbs/a (4,560.52 kg/ha)
	Grade No. 5: 4 t/a x 22.40% =	1,792.0 lbs/a (2,008.56 kg/ha)
	Usable fruit:	5,860.8 lbs/a (6,569.08 kg/ha)

[13]Usable fruit is defined as the sum of grade No. 1 and grade No. 5.

Case B: The amount of gross product harvested accounts for 90 percent of the amount of hand-picked strawberries

SKH&S	Grade No. 1: 4 t/a x 90% x 36.22% = 2,607.8 lbs/a	(2,922.95 kg/ha)
	Grade No. 5: 4 t/a x 90% x 31.83% = 2,291.8 lbs/a	(2,568.77 kg/ha)
	Usable fruit: 4,899.6 lbs/a	(2,568.77 kg/ha)
OSU	Grade No. 1: 4 t/a x 90% x 50.86% - 3,661.9 lbs/a	(4,104.44 kg/ha)
	Grade No. 5: 4 t/a x 90% x 22.40% = 1,612.8 lbs/a	(1,807.71 kg/ha)
	Usable fruit: 5,274.7 lbs/a	(5,912.15 kg/ha)

ESTIMATION OF USABLE FRUIT OF HAND-PICKED STRAWBERRIES

For hand-picked strawberries with more than 95 percent of grade No. 1, the growers are paid in full. Culls account for 3.7 percent on average and 6 percent for grade No. 2 (Table 15). Therefore, the usable fruit of hand-picked strawberries is classified as follows:

Grade No. 1: 4 t/a x 90.3% =	7,224 lbs/a	(8,097 kg/ha)
Grade No. 2: 4 t/a x 6.0% =	480 lbs/a	(538.01 kg/ha)
Usable fruit:	7,704 lbs/a	(8,635.04 kg/ha)

Table 15. Classifications of hand-picked strawberries, 1979[a]

Grade	Variety			Average
	Benton	Olympus	Hood	
	(%)	(%)	(%)	(%)
Grade No. 1	90	90	91	90.3
Grade No. 2	7	5	6	6.0
Culls	3	5	3	3.7

[a]Obtained from participating processing company.

Table 16. Classification of hand-picked strawberries, 1978[a]

Grade	Variety: Olympus	Linn
	(%)	(%)
Grade No. 1	92.4	91.4
Grade No. 2	3.0	4.6
Culls	4.6	4.0

[a]Obtained from participating processing company.

COMPARISON OF TOTAL COSTS, UNIT COSTS, AND NET REVENUE

Total costs. For hand picking, the total costs increase as yield per acre increases because of the increase in picking and handling costs, as well as in hauling costs. There is little change in harvesting costs, as yield per acre increases for mechanical harvesting. However, hauling and net processing costs change and so will total cost. Total costs include production, harvesting, and processing costs and are computed for hand picking and mechanical harvesting as follows:

Total cost for hand picking

Standard production cost[14]	$ 1,026.9/a
Picking and handling (14¢/lb)	$ 1,120.0/a
Hauling (1¢/lb)	$ 80.0/a
Total cost	$ 2,226.90/a

Total cost for mechanical harvesting

Total cost for mechanical harvesting

	Case A[a]	Case B[b]
Standard production cost	$1,026.9/a	$1,026.9/a
Cost for harvesting	$ 171.84/a	$ 171.84/a
Cost for hauling (1¢/lb)	$ 80.0/a	$ 72.0/a
Net processing cost	$ 16.23/a	$ 9.77/a
Total cost	$1,294.97/a	$1,280.51/a

[14]Standard production cost is the total production cost excluding harvesting costs and hauling costs as shown by the production costs sheet (Appendix Table 1).

[a]For Case A the weight of gross raw product harvested is assumed to be equal to the weight of the hand-picked strawberries.

[b]For Case B, the weight of gross raw product harvested is assumed to equal 90 percent of the weight of hand-picked strawberries.

Unit cost

The unit costs are computed for 3.77 hrs/a harvesting time and a 3,500 lbs/hr (1,587.57 kg/hr) processing rate (Table 17).

Table 17. Comparisons of unit costs

		Tons/acre			
		3	4	5	6
Hand picked ($/lb)		0.3335	0.2891	0.2624	0.2446
Case A:	SKH&S ($/lb)	0.3113	0.2379	0.1939	0.1645
	OSU ($/lb)	0.2892	0.2210	0.1801	0.1528
Case B:	SKH&S ($/lb)	0.3428	0.2613	0.2124	0.1797
	OSU ($/lb)	0.3185	0.2427	0.1973	0.1670

Net revenue

It is anticipated that 33¢/lb (72.75¢/kg) for grade No. 1 and 27.5¢/lb (60.63¢/kg) for grade No. 2 will be paid to growers by a participating processing company for hand-picked strawberries during the 1969 season, while 27.25¢/lb (60.08¢/kg) for grade No. 1 and 23.65¢/lg (52.36¢/kg) for grade No. 2 were paid to growers in 1978.

Net revenues were computed for 3.77 hours per acre required for mechanical harvesting and a 3,500 lbs. per hour (1,587.57 kg/hr) processing rate, and the results are shown in Tables 18 and 19. Results indicate that mechanical harvesting may be more profitable for growers than hand-picking if harvesting takes place on the appropriate dates. Also, mechanical harvesting is more favorable to growers for relatively lower farm prices. From 1974 to 1978, the highest farm price was 27.6¢ per pound and average farm price was 25.58¢ per pound.

Table 18. Net revenue comparisons with 1979 farm prices[a]

		Tons/acre			
		3	4	5	6
Hand picked ($/a)		- 39.96	289.02	618.0	946.98
Case A:	SKH&S ($/a)	-216.04	111.53	439.10	766.67
	OSU ($/a)	- 26.31	364.50	755.31	1,146.12
Case B:	SKH&S ($/a)	-310.19	- 14.01	282.17	578.35
	OSU ($/a)	-139.44	213.66	566.76	919.85

[a]Grade No. 1, 33¢/lb; grade No. 2, 27.5¢/lb; grade No. 5, 17.7¢/lb.

Table 19. Net revenue comparisons with 1978 farm prices[a]

		Tons/acre			
		3	4	5	6
Hand picked ($/a)		-365.35	-144.84	75.67	296.19
Case A:	SKH&S ($/a)	-396.38	-128.93	138.53	405.98
	OSU ($/a)	-240.75	78.58	397.90	717.23
Case B:	SKH&S ($/a)	-472.50	-230.42	11.65	
	OSU ($/a)	-332.44	- 43.67	245.09	533.86

[a]Grade No. 1, 27.5¢/lb; grade No. 2, 23.65¢/lb; grade No. 5, 14.8¢/lb.

Limitations

The net revenue figures in Tables 18 and 19 are based on several assumed conditions, and growers operating under different conditions could have worse results from using the mechanical strawberry harvester. For example, it was assumed the mechanical harvester would be used on 57 acres per year (on 20 acres of berries owned by the grower and on 37 acres to be custom harvested). If the harvester were used on fewer acres, much higher costs per acre and lower net revenues from machine harvest would result. Another limitation of the figures in Tables 18 and 19 is that the harvesting and efficiency estimates were based on only 2 years' data. Specific prices for some grades of mechanically harvested berries have not yet been firmly established, adding more uncertainty to the economic comparisons between mechanical harvesting versus hand picking.

Appendix table 1. Production costs[a]

Based on:

1. 20 ac. on a 200 ac. farm
2. 3 bearing yrs., 4 ton/ac. ave.
3. Operator's labor, $8/hr.[b]
4. Hired labor, $5/hr.[b]
5. Tractors:
   90-100 HP $12/hr.
   50 HP $ 6/hr.
   25 HP $ 3/hr.

Producing years	Labor Hrs	Labor Value ($)	Machinery ($)	Other Item	Other Value ($)	Total cost ($)
Preharvest cultural operations						
Cultivate (3x)	3.0	24.00	12.00			36.00
Hoeing	8.0	40.00				40.00
Insecticide & fungicide spray or dust (3x)	1.0	8.00	9.00	mtl.	40.00	57.00
Irrigation (2x, 2" ea.)	2.0	10.00	20.00	elec.	3.50	33.50
Postharvest operations						
Irrigation (2x, 2" ea.)	2.00	10.00	20.00	elec.	3.50	33.50
Clip tops	.33	2.65	4.60			7.25
Weevil control (banded)	.2	1.60	1.80	mtl.	18.00	21.40
Cultivate & runner control (2x)	2.0	16.00	10.00			26.00
Subsoil	.5	4.00	6.75			10.75
Herbicide	.2	1.60	1.80	mtl.	6.00	9.40
Sidedress fert.[c]				fert.	47.00	47.00
Other charges						
Bookkeeping		80.00		supp.	9.00	89.00
Land chgs., incl. taxes					150.00	150.00
Operating capital int. (11%)					18.00	18.00
General overhead					15.00	15.00
Cash costs		1,180.00	50.40		153.50	1,383.90
Non-cash costs		177.85	75.55		156.50	409.90
Total Annual Production Costs		1,357.85	125.95		310.00	1,793.80
Amortized establishment cost						480.00
Credit for postharvest practices not incurred in last year						(46.90)
Standard production cost						$1,026.90
Harvest costs						
Picking & handling (14¢/lb)		1,120.00				1,120.00
Hauling (1¢/lb)		90.00				80.00
Total cost						$2,226.90

(continued)

Appendix Table 1. Production costs (continued)

Producing years	Labor Hrs	Labor Value	Machinery	Other Item	Other Value	Total cost
		($)	($)		($)	($)
Cultural operations						
Subsoil	.5	4.00	6.75			10.75
Plow	.4	3.20	7.20			10.40
Disc & harrow (3x)	.75	6.00	13.50			19.50
Field cultivator (2x)	.5	4.00	8.00			12.00
Fumigation[c]	.5	4.00	6.00	mtl.	140.00	150.00
Cultimulcher (2x)	.33	2.65	5.96			8.60
Fertilize (broadcast)	.17	.85	1.20	fert.	15.00	17.05
Preplant insecticide	.2	1.60	1.80	mtl.	43.00	46.40
Lime (2 tons)[c]				custom	50.00	50.00
Plant trimming	3.0	15.00				15.00
Planting, 11,000 plants/ acre, 5 people (5 acres in 8 hours)	8.00	44.80	14.40	plants	385.00	444.20
Roll plants	.2	1.00	2.60			3.60
Fertilize[d]				fert.	47.00	47.00
Herbicide	.2	1.60	1.80	mtl.	45.00	48.40
Irrigation (3x, 6" tl.)	3.0	15.00	60.00	elec.	6.00	81.00
Cultivate (3x)	3.0	24.00	12.00			36.00
Herbicide (fall)	.2	1.60	1.80	mtl.	20.00	23.40
Hand weeding, crew	8.0	40.00				40.00
Pest control	.2	1.60	1.80	mtl.	14.00	17.40
Other charges						
Land charge (cash rent basis)					150.00	150.00
Operating capital interest (11%)					45.60	45.60
General overhead					36.50	36.50
Total cash costs		103.85	58.00		816.00	977.85
Total non-cash costs		67.05	86.80		181.10	334.95
Total establishment costs		170.90	144.80		997.10	1,312.80
Amortized for 3 years at 10%						480.00

[a]Costs are based on the following assumptions: 20 acres on a 200-acre farm; 3 bearing years, averaging 4 t/a; operator's labor, $8 per hour; hired labor, $5 per hour; tractors, 90-100 hp, $12 per hour, 50 hp, $6 per hour, 25 hp, $3 per hour.

[b]Includes Social Security, Workmen's Compensation, and other labor expenses.

[c]Generally done but not required in all cases.

[d]Applied during another operation and includes soil insecticide.

PERFORMANCE MEASUREMENT OF THREE STRAWBERRY HARVESTERS IN OREGON

R. D. Langmo and Chong S. Kim

Summary. Strawberry harvesting machines have demonstrated, within study limits, the ability to operate at ground speeds ranging up to 1.31 km per hour (0.82 mph) and to cover 0.133 ha (0.328 a) per hour. Machine and crew performance rates contribute to the economic evaluations and production-estimating needs considered by users of harvesting machines. Time measurements indicate opportunities for more effective use of machines and their crews. Two of the harvesters generated sound levels that would make noise protection equipment advisable.

INTRODUCTION

Performance measurement of machines for harvesting strawberries makes up a small part of the complete study of producing, processing, and marketing strawberries harvested with mechanical assistance. Objectives of this part of the study are: (1) to provide man and machine production rates that can be used to determine costs of harvesting strawberries mechanically; (2) to enable interested growers to estimate the time needed for mechanical harvesting; and (3) to present production rates and operating characteristics in sufficient detail to permit equipment builders and users to make further improvements.

Field studies in 1978 and 1979 included combinations of the variables involving three machines, three growers' fields, plots at Oregon State University's North Willamette Experiment Station, five cultivars, and machine harvesting following zero, one, and two or more hand pickings. Various restraints during the field work eliminated or greatly limited some combinations of observations. Summarization of results in this report was based on only those conditions in which a substantial amount of information was accumulated. Therefore, most of the comparative results were derived from the use of two types of machines, the SKH&S and OSU; three cultivars, 'Benton,' 'Olympus,' and 'Linn'; plots located at the North Willamette Experiment Station; and harvesting prior to hand picking.

METHODS AND MATERIALS

To establish the comparative performance of the harvesting machines, it was necessary to relate production to units of time. A work-sampling technique was best suited to estimating the time use for simultaneous activities of two to eight crew members. Sampling was further justified by workers occasionally changing job functions and locations. Observations at the rate of five per worker per minute and numerous irregularities in the work sequence negated any need to randomize the interval between readings.

For use in economic analysis, overall production time was separated from idle time. However, to recognize opprotunities for more effective use of mechanical harvesting, functions of the crew members were further divided into several activities.

"Running time" was common for all machines. An equivalent amount of time was required in each case for the machine driver, so machine and driver were observed as one unit. Functions of the crew for each machine varied in detail, but each crew executed the following four main activities:

1. Empty box handling involved workers moving empty tote boxes from their storage area on the machine to a conveyor or rack adjacent to the exit of the raw product conveyor.

2. Leveling, or sorting and filling, included moving the empty box a short distance from the conveyor or rack to a position under the filler, leveling the berries and vine material as the tote filled, and, as time permitted, sorting foreign material out of the raw product.

3. Unloading full boxes to stack or ground referred to workers moving full tote boxes from the filler to a pallet carried on the machine (SKH&S) to a machine-pulled trailer (BEI), or to the ground (OSU).

4. Waiting by handlers or sorters accounting for the time when crew members were accompanying a running machine but not engaged in any of the previous three work requirements.

Times for work delays, such as those needed for machine repairs or adjustments and making end-of-row turns, were eliminated because observations from a series of short studies would not accurately reflect the nonproductive delays typical of commercial use of machines.

Comparative performance in this discussion cites actual running time. However, cost and production projections, to be realistic, must include additional reasonable allowances to provide time for personal needs, mostly in the form of rest periods for the crews, unavoidable delays, imperfections in scheduling of work and materials flow, and nonproductive maneuvering time of the machines.

To accommodate for those additional allowances for cost study purposes, a uniform 20 percent allowance was prorated into the mechanical harvesting production rates (3). Twenty percent is an allowance derived from industrial activities with performance requirements similar to those needed for harvesting work (1). Inclusion of a 20 percent allowance, in effect, reduces an 8-hour work day of 480 minutes to a productive time of 384 minutes.

The machines observed during the harvesting tests were three models of SKH&S, the OSU harvester, and the BEI. Built by Charles Hecht and Associates of Stayton, Oregon, the 1978 SKH&S machine employed a power take-off from a towing tractor to operate the conveyor and fans. By adding an on-board engine to provide all power needs except locomotion by a tractor, Hecht and Associates developed the SKH&S(A). A second machine, SKH&S(B), is illustrated in Figure 1. Similar to model A but incorporating additional design refinements, this machine was built to be included in the 1979 tests.

The OSU harvester (shown at the top of Fig. 2) was designed and built with the direction of Dean Booster, Department of Agricultural Engineering, Oregon State University, Corvallis. After the 1978 experiments, modifications were made on the conveyor and air blower systems. Both versions were tractor-drawn and had two 18-hp engines to operate the product handling and air supply equipment.

Also observed was a self-propelled, double-row harvester, the BEI, shown at the bottom of Figure 2. It was manufactured by Blueberry Equipment Co., Inc., South Haven, Michigan.

Measurements of noise levels of the harvesters and tractors were made with an impulse Precision Sound Level Meter, No. 2209, manufactured by Bruël and Kjaer, Denmark. The instrument is capable of measuring the noise spectrum in terms of a single weighted sound level in decibels (dBA) or in individual sound levels (dB) for several frequency bands from 31.5 to 32,000 cycles per second (hertz).

RESULTS

Data from 22 individual studies in 1978 and 56 studies in 1979 have been summarized to give a general indication of the performance of harvesting machines. Speed and terms expressing production reflect actual performance rates and do not include nonproductive allowances.

Running speed

Average speeds for all machines for the two seasons are shown in Table 1. In 1979 all the SKH&S models and the OSU machine showed some increase in general speed compared to 1978. Causes for the improvement cannot be assigned singularly to changes in machine design, operating methods, or field conditions. Results indicate that speed increased with the reduction in crop density following one or two hand pickings. This trend is most uniformly demonstrated by the SKH&S machine in 1978 as the kilometers per hour progress respectively from 0.87 to 0.90 and 1.01 following zero, one, and two hand pickings.

Figure 1. SKH&S machine used in harvesting tests of Oregon Strawberries. Top: front view. Bottom: filling tote boxes at rear of machine.

Figure 2. Machines used in harvesting tests of Oregon Strawberries. Top: Oregon State University (OSU) machine. Bottom: Blueberry Equipment, Inc. (BEI) machine.

Table 1. Comparative average running speeds in kilometers (miles) per hour for machines harvesting strawberries, 1978 and 1979[a]

Prior hand pickings	Season and machines						
	1978			1979			
	SKH&S	OSU	BEI[b]	SKH&S (A)	SKH&S (B)	OSU	BEI
0	0.87 (0.54)	0.60 (0.37)	0.93 (0.58)	1.10 (0.68)	0.91 (0.57)	1.31 (0.82)	-- --
1	0.90 (0.56)	0.71 (0.44)	-- --	-- --	-- --	1.39 (0.86)	-- --
2	1.01 (0.63)	0.63 (0.39)	1.29 (0.80)	-- --	-- --	-- --	0.92 (0.57)

[a]Kilometers/hour x 0.6214 = miles per hour.

[b]Ground speed for the BEI is one-half the rates shown. Doubling the recorded values compensates for the machine's ability to simultaneously harvest two rows, whereas the other machines harvest one row.

Productivity

In production of raw product, both the SKH&S and OSU machines showed substantial performance improvement in 1979 over 1978 (Table 2). Area coverage also improved but to a lesser degree. The largest increase in production and area coverage between 1978 and 1979 was obtained by the OSU harvester.

Machine and crew activities

The operating relationship between harvesting machines and crews are expressed in detail by bar charts representing machine- and man-minutes per 45.36 kg (cwt) of a raw product harvested. Machine and driver time is shown as a single bar because the two must always work simultaneously during running time. The length of the bar for the rest of the crew reflects the man-minutes of the number of operators. In terms of elapsed time, their work must be accomplished during the running time of the machine.

Some operator waiting time was apparent in the use of all machines. This idle time was difficult to use for productive work because it usually occurred in very short but often frequent intervals. Waiting time indicates the work requirements and work crew are not balanced.

Table 2. Productivity rate by weight in kilograms (tons) and area in hectares (acres) for both machine and man-hours for three machines harvesting stawberries[a]

Production units[b]	1978			1979			
	SKH&S	OSU	BEI	SKH&S(A)	SKH&S(B)	OSU	BEI
Kg/mach. hr	1750	990	1,170	1,907	1,980	2,136	353
(tons/mach. hr	(1.929)	(1.091)	(1.290)	(2.102)	(2.183)	(2.354)	(0.389)
Kg/man-hr	553	327	172	636	660	712	1,118
(tons/man-hr[c]	(0.610)	(0.360)	(0.190)	(0.701)	(0.728)	(0.785)	(0.130)
Hecatres/mach. hr.	0.095	0.064	0.113	0.117	0.096	0.133	0.111
(acres/mach. hr	(0.234)	(0.157)	(0.279)	(0.289)	(0.238)	(0.328)	(0.274)
Hectares/man-hr	0.030	0.021	0.016	0.039	0.032	0.044	0.037
(acres/man-hr)[c]	(0.074)	(0.052)	(0.040)	(0.096)	(0.079)	(0.109)	(0.091)

[a]Values are for harvesting prior to hand picking except for the BEI in 1979, which is for performance following two hand pickings.

[b]Kilograms x 1.102 x 10^{-3} = tons (short); hectares x 2.471 = acres.

[c]Average operating crew size varied both with machine type and season. Crews in this table were: in 1978, SKH&S 3.17, OSU 3, and BEI 7; in 1979, SKH&S(A&B) 3, OSU 3, and BEI 2.

Also displayed by bar charts for all the machines is evidence that working time in man-minutes became longer with lower production rates for most of the activities. This relationship demonstrates that operators, though still working, normally slow their work pace to match requirements of product flow. If they worked faster, they would have more waiting time.

Comparative performance of the SKH&S(A&B) models and their crews are shown graphically in Figure 3. Though individual working times varied for models A and B in 1979, there was little difference in the total operating times per unit of product. Both models A and B were more productive than their 1978 predecessors. Use of the 1978 SKH&S machine following one hand picking revealed the disadvantage of 6.41 (4.47 + 1.94) man-minutes per 45.36 kg (cwt) of production compared to the 4.91 (3.35 + 1.56) man-minutes needed when the same machine was used before any hand picking.

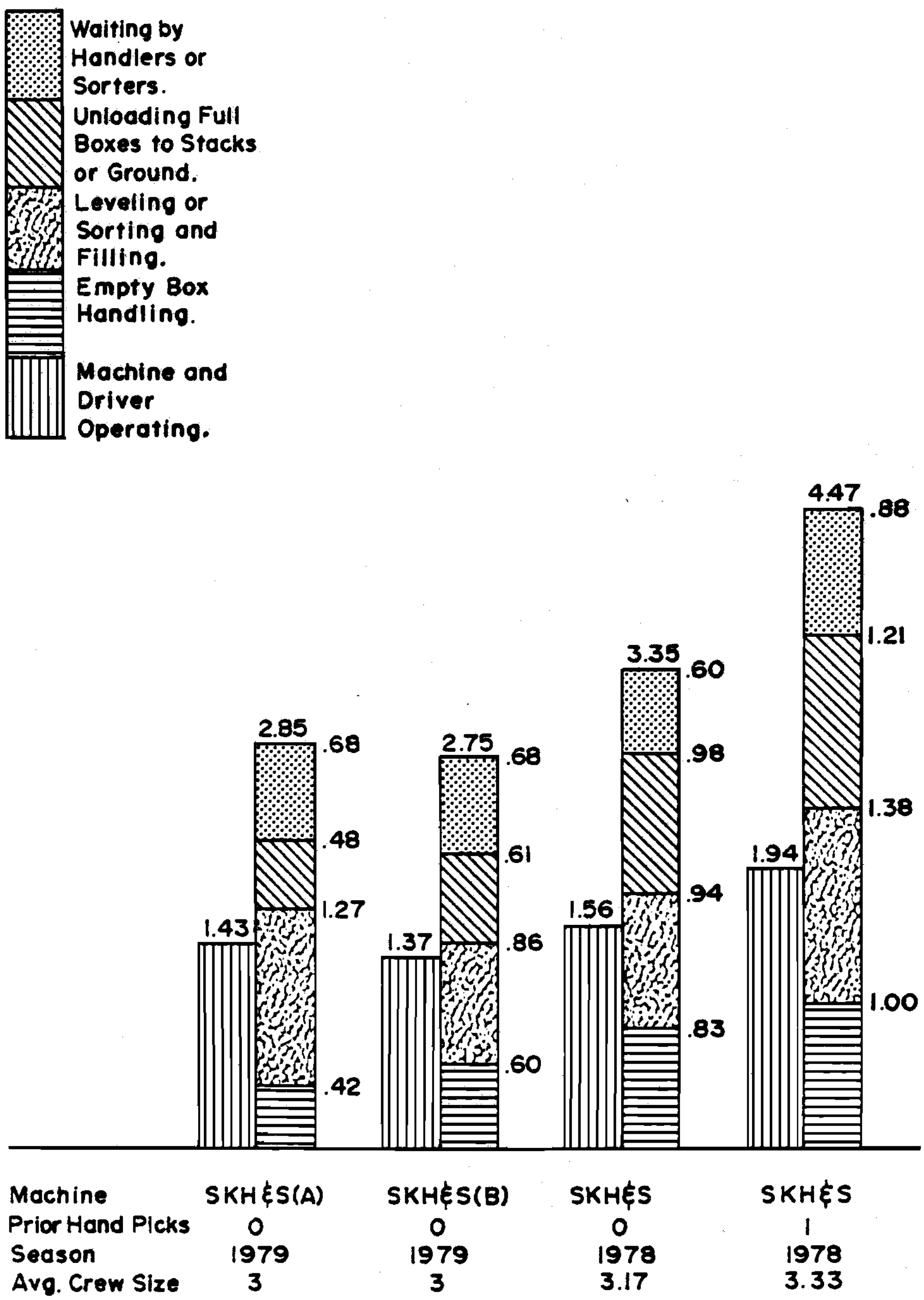

Figure 3. Comparative performance of several SKH&S strawberry harvesters. Average times are in machine- or man-minutes per 45.36 kg (cwt) of gross raw product harvested. The activity of operators, other than the driver, is divided into four work elements.

Production rates of the OSU machine in Figure 4 show work-activity trends similar to those for the SKH&S machines. In this case, there is a dramatic advantage favoring the 1979 OSU machine.

A fair comparison between the BEI machine and the other harvesters was not possible because of the extreme differences in conditions that influenced working methods and production. Two limited but unique situations with respect to crew size are demonstrated by the production rates for the BEI harvester (Figure 5).

The bar chart on the left side (Fig. 5) was derived from studies in which the machine was used following two hand pickings. The quantity of fruit salvage was very low, hence only one crew member in addition to the driver was required for handling tote boxes. In this instance, the bars for the machine-driver and man at the filler are equal at 7.72 minutes per 45.36 kg (cwt).

The chart at the right in Figure 5 shows the impact of having a large number of workers sorting at the filler end of the machine. In this instance there were 3.45 man-minutes of waiting time, which was greater than the machine running time of 2.69 minutes per 45.36 kg (cwt). This relationship shows that one person could have been eliminated at the filler end without changing the workload of the remaining workers.

Environmental conditions

Hand picking often occurs in a tranquil, pleasant area where pickers only need some tolerance for sticky hands, soiled clothes, weather variables, stiff legs, and a bit of boredom. In contrast, machine harvesting substitutes vibration, particulate matter in the air, and noise.

Vibration was not measured, but it was very evident on the SKH&S and BEI machines that carried the workers. Persons in a seated position, equipment drivers in this case, are more subject to vibration discomfort and physical harm than those that are standing (4). Adverse physiological effects can be experienced that do not become apparent until long after exposure.

No measurement was made of the dust and vegetation exhausted by fans that supplied air to separate foreign materials from strawberries moving through the machine. When not properly directed away from the machine (as was often observed), these particles proved to be an eye, nose, and throat irritant to workers and added gritty material to berries in exposed tote boxes.

Noise deserves serious attention by machine builders, owners, and users. The racket made by machines is more than a cure for tranquility. It can permanently damage hearing ability, it interferes with worker performance, it can be measured, and it is subject to regulation.

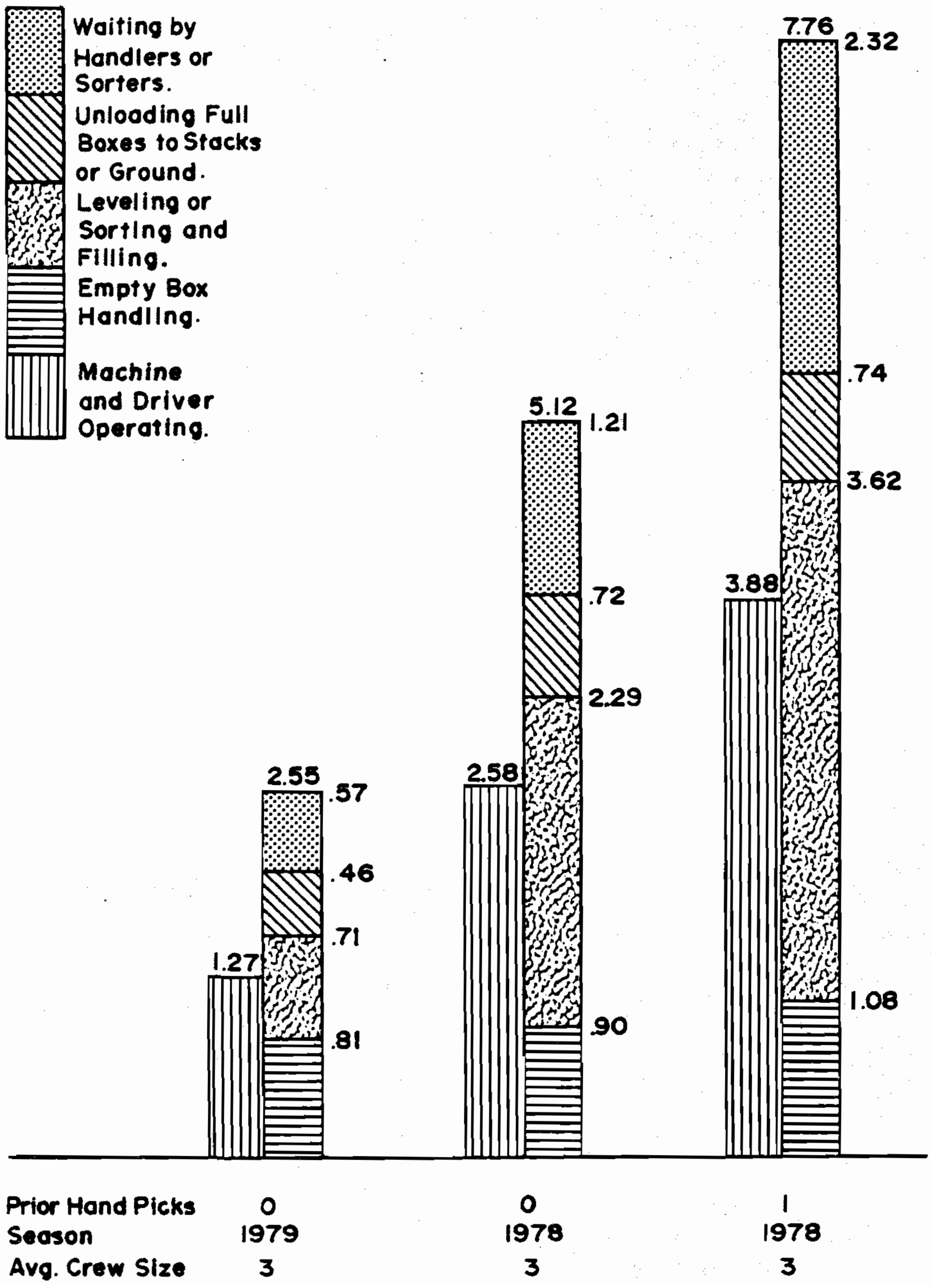

Figure 4. Comparative performance of 1978 and 1979 models of the OSU strawberry harvester. Average times are in machine- or man-minutes per 45.36 kg (cwt) of gross raw product harvested. The activity of operators, other than the driver, is divided into four work elements.

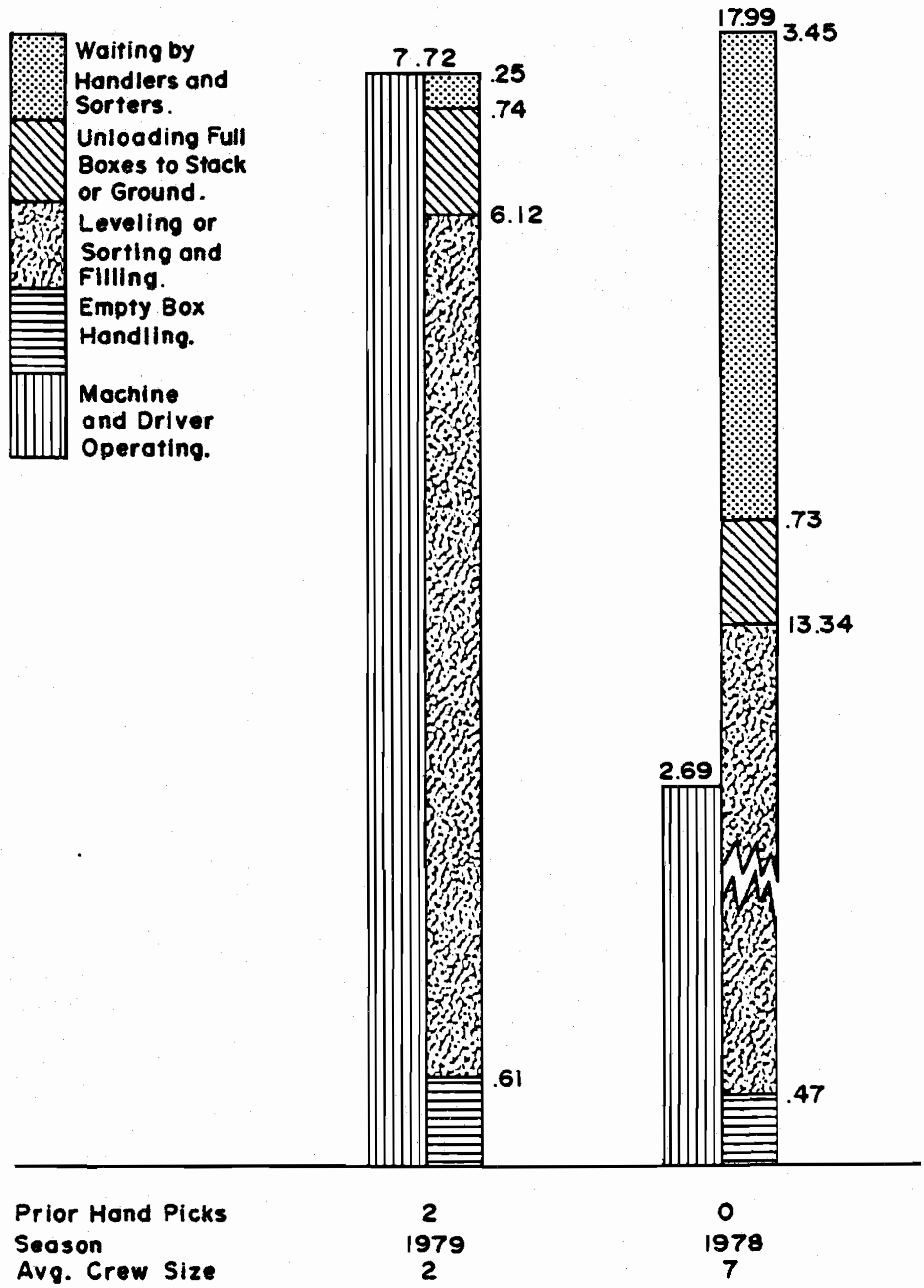

Figure 5. Performance of the BEI strawberry harvester. Average times are in machine- or man-minutes per 45.36 kg (cwt) of gross raw product harvested. The activity of the operator(s) other than the driver is divided into four work elements. Note the scale of the box filling element is broken for the 1978 test result.

Recognition of noise control is summarized in the quotation, "Noise generation and penetration shall be controlled to the extent that acoustic energy will not cause personal injury, interfere with voice or any other communication, cause fatigue, or in any other way degrade overall system effectiveness."(2)

The guideline for exposure to noise is generally considered to be the federal Walsh-Healy Act. Exposure of humans to noise, as set by this directive, must not exceed 90 dBA or its equivalent for a continuous period of more than 8 hours per day.

Noise levels of the three machines were measured at the filler station occupied by workers. In addition, measurements were made at the driver's position on the BEI machine. Results of the noise level values taken at 10 octave band centers between 31.5 and 16,000 cycles per second are recorded in Table 3. Included in the table for comparison is the 90 dBA equivalent sound at 7 octave bands between 125 and 8,000 cycles per second. Sound levels for the machines are shown for the 1978 and 1979 tests. Differences in results for the two years may be caused by design changes or variations in operating or field conditions.

Table 3. Sound levels in decibels for three mechanical strawberry harvesters compared to an equivalent sound of 90 dBA, 1978 and 1979[a]

Octave band center cycles/sec. hertz	Equivalent sound 90 dBA	SKH&S		OSU		BEI		
		78 Filler	79 Filler	78 Filler	79 Filler	78 Filler	79 Driver	79 Filler
31.5	--	83	78	85	86	90	89	72
63	--	93	88	87	89	93	100	95
125	103	104*	97	101	97	97	101	104*
250	96	92	98*	91	93	92	98*	102*
500	91	90	89	94	90	93*	92*	89
1000	88	87	85	83	87	93*	92*	86
2000	86	83	84	75	84	95*	92*	86*
4000	86	81	76	74	82	87*	86*	82
8000	88	76	68	68	80	84	80	72
16000	--	67	58	61	75	66	61	61

[a]Operator exposure to the 90 dBA sound level should not exceed 8 hours per day without some form of noise control. Numbers with an asterisk indicate decibel levels equal to, or above, the equivalent sound of 90 dBA.

Only the OSU machine was consistently below the 90 dBA equivalent sound level. Noise of the SKH&S machines is graphically related in Figure 6. In both 1978 and 1979, these machines just exceeded the 90 dBA level at lower frequencies.

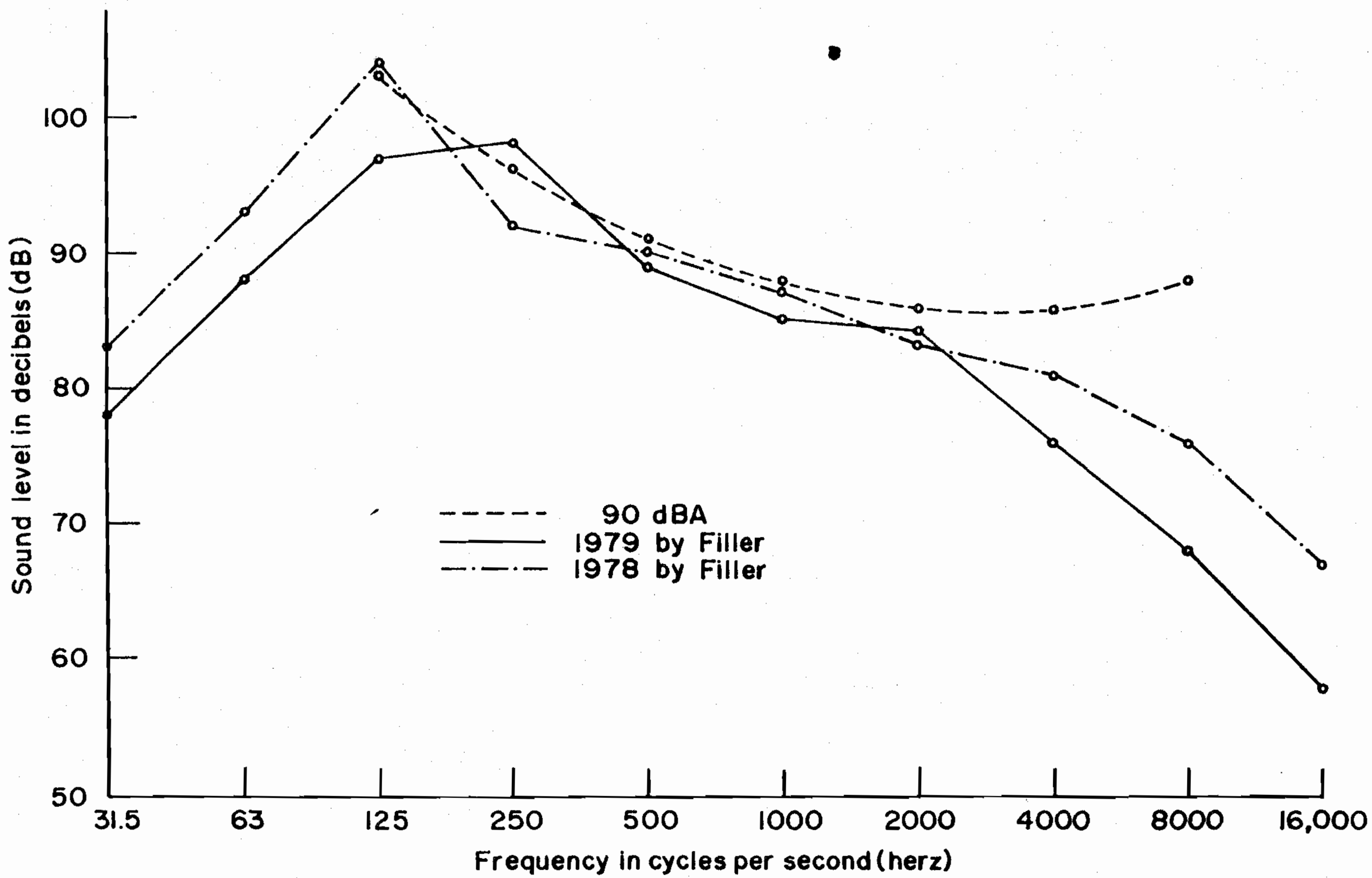

Figure 6. Operating sound levels of two models of SKH&S strawberry harvesters compared to a 90 dBA equivalent sound.

During both seasons the BEI had noise levels that were substantially above the recommended limit. Noise generation by the BEI machine was understandably related to its being a self-propelled, double-row harvester. These capabilities required a large engine and the added sound from dual conveyor systems and fans. Wearing sound-suppressing equipment would be essential to all personnel working with the BEI harvester for 9 hours within a day. Without protection, exposure to the operating machine should not exceed 4 hours per day. This reduction of working time would respond to an additional standard stating that, for each 5 dB sound level above 90 dBA, the worker exposure time should be rediced by one-half from the base 8 hours.

Decibel readings for the tractor drivers of the OSU and SKH&S machines were in the eighties but below the critical 90 dBA.

CONCLUSIONS AND RECOMMENDATIONS

Measurement of the productivity and labor requirements of machines tested in harvesting strawberries has provided information needed in managing mechanized harvesting systems. In parallel, a portion of the data essential to the economic cost analysis of mechanical harvesting addressed by C. S. Kim and others has been derived from the study.

Experience with the strawberry harvesting project has generated the following suggestions that may lead to future improvement in mechanized harvesting:

1. Provide full machine maintenance before the season starts and establish sources of service and supplies in case they are needed during harvesting.
2. Inspect machines for service needs following each day of use.
3. Plan crop production practices to spread the maturing of fruit, as nature permits, over the duration of the harvesting season. The economic goal is to obtain as much grade 1 fruit as possible within a high level of usable strawberries.
4. To the extent controllable, avoid having fields too wet or dry.
5. Remove obstructions such as trays, stakes, and irrigation equipment from the field.
6. Prepare smooth fields to minimize vertical movement of the harvester. Such movement can cause overcutting and undercutting of the plant crowns and possibly damage harvested fruit being carried on the machine.
7. Balance the filler crew to match current operating conditions and flow of product.
8. Consider the use of roller conveyors to reduce operator handling of tote boxes.
9. Arrange the field layout to permit quick turns of the machine at the ends of rows.

10. Quickly haul harvested fruit, some of which is severely damaged, to the processor to avoid further deterioration.

11. Convert harvesters to carry and fill bulk bins, thus eliminating one and, in some operations, possibly two workers at the output end of the machine.

Following are potential adjustments in mechanical facilities directed at improving the environment for operators. Some of the modifications, also, may indirectly benefit production:

1. Provide durable vibration and shock-resistant seating at locations where operator is normally seated.

2. Place a mowing device ahead of the cutter to remove some upper foliage on the plants to (a) reduce vegetation exhausted from air chutes, hence reducing irritation to workers, (b) increase the proportion of fruit in the raw material, (c) diminish the plugging of conveyors and air plenums, and (d) possibly permit faster running speeds.

3. Reduce noise through the use of efficient engine mufflers, vibration-absorbing mountings, balanced rotating parts, and dampening materials or stiffeners applied to metal shrouds.

4. Protect workers by supplying noise attenuation equipment.

5. Improve safety and reduce delays caused by poor communication by installing a visual or audio signal system between the filling station and the driver.

Acknowledgments. Contributions of the Department of Agricultural and Resource Economics, Oregon State University, in evaluating the use of mechanical harvesting of Oregon strawberries were coordinated with and interdependent upon parallel research of other groups. Within the University these included staff and facilities at the North Willamette Experiment Station and researchers in the departments of Food Science and Technology and Agricultural Engineering. Equally involved were equipment manufacturers noted earlier, several private growers, and two processing plants--Stayton Canning Co. (a cooperative at Stayton, Oregon) and Clermont West, Inc., Hillsboro, Oregon.

A grant fundamental to the two-year project was made by the Pacific Northwest Regional Commission and administered for the Oregon Strawberry Commission by Oregon State University.

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CONSUMER ACCEPTANCE OF MECHANICALLY HARVESTED STRAWBERRIES

Janette Riley

Summary. The results of the testing of each sample group bore remarkable similarity to each other. In a sample of 104 people tasting 'Olympus' berries, 46 people tasting (or 44.2%) preferred the mechanically harvested berries, 47 (45.2%) chosed hand-picked berries, and 11 samplers (10.5%) found no difference. Of the 105 people who sampled the 'Benton' variety, 41 (39.3%) preferred the mechanically harvested berries, 50 (47.4%) preferred hand-picked ones, and 14 (13.3%) had no preference.

INTRODUCTION

This survey evaluates consumer acceptance of mechanically harvested strawberries. The tasting was done for Pacific Northwest Regional Commission, Project No. 842.

The test berries were identified as mechanically harvested and the control berries were hand picked. Processed strawberries were used in the sampling. The berries were sliced, sugared, and frozen in 10-ounce packages. Two varieties--'Olympus' and 'Benton'--were tasted. George Varseveld, Department of Food Science and Technology, Oregon State University, isolated and marked the test berries, as well as the control berries, and held them in a walk-in freezer until they were needed. Slightly over 100 consumers tasted each variety of berry, making a total of 200 tests.

The goal of the consumer advisor was to reach the "grass roots" consumer in a relaxed setting. Consumers were contacted through Fred Meyer luncheons. Strawberry tasting was set up prior to the luncheon and was available after the meal. Through this method, testing was conducted at Trinity Lutheran Church in Silverton, the Methodist Church in Wilsonville, and Loaves and Fishes in Portland. Another church group in Tigard (Southwest Church of Christ) rounded out the total 200+ sample. The participants were made up of approximately 70% women, 25% men, and 5% children.

The survey seemed to add a festive air to the proceedings. One lady remarked, "This is just like TV"; a child asked, "Where's the TV camera?" An older lady in Silverton said, "You couldn't find people who know strawberries better than residents of Silverton."

METHODS AND MATERIALS

The 2-ounce souffle cups containing the different strawberry samples were marked by a random numbering system. Two cups were placed on each taster's questionnaire, and the test samples were alternated between the right or left position of the control samples. Because of this and the excellent random numbering system, even the administrators of the test did not know which cup was test or control without looking at the master sheet.

Expanded statistical tables for estimating significance in paired-preference were used from the Journal of Food Science, volume 43 (1978), to examine statistical preference.

The questionnaire simply asked, "Which product do you like best and why?" Reasons for liking the product were not included, so "programming an answer" could not take place.

Additional information was requested on the questionnaire because it could be of interest to industry and the Strawberry Commission. Many people declined to answer the questions, but the information we did receive was passed on.

RESULTS

'Olympus' strawberries

The following are the results for the taste test of 'Olympus' strawberries. The total number of people sampling the berries was 104.

Question 1: Please taste each sample of frozen strawberries and then check which sample you prefer.

	Total	Silverton	Wilsonville
Mechanically harvested	46(44.5%)	27	19
Hand picked	47(45.1%)	31	16
No difference	11(10.4%)	5	6

Why do you prefer the one you have chosen?

Of the people tested, 44.5% showed a preference for mechanically harvested berries. The following are their reasons for that choice:

Primary reasons	Total	Silverton	Wilsonville
Sweeter	8	2	6
Not as sweet	7	2	5
Fresher taste	7	5	2
Color	2	2	0
Appearance	1	1	0
Texture	3	3	0
Flavor	6	6	0
No reason	8	6	2
Less acid taste	1	0	1
More natural taste	1	0	1
Firmer	2	0	2

Secondary reasons	Total	Silverton	Wilsonville
Not as sweet	1	1	0
Flavor	1	1	0
Texture	5	5	0
Fresher taste	1	1	0
Sweeter	4	2	2
Not as firm	1	0	1

Of the people tested, 45.1% showed a preference for hand-picked berries. The following are their reasons for that choice:

Primary reasons	Total	Silverton	Wilsonville
Sweeter	16	13	3
Not as sweet	7	5	2
Fresher taste	4	3	1
Riper	1	1	0
Flavor	8	5	3
Eye appeal	1	1	0
No reason	8	4	4
No aftertaste	1	0	1
More natural	1	0	1
Secondary reasons			
Firmer	1	1	0
Fresher taste	1	1	0
Flavor	1	1	0

Question 2: I usually purchase frozen strawberries (check one):

	Total	Silverton	Wilsonville
10 oz. sliced, sweetened	33	16	17
16 oz. whole, unsweetened	13	9	4
16 oz. sliced, sweetened	8	3	5
20 oz. whole, unsweetened	6	4	2

Question 3: When I purchase frozen strawberries, I am most influenced by:

	Total	Silverton	Wilsonville
Flavor	43	17	26
Price	24	11	13
Nutritional value	10	5	5
Sweetness	10	6	4
Convenience of serving	12	9	3
Available brand	1	0	1

Question 4: Please indicate how often you serve frozen strawberries:

	Total	Silverton	Wilsonville
Very often	4	3	1
Often	8	3	5
Moderately	33	18	15
Seldom	28	11	17
Never	8	1	7

If you checked "never," do you have a particular reason?

	Total	Silverton	Wilsonville
Cost	1	0	1
Freeze my own	9	9	0
Family doesn't like them	2	0	2
Diabetic	1	0	1

'Benton' strawberries

The following are the results for the taste test of 'Benton' strawberries. The total number of people sampling the berries was 105.

Question 1: Please taste each sample of frozen strawberries and then check which sample you prefer.

	Total	Portland	Tigard
Mechanically harvested	41 (39.3%)	27	14
Hand picked	50 (47.5%)	19	31
No difference	14 (13.3%)	6	8

Why do you prefer the one you have chosen?

Of the people tested, 39.3% showed a preference for mechanically harvested 'Benton' berries. The following are their reasons for that choice:

Primary reasons	Total	Portland	Tigard
Color	2	2	0
More natural taste	3	3	0
Appearance	1	1	0
Greens on berries	1	0	1
Fresher taste	10	3	7
Less sweet	12	11	1
Sweeter	2	2	0

Secondary reasons	Total	Portland	Tigard
Fresher taste	2	2	0
Lighter color	2	2	0
Texture	2	2	0

Of the people tested, 47.5% showed a preference for hand-picked 'Benton' berries. The following are their reasons for that choice:

Primary reasons	Total	Portland	Tigard
Not as sweet	6	5	1
Sweeter	13	3	10
Riper	1	0	1
Color	2	0	2
Better texture	6	1	5
Fresher taste	4	2	2

Question 2: I usually purchase frozen strawberries (check one):

	Total	Portland	Tigard
10 oz. sliced, sweetened	22	16	6
16 oz. whole, unsweetened	14	10	4
Freeze my own	9	8	1
16 oz. whole, sweetened	6	5	1
20 oz. whole, unsweetened	7	4	3
Other	1		

Question 3: When I purchase frozen strawberries, I am most influenced by:

	Total	Portland	Tigard
Flavor	30	19	11
Price	16	12	4
Nutritional value	10	6	4
Sweetness	9	7	2
Convenience of serving	15	10	5
Lack of preservatives	1		

Question 4: Please indicate how often you serve frozen strawberries:

	Total	Portland	Tigard
Very often	5	1	4
Often	6	1	5
Moderately	29	9	20
Seldom	24	10	14
Never	2	1	1

If you checked "never," do you have a particular reason?

	Total	Portland	Tigard
Too expensive	1	0	1
Freeze my own	1	0	1

DISCUSSION

There were two formal taste tests involving 'Olympus' strawberries, and one informal sampling. In none of these was there any significant preference expressed by the taster. In one of the formal tests, the difference in preference was only four, while in the other test it was three. In the informal sampling situation, the results were evenly divided. When combined, the two formal tests revealed a test preference (mechanically harvested) of 46 and a control preference of 47. In no way could any of these results be interpreted as significant preference indications. Furthermore, when asked why they preferred one sample to another, eight tasters said the preferred berry was sweeter, while seven stated that the preferred berry was not as sweet as the other sample berry. Obviously, consumers will not express a definite preference for either mechanically harvested or hand-picked 'Olympus' berries.

The results of the test using 'Benton' variety strawberries varied somewhat from the 'Olympus' tests. Again, there were two formal consumer tests; the results were very definite, but, interestingly, exactly opposite each other. In one test, consumers chose test berries, 27 to 19. In the second sample test, however, the results overwhelmingly favored control berries, 31 to 19. Consequently, the final conclusion would agree with that of the 'Olympus' berries: Consumers will not exhibit a preference for either test or control berries overall.

Acknowledgments. To Lloyd Martin, the Project Coordinator, and Bob Brown, the Project Manager, for guiding me. To George Varseveld for keeping the berries "safe"; to Lois McGill who shared her expertise. To Fred Meyer, Inc., for allowing us to attend their functions to get to the consumer, and to the participants who accepted this occasion for what it was--history in the making.

GROWER EVALUATION OF STRAWBERRY MECHANIZATION

Lloyd Duyck, Eugene Ashcraft,
Jim Fujii, and Joe Brooks

Panel 1

Lloyd Duyck

We started producing strawberries in 1953 with 7 acres; we had no harvest problems that year. Later we learned that the only reason we didn't have any harvest problems was because we didn't have any fruit that first year. From 1953 to 1960, we increased our planting to 130 acres. To handle this increased acreage, we ran 15 labor buses and went as far as Portland (30 miles) to get labor, which consisted entirely of kids. In 1960, we began to notice a decline in the output from this labor source. For example, one day we only averaged 1,400 pounds of berries per busload of kids. Because of this problem, we began to investigate the possibility of using migrant labor and built our first migrant labor camp. This camp worked well and we built a second camp 2 years later. The additional labor camp allowed us to phase out most of the unreliable local help, and migrant labor was adequate until about 1973. At that time, we decided to reduce our strawberry production to 80 acres, with the intention of phasing out all production at Lloy-Dene Farms. We decided there was still profit to be made with strawberries, since we could produce a high-quality berry that was in demand by our processing industry in Oregon. Our thoughts were that we could increase efficiency and production by using new and innovative production methods. In 1975, I went to California to observe cultural systems with machine harvesting in mind. I realized very early that it would be impossible for us to machine harvest without modifying our cultural methods. In 1976, I learned of the Arkansas research and we tested their single-row machine that year. In 1977, I went to Arkansas to observe their bed shaping, cultural systems, and harvesting operations. Later that same year, I went to Michigan during their harvest season and observed four different harvesters. After these trips, I was convinced I could produce berries for machine harvesting. With mechanical harvesting in mind, I built bed shapers and additional equipment necessary for mechanization and we planted with machine marvesting in mind.

After observing harvesters operating in Arkansas and Michigan, we decided on the U of A-BEI harvester because I felt that of the harvesters observed, it would adapt best under our conditions. We purchased a 2-row BEI harvester in 1978. We also selected this harvester because it would harvest wide rows and had high picking efficiency. We established our rows on a raised bed with a fruiting surface 2 feet wide; however, a few berries that hung off the edge of our high bed were missed by the harvester. I've now adapted our harvester so that the fruit hanging on the sides of the bed can be collected. Our plans for 1980 are to harvest up to 50 acres with this machine, and our fruit will be sold to Clermont West. In our original test, we had a reserach model of the U of A-BEI cleaning line installed in the Clermont West plant. They did not have time to properly handle our machine-harvested fruit along with their existing hand-picked fruit. In 1979, in cooperation with Clermont West, we set up the cleaning and sorting equipment on my farm. Last year, after three hand pickings, we harvested 5 to 6 acres with the machine, and in another test we machine picked after two hand pickings. We have decided, because of excessive rot after three hand pickings, that we probably will not wait for a third hand picking before we machine harvest in 1980.

Question: Will you continue to use both machine and hand harvesting?

Answer: Yes. For us, hand picking will still be around for the next 5 to 10 years before we see a complete changeover to the machine. I would hope the change would be sooner, but realistically it will take this length of time to develop the inplant equipment. We intend to use hand labor supported by a machine.

Question: What percentage of hand picking as compared to the machine do you plan?

Answer: We are going to lose one of our migrant labor camps because the town is growing rapidly in our direction and I am not going to replace it, so I am estimating about 60 to 70 percent of the crop will be hand picked and the balance machine harvested.

Question: How many pickers do you employ in a normal season?

Answer: Currently, we are down to about 250, but we have used as many as 800 in the past--mostly kids, and it was a nightmare. We totally use migrant labor now for picking. We plan to cut down our labor requirement to about 200 pickers in the future.

Question: You are not in complete agreement with the newspaper editorial that was previously read regarding the fact that strawberry mechanization would put a lot of the younger children out of part-time work, are you?

Answer: I would love to work with young people, but our federal government and state laws don't allow it. Unfortunately, I don't see any reason why these young people shouldn't be working in the fields. We have employed a lot of them in the past, but there are many that we can't employ now because of the law requiring pickers to be at least 12 years old. I personally believe that it won't be long until the age limit is 16. A 12-year-old child is limited to about 5 hours of work per day. Bus-scheduling problems develop with the 14- or 16-year-olds riding on the same bus who want to work for 7½ hours. It becomes difficult to manage these situations. Other problems involve distance from home and the number of days a picker is employed in agriculture with regard to the applicability of the minimum wage laws. Once they reach 16 or 17, most teenagers want jobs other than picking. But we still use about 100 teenagers around the farm doing various jobs other than picking.

Question: What is the difference in efficiency between the local kids and migrant workers?

Answer: The difference is tremendous today, about 5 to 1. This was not true 10 years ago. The picking efficiency of kids is progressively getting worse. However, the kids are good at other jobs; the older kids are used on machines and picking equipment where this is legal. These kids do a good job, and I do not want to "downgrade" kids. It is just when we collect a sufficient volume of these kids to harvest our acreage, we are not finding the same efficiency that we did 10 years ago.

Question: What are your major problems with migrant labor?

Answer: We're having a lot of problems, and some of these are with OSHA. Furnishing housing is affected by numerous laws and regulations. Another problem is minimum wage laws on piecework. There are a number of lawsuits in our area of Oregon now involving minimum wage on harvest work. So far we have not had this problem. Some people will take advantage of the situation if they know they can get $3 or more per hour without working. In situations like this you may be paying a person $3 an hour while he only picked $.50 worth of fruit per hour. On the other hand, another worker may be earning $10 per hour. I don't know if we will continue with hand picking under these conditions. A farmer cannot afford to pay a person who doesn't pick enough berries.

Question: Are you paying all your hand pickers for piecework?

Answer: Yes. All picking is done on a piecework basis and all other labor is on an hourly or salary basis.

Question: In California it has been our experience in other commodities that mechanization has not been related to labor cost (currently about $5/hour plus $1.50/hour fringe benefits), but that mechanization has been related to an absence of labor. I get the impression that you, as a strawberry grower, look at this from a different viewpoint. Is this a correct assumption?

Answer: I think there will be an insufficient labor supply in Oregon in a very short time. A number of labor camps are closing in our area because growers are not putting forth sufficient effort to recruit labor to fill these camps. This is probably the reason I have been able to fill my labor camp for this long, but the situation is coming to an end fast. Migrant labor is not as stable as it once was, and you are never sure of the amount of help that you will have from day to day.

Question: What are your primary varieties of strawberries?

Answer: I'm currently producing 5 varieties: 'Linn,' 'Hood,' 'Benton,' 'Shuksan,' and 'Olympus.' I plan to stay with 'Benton' and 'Hood' in the next plantings.

Question: Does it cost more to produce strawberries for mechanical harvesting?

Answer: It cost quite a bit more to build equipment for the first year, but not as much in the following years. We have gone to a no-tillage system and have fields that have not been cultivated since we started our mechanization program. Our costs, therefore, were less in following years as a result of no-tillage. Probably the overall cost is the same as before mechanization.

Question: What is the average lifespan of a strawberry planting in Oregon?

Answer: We try to keep them in production for 2 to 3 years. However, some fields are kept in production 4 to 5 years.

Eugene Ashcraft

Labor problems were our reason for considering going to a mechanical harvest of strawberries. In 1976, we began working with both the CML and BEI harvesting systems on a 5-acre plot. Based on these tests, we purchased a 2-row BEI unit in 1977. We ran this harvester over 15 acres, including older plantings that had been hand picked only once prior to machine harvest and fields where the machine was used as a "clean-up" operation. In 1978 and 1979 we went over 30 acres with the harvester. In the older fields we didn't hand pick before machine harvesting, while in the other fields the harvester was again used as a "clean-up" operation.

We had reached the point with our labor supply where we needed to reduce our acreage by one-half to two-thirds; however, with the machine we have been able to maintain our 30 to 40-acre plantings and reduce our crew size. As a result, the efficiency of the hand-picking crew increased. With the machine, we have harvested two to three times as many berries as the crew could possibly have picked. Before the machine harvest, the crew can pick the largest, easiest to pick berries without having to hunt for fruit--a situation which they like. When the crew gets behind, we start the machine. This system has worked quite well, and we have a good working relationship with our hand-picking crew.

Our yields from the clean-up operations have varied from 1,000 pounds/acre to 5 tons/acre field weight.

Question: Are you going to continue to use hand labor in the future?

Answer: Yes. I don't know how long we will be able to continue to have a crew. I would hope for the next 2 or 3 years at least.

Question: Are you doing any on-farm cleaning or processing of your own fruit?

Answer: No. Our fruit goes to Smeltzer Orchard Company at Frankfort, Michigan. On-farm clean-up may be a future possibility, but I would prefer not to be involved in any of the processing operations.

Question: What are your primary varieties?

Answer: 'Midway' is the major variety, and we are looking at 2 acres of 'Holiday.' We are in need of some varieties for machine harvesting.

Question: Has machine harvesting cost you more to grow your berries with regard to cultural systems than for hand harvesting?

Answer: I wouldn't say it cost us more. We have dropped some old cultural practices and added some new ones. There's been no overall cost increase.

Jim Fujii

I've been in the strawberry industry in some capacity since about 1930. Today, my production is as large as it has ever been--180 acres. I hand harvest all the fruit crops that I grow. To have hand labor available later in the season for my blackberry and raspberry operations, I need this large an acreage of strawberries. However, from this series of meetings I can see where I, too, will one day be machine harvesting strawberries. It is really the only way to go in the future.

We do need new varieties, especially ones that will cap easily. I have been a big advocate of saying that an efficient capper is essential to the success of strawberry harvest mechanization. With the research that is going on to develop a capper, one day soon we'll have one that will work in volume.

Basically, I feel that the air-type harvesters that collect all of the fruit are going to work. In the past, there has been skepticism with regard to mechanization of crops such as blackberries and raspberries, but these harvesters have worked after adapting cultural practices.

I am not in a big hurry to get into strawberry harvest mechanization because Smucker's, the processor that buys all of my fruit, is still leery of some of the problems regarding the in-plant equipment required for machine-harvested strawberries.

With regard to strawberry varieties, I once primarily grew 'Hood,' but I had a problem with winter hardiness one year and lost most of my crop. Now I grow 'Benton,' 'Olympus,' 'Totem,' 'Tioga,' and 'Linn.'

Troutdale has very severe winters. 'Benton,' 'Olympus,' 'Tioga,' and 'Linn' have been much more cold hardy, and I have not had to hill for protection. With these varieties and a level bed, I should be able to start strawberry mechanization relatively easy as soon as my processor is ready.

Question: Where do you get your berry pickers?

Answer: We have a somewhat better situation with regard to labor than Lloyd Duyck does. We recruit about 500 to 600 kids and use some migrant labor. We pay $.10/pound to pick, and our overhead costs for bringing pickers to the field and supervising them are around $.10/pound. The good migrant picker requires about $.03/pound in overhead cost and we get more fruit harvested.

Question: You mentioned the reluctance of your processor to accept mechanically harvested strawberries. I would like to comment that there have been some conflicts in the minds of processors in the Northwest as to how they can stay in a market that has become steadily more competitive. The Northwest processors have felt they could remain in the market because of the good quality of their fruit. Mechanical harvesting did not appeal to some processors because they felt it would not maintain this image of high-quality fruit. However, perhaps they are changing their viewpoint since the demands are changing. I think we are seeing now that it is possible to maintain quality and machine harvest. Would you respond to these comments?

Answer: In the blackberry and raspberry industry, the processors did not resist mechanization because they did not have to change their in-plant equipment. Strawberry mechanization will require the processors to retool to handle the machine-harvested fruit, and this will be expensive. The processors must be certain there will be a sufficient volume of machine-harvested strawberries available to justify the expense of installing this in-plant equipment.

Another factor is that the strawberry processors realize the strawberry acreage is declining. I would think they would be reluctant to install new in-plant equipment if they felt the industry might be dying. Mechanization could turn this situation around.

Joe Brooks

We are in the green bean business and are considering diversifying into the small fruit business.

I have had an opportunity to follow the experimental and commercial development of the strawberry harvester, and I can still see the need for further refinements to make the total system work. Economical capping is currently the major bottleneck in getting the whole and sliced berry pack market into the mechanization picture. Processors need to upgrade their in-plant equipment. This should be accomplished within the next 5 years. We need more cultivars suitable for machine harvest and we need to increase once-over yields to make the system economically feasible. Since the equipment for mechanization would require a considerable investment by an individual grower, the economic feasibility of purchasing an expensive harvester that would be required for only 2 to 3 weeks' work could be difficult to justify. There may be a possibility, as with our green bean harvest system, to mobilize the cleaning systems as well as the strawberry harvester. This would allow these units to be used in several different areas which would encompass several growing seasons within one year.

I believe that hand labor in the strawberry industry will be replaced by machine harvesting because of difficulties in labor management as well as increased government regulations. However, you also have to consider the economics of machine harvesting. The growers have to make a return on their plantings and machinery investments, and the processors have to receive a monetary return as well.

For the future of the processing market, growers and processors will be forced to use mechanization in strawberry production, harvesting, handling, and utilization. As a part of this approach, we need to educate the public that the time for mechanization has arrived for the consumers' benefit as well as industry's benefit.

PROCESSOR EVALUATION OF STRAWBERRY MECHANIZATION

Courtney Lasalle, Dave Gross, Dwayne Heikes
and Jim Brian, Jr.

Panel 2

Courtney Lasalle

I would like to discuss how Clermont West became involved in mechanical harvesting of strawberries. In November of 1975, the owner and general manager of our company, Henry Abrahams, went to a National Preservers meeting in Colorado Springs. Upon his return from the meeting, we had a long discussion about a paper presented at the meeting by Justin Morris on the University of Arkansas-Blueberry Equipment, Inc. mechanical strawberry harvesting system. We felt that we might benefit from mechanical harvesting quicker than packers who were packing IQF, sliced, and whole sugared berries because we are strictly in the juice, pulp, and concentrated juice and pulp business.

We arranged a meeting with Justin Morris (University of Arkansas), Al Patzlaff (BEI, South Haven, MI), and Lloyd Duycks (Lloy-Dene Farms, Cornelius, OR) during the Oregon Horticultural Society meeting in January 1976. At this meeting we designed a pilot plant study in our processing plant to run machine-harvested fruit in 1976. Three acres of strawberries (2 of 'Hood,' 1/2 of 'Shuksan,' and 1/2 of 'Olympus') were set aside at Lloy-Dene farms for machine harvesting. This project also involved the cooperation of Lloyd Martin at the North Willamette Experiment Station. Similar efforts with Jim Fujii (Jim Fujii Farms, Troutdale, OR) and the J. M. Smucker Company at Woodburn were initiatied. We set up an in-plant cleaning line in our plant for handling the machine-harvested berries. The line consisted of a square-type whirlpool washer, a McLaughlin-type vibrating washer, a U of A-BEI trash removed, and an inspection belt. The berries were passed over the line and placed in barrels for freezing until they could be processed. We handled about 9,300 pounds of product over the line. We suggested that the friction-driven trash eliminator be redesigned to handle greater amounts of foliage.

The coordinators of the 1976 project felt that it would be best to spend their time and efforts in 1977 on travel to see harvesting systems working in other areas. Lloyd Duyck and I came to the University of Arkansas to observe their production, harvesting, handling, and utilization work. Lloyd Duyck went on to observe commercial operations in Michigan.

When Lloyd Martin received financing on his proposal to the Northwest Regional Strawberry Commission for a field scale technical and economic evaluation of mechanical strawberry harvesting and subsequent handling and processing, we became one of the cooperators along with Stayton Canning Co., BEI, SKH&S, and numerous growers.

We worked with Lloyd Duyck and eventually he purchased a 2-row BEI harvester. We used about the same equipment in our plant as we had used in 1976, except that BEI had redesigned the dewatering reel, trash remover, and washer. Some of the berries that we ran across the line were immediately processed into juice, while the rest were frozen in barrels for later processing. Most of the fruits were from test plots on the Lloy-Dene Farms that had been hand picked prior to the machine harvest. There were a lot of moldy berries in the late season due to fruit missed earlier by the hand pickers. Because of conflicts with other fruit crops coming into production, we abandoned the machine-harvested strawberries for that year, but we were able to handle 33,000 pounds of fruit.

The redesigned trash eliminator in 1978 had an alternating series of round, rubber-coated, and hexagonal metal rollers which were gear driven. The gears tended to get out of mesh and stripped the gears. We learned quite a lot in 1978 on how to handle machine-harvested strawberries. First, the trash eliminator needed to be redesigned. Second, the berries needed to be moved into the plant sooner and handled in the plant faster. Third, you really couldn't handle machine-harvested fruit in the plant with the amount of trash we were receiving; cleaner fruit was necessary to allow prompt processing at the plant.

In 1979, we moved the in-plant cleaning equipment to Lloyd Duyck's farm. Justin Morris helped us install the redesigned BEI trash eliminator that had soft, neoprene rubber rollers. The rollers on this unit were positively driven with a chain and were very successful in removing the trash. We only procesed about 8,000 pounds of machine-harvested berries because of an early season and late arrival of the cleaning equipment. We did confirm that it was better to have the cleaning equipment away from the processing plant. We also found it was better not to try to do any sorting on the harvester because the motion, dirt, and heat made it difficult to work. One person on the cleaning line could do a better job than three people on the harvester. Also, we confirmed that you could not machine pick a field that had been hand picked several times because moldy berries and a lack of fruit made it uneconomical.

In 1980 we plan to harvest five varieties of strawberries to help spread our harvest season. This should allow us to machine harvest 50 acres that will be hand picked once prior to the machine harvest. We feel we should be able to get 100 to 200 tons of berries through the machine. All of this fruit will be cleaned by the new on-farm cleaning line.

I think we are on the threshold of the "take-off" of strawberry mechanization. New varieties are being developed that are suited to machine harvesting. Also, the harvest season in Oregon can be spread by taking advantage of the different climatic regions--starting in the Willamette Valley floor with its adapted varieties that have a different maturity season, then moving the harvest operation up to the Silverton hills, then further up towards Mount Hood, and then to the Hood River area around Parkdale. Taking advantage of these varietal and climatic differences, we should be able to get an 8-week spread in the harvest season in Oregon.

Question: Do you feel that the juice and puree market will be "crowded" if everyone switches to machine harvesting?

Answer: I don't think everyone can go to machine harvesting with the intention of going into this market. I think cappers need to be developed to provide a complete line of products. However, the status of machine harvesting at present fits the needs of our company, and the juice and puree market is growing.

Question: Did you indicate that it would be less economical to machine pick after one hand pick?

Answer: No, I said after you finish hand picking for the season, it is not economical to try to salvage the remaining good fruit because too much fruit that has been missed by hand pickers has molded. The cost of the extra labor on the sorting line is greater than the value of the good fruit recovered.

Question: How many tons of strawberries do you run in a season at Clermont West?

Answer: We run about 1,000 tons per year.

Question: Do the caps present a problem to your operation?

Answer: No, the caps present no problem in our juice line.

Question: Many people once felt that green bean harvesting couldn't be mechanized, in Oregon; is this situation similar?

Answer: When I was working with the pole bean harvester, we never got the pole bean harvester off the ground even after spending almost a half a million dollars. One reason it didn't work was the lack of proper cleaning equipment. If the cleaning equipment we now have for bush beans had been available, we probably could have made the pole bean harvester work. I was one of the individuals who said that bush bean harvesters would never work because the harvested beans looked more like silage than processing beans. However, with improvements in the harvester, the development of in-plant cleaning equipment, and the introduction of new varieties more adaptable to mechanical harvesting, the industry very quickly switched to bush beans that were 100 percent mechanically harvested. I think the processed strawberry industry is at about the same point in development of mechanical harvest as the bean processing industry was when the first mechanical harvesters for beans were introduced. Consequently, I think the same changes will take place in the processed strawberry industry and gradually it will change to mechanically harvested fruit.

Dave Gross

I was very pleased to be invited to participate in this conference since it has provided me with the opportunity to become thoroughly acquainted with the progress that has been made in strawberry mechanization. Also, people who make preserves are not normally asked to give their opinion about the fruit they will eventually receive. The quality attributes of a strawberry are affected in many different ways during the preserving process as compared to the frozen, sliced berries.

I am not speaking for the preserve industry, although there was considerable interest in this conference at a recent preserver's meeting.

Smucker's is unique in that it is both a fruit processor and a preserver. We pack and freeze every pound of strawberries that we use in our processing plants. We market almost the same quantity of fruit in the typical frozen whole and sliced berries as we do in preserves. Also, we make puree and juice, primarily for our own use in jellies and various fillings.

We normally freeze all of our fruit in a 5+1 pack in 50-gallon steel drums. For processing, we have to thaw this fruit before blending with the rest of the sweetener and pectin. The water is evaporated to 65 percent solids at 140°F with essence recovery. Then the product has to be pasteurized at 185°F and placed in glass jars.

At this point, I would like to comment on some previous remarks by plant breeders with regard to fruit firmness. Some of this soft fruit went on through the preserving process and maintained its identity, while the firmer fruit did not. We still do not understand what contributes to final firmness in preserves. Maybe firmness losses are caused by enzyme activity or some other factor we do not yet understand. Therefore, it would be interesting to include how these fruit hold up when cooked in your varietal evaluations. Berries must be able to withstand a certain amount of abuse during heating, pumping, and filling.

In general, I think that every time mechanical harvesting of fruits and vegetables has been introduced for another crop it has met with a certain amount of resistance by the processing industry. This is because some changes in plant equipment or labor are usually required. For example, the processing of machine-harvested cane fruit required more sophisticated cleaning equipment in the plant, but did not require much more labor on the inspection lines. As a matter of fact, in many cases, machine-harvested raspberries are superior in quality to hand-picked raspberries. However, in many cases the transition from hand picking to machine picking has not been this smooth.

Processors are beginning to recognize that the development of mechanical harvesting has slowed down the ever-increasing cost of purchasing these fruits. Another important contribution of mechanical harvesting has been that fruit is still being grown in some areas where it otherwise would have been eliminated by harvest labor cost or labor availability.

I feel that strawberry mechanization presents the greatest challenge to date because of the berry's delicate nature. I see two main approaches for mechanization. The first approach would be "fully mechanical"--the immediate use of once-over harvested strawberries across a cleaning and grading line and into the juice and puree markets. Although the juice and puree market is strong, I do not feel that it can immediately absorb all of our strawberry acreage. This would result in a depression of the price for these products. Of all the strawberries that are not sold on the fresh market, and 15 percent are sold as puree and juice stock. However, this market is increasing.

I feel that the second approach (and potentially the best one) is to obtain a substantial quantity of Grade A fruit from the machine-harvested berries. I do not know what percentage of Grade A fruit would have to be separated in order to make this operation economically feasible. I feel that it would have to be much higher than indicated in some of the experiments conducted to date.

Two developments needed to achieve economical feasibility with this approach are: (1) new varieties, and (2) a machine that efficiently removes stems and caps. These developments will allow us to maintain our existing production area and should revive some of the strawberry acreage that has already gone out of production.

When our growers stop bringing us hand-picked strawberries that will grade 90 percent "Grade A" across our line, we will have an incentive to convert our plants to accommodate machine-harvested strawberries. This has already started and is one of the main reasons I am attending this meeting.

I would like to make one final comment. After the 1975 Colorado Springs Preservers meeting, I wrote to Justin Morris and told him I did not feel it would be possible to make jam that contains green fruit. It has been our opinion that the presence of any great amount of immature berries in products being crushed for puree or juice would result in lower flavor levels and a faster deterioration of the color of the final product. Because the anthocyanins in strawberries are so subject to degradation, only the large amount of pigment in the strawberry itself makes it possible to make an attractive product, even though 70 to 80 percent of the pigment may have been destroyed. If the pigment is diluted by the presence of immature fruit, the color eventually suffers. We also felt that the tannins and chlorophyll present in the immature fruit could contribute to more rapid browning which would be more visible because of the lack of true red pigment. However, the researchers at the University of Arkansas responded to my letter by starting a research program to investigate the utilization of green fruit in jam. The results of these studies were reported at this meeting and appear to have proven me wrong.

Question: As growers, we can mechanically harvest strawberries that would otherwise be left in the field. Will this amount of increase in juice and puree fruit cause the industry a problem?

Answer: I think there will be an increase in the number of products that utilize puree stock to absorb some of this extra fruit. Naturally, we do not know the extent of this market or how fast mechanization will occur.

Dwayne Heikes

I am faced with the problems of both the grower and processor. I have 100 acres of strawberries and operate my own processing plant. I depend upon kids for harvesting, and this requires about 15 buses. I also use some migrant labor. Harvest labor is our major problem.

Machine picking of strawberries is here to stay. At the present time it is a close race as to whether machine harvesting operations can be sufficiently sophisticated before there are no hand pickers available. The 5-acre growers will probably be able to continue picking fruit by hand longer than the larger growers. Granted, I would prefer to use just hand-picked fruit in my processing plant, whether it is my own fruit or fruit purchased from other growers. However, we must realize that the time has come to start making in-plant modifications that will allow us to start handling machine-harvested strawberries. The sooner we do this, the better off our industry will be. We do not want to lose our industry or the quality market we now enjoy. Ultimately, we would like to have a system that would get as much fancy fruit as possible out of a machine-harvested picking so we can continue to capture a percentage of the fancy fruit market. We have come a long way toward this objective, but I think we need a totally workable system in the immediate future. Otherwise, our industry may not survive more than 5 years.

I have a processing plant where I process the fruit that I produce, which is about one million pounds per year. I also buy about 500,000 pounds from other growers. I pack only in institutional size containers, either in a 30-pound tin or a 6½-pound No. 10 can. In the 4 years I have owned the processing plant, my philosophy has been to produce a high-quality, grade A institutional pack.

Strawberry harvest mechanization has involved a lot of work by a lot of people. To date, I have been involved little in the mechanization efforts, but I am aware of what is happening to our labor supply and realize that the day of strawberry mechanical harvesting is here. In my opinion, it will eventually prevail. Fifty percent of doing anything is getting started, and we have made a good start.

I, for one, will have to install the in-plant equipment for my own fruit as well as for fruit that I buy, whether it is hand picked or machine picked. Good equipment is available at this time, but it still needs improvement. We also need to have improved varieties. We will all have to pull together to make mechanical strawberry harvesting work. I am confident that in the near future we will be able to machine pick and process berries that are equal in quality to hand-picked fruit.

Jim Brian, Jr.

It is a pleasure to attend this conference on strawberry mechanization. I feel that the challenges of mechanization can and will be met. We can reach these goals with the incentives provided by our free enterprise system. In a free market, the price will predicate the most economical and available choice. Our future in agriculture basically depends on mechanizing to eliminate the huge cost of hand labor and the resulting economic and social problems.

Freedom and the free enterprise system do something for an individual that cannot be done in any other way. With four million free American farmers, we produce all the food we need for 220 million people plus a huge surplus for export. Only 3 percent of the earth's surface is farmed. If all of the land currently cultivated were brought up to the highest standards of efficiency achieved by American farmers, it is estimated that the world could feed 15 times today's world population. Mechanization is a part of the high efficiency achieved by the American farmer.

Strawberry mechanization is an interesting challenge; we have come a long way, but we have as far or farther to go on this project.

We are concerned with some problems in the area of strawberry mechanization that affect our company. We are processing strawberries that are picked with the U of A-BEI harvester, and we use their cleaning line. We sell puree to several companies and we also sell grade A frozen berries. In some products where the consumer does not need to see whole fruit or slices, we can use more puree. Some of the ice cream manufacturers have reported to us on studies they have made. It was interesting to note that taste panelists preferred ice cream containing as little as 5 percent chunks of fruit to that containing 30 percent puree.

Therefore, we do have some challenges in marketing this puree. Our company feels we can increase our puree market on a "phase-in" basis over a number of years.

As our company became involved in strawberry mechanization, I saw some problems paralleling the ones that we faced with cherry harvest mechanization. We found that a major problem was scheduling the machine-harvested fruit into the processing plant. In trying to solve such problems, we as processors have become closer to the growers, not farther apart. To make the best product possible with machine-harvested fruit, we must receive and handle the fruit as soon as possible; it is also important to clean and handle the fruit properly.

I feel that this meeting has provided some answers to the problems faced as we attempt to mechanize the strawberry industry. Certainly, it has allowed us to better understand our problems and challenges.

PRESENT STATUS AND COMMERCIALIZATION OF THE U OF A-BEI HARVESTER

Albert A. Patzlaff

Once the experimental prototype of the University of Arkansas strawberry harvester was successfully field tested, the rights to manufacture this unit were granted to us at Blueberry Equipment in South Haven, Michigan.

Our first job then was to build a commercial prototype for field testing in Arkansas and Michigan during the 1972 season. An amazing thing about this commercial unit was that it picked successfully--right from the start! Its picking efficiency was checked at 98 percent recovery on one large planting in lower Michigan. This proved to our complete satisfaction that the Arkansas concept was basically sound. Growers stated the fruit itself was of fresh market quality. The unique suction system incorporated in the Arkansas machine enabled it to lift the fruit off the ground pneumatically and positioned it for the picking fingers to strip the fruit without damaging even the ripest berries or softest varieties.

Extension field tests indicated that picking efficiencies approaching 100 percent were possible with this machine if field conditions and bed preparation were optimum. Under normal field conditions, picking efficiency will range from 90 to 95 percent.

The harvesting rate of this unit ranged from one-half to one mile per hour, depending on field conditions.

So there we stood with a high capacity, highly efficient harvester and still no place to go, for during the early commercial tests it was realized that the limiting factor in strawberry mechanization was not in the harvesting operation, but in the handling of the fruit after harvest. The processing industry was not prepared to handle and clean machine-harvested berries.

The research team at the University of Arkansas then set about to design an in-plant cleaning line, which was streamlined and manufactured by BEI. This system eliminates trash such as leaves and stems and allows for a grading table to remove the molded fruit. This was discussed in greater detail in another presentation by Morris and others.

Thus, through these combined efforts, we were approaching a workable system for harvesting and handling strawberries. However, there were still problems. Under certain field conditions, molded fruit found its way into the finished product. Further investigation revealed that little or no grading of molded fruit was being accomplished at the processing plant. The reason for this was the large capacity of the BEI cleaning line. It was possible for processors to clean berries involving washing, breaking up clusters, and removal of leaves and stems at the rate of approximately 2 tons per hour. At this rate, individuals on the line had little opportunity to remove molded fruit.

The 1975 harvester was updated to meet this contingency by adding more power, better control of the pneumatic system, and an extended conveying system with an apron for on-the-machine grading of molded fruit. This model was successfully tested in Arkansas, California, Oregon, and Michigan. The extended conveyor and fruit grading system worked satisfactorily in each of the states where it was tested. However, molded fruit was eliminated only when the graders on the machine were trained to forget the few leaves and stems that came over the apron and concentrate on molded fruit alone. The BEI in-plant cleaning line would take care of the leaves. When this was done, the system functioned smoothly.

In 1976, when the machine was being evaluated by Gene Ashcraft of Copemish, Michigan, he felt that he would like a machine with still greater harvesting capacity. The most logical approach for additional capacity was a two-row unit. This was supplied for the 1977 harvest season. The new unit also had trailers designed to trail the machine for moving harvested fruit in large volume to the ends of the rows.

We feel strongly that for strawberry mechanization to be economically feasible, the total system must be designed for high capacity. From the start, we urged growers to widen their beds. The width of the bed presents no problem to the BEI harvester. The time for a 6-foot-wide bed is at hand. We have plans already formulated for a machine that will harvest these 6-foot beds. Research at the University of Arkansas indicates that yields obtained from 6-foot-wide beds are approximately one-third greater than those obtained under the conventional 24-inch bed system currently used for our two-row machines. The 1980 model of the BEI strawberry harvester features the following:

- Picking speed of 3/4 to 1 mile per hour.
- Hydrostatic 4-wheel drive.
- Infinitely variable speed adjustment.
- Gasoline or diesel engines.
- Adjustable pneumatic system.
- Zero inches turning radius.
- Power steering for operating ease.
- Overall length, 19 feet.
- Overall width, 10 feet.
- Overall height, 10 feet.
- The operating crew consists of one machine operator, two to four graders, and two lug tenders for the double-row and wide-bed machines.
- Lug carts trail the harvester for handling both empty and filled lugs.

1979 - THE PROVING YEAR OF THE SKH&S HARVESTER

Charles Hecht

During the 1979 harvest season, two SKH&S machines harvested approximatly 75 acres of strawberries in Oregon in addition to performing research work with the Northwest Region Project.

In so doing, we proved the principles to allow formal production of a commercial machine. Operation of one engine-driven unit and one PTO unit convinced us that the PTO pull-type machine is the more practical to the grower for reasons of operation and maintenance as well as purchase price.

In operation, the harvester employs rowside lifters and sickle bar separation as per our 1972 patent. In addition, our patented air lift is used to improve fruit recovery and row speed.

Using these principles, fruit is gathered into the row by lifter fingers, raised by air over the cutter bar, and then moved by air to a conveyor.

There the separation of most of the leaves is accomplished, after which berries are deposited in a container at the rear of the machine. There the containers are placed on a pallet which, when full, is set on the ground by means of a hydraulic hoist.

We have found it is advisable not to remove all of the leaves in the field operation for two main reasons. Intensive separation causes loss of small fruit and, secondly, the presence of some leaves in the container helps to cushion and preserve the fruit until it reaches the processing plant.

Therefore, we recommend final cleaning and declustering be accomplished in-plant, where more controlled conditions, such as air flow and feeding rate, exist.

For the purpose of efficiency and simplicity, we have designed our machine as a straight, in-line harvester from sickle bar to container. This also allows for economy of manufacture, and the combination offers the grower a unit that is simple to run and simple to maintain at a reasonable price.

To obtain optimum results with our machine, growers should be certain their fields are smooth and clod free.

Top row speed this past year was 1.8 miles per hour on a field with two tons. In this instance, container size was the limiting factor. Of course, row speed varies with the amount of fruit per acre.

At present, our greatest concern is the in-plant equipment needed to handle a large volume of fruit per hour.

The SKH&S harvester is manufactured by the McNair Manufacturing Company, a company that makes about 60 percent of the nut harvesters sold in the United States. Because many of the parts of the two machines are interchangeable, we are able to market the unit for $17,981 FOB factory.

In conclusion, we believe the SKH&S harvester to be as mechanically sound as a corn or bean picker.

A NEW APPROACH TO STRAWBERRY DECAPPING

Van Leban

I want to thank our host for the invitation to be here and for the opportunity to tell about my research on a strawberry decapper that "to my knowledge is totally different from any other approach."

I started the experiment in 1973-74 on the theory that aerodynamics and vacuum, if applied properly, could orient the berry and hold it firmly enough for a knife to cut off the sepal and stem.

The first machine capped 90 berries a minute and was somewhat successful. It capped from 50 to 60 percent of all berries direct from the field. With this encouraging test in 1975, I proceeded to build a larger machine that was capable of capping 10 berries a second.

In 1976 the machine was ready for a field test. We instructed the pickers not to worry about stems and found that 40 to 60 percent of the berries had no stems. As the years passed, we found that 40 to 50 percent of the berries picked for fresh market had no stems, regardless of how we instructed the pickers. The tests were gratifying; 77 percent of the berries were decapped perfectly the first time. After putting the remaining 23 percent back into the machine, 14 percent were decapped and 9 percent did not cap well enough for canning purposes. This 9 percent included berries less than 3/4 inches wide. This was a total of 91 percent berries decapped for the can.

Silver Mills in Eau Claire, Michigan, agreed to take my berries and evaluate them. They gave me barrels for juice and containers for the capped berries and carefully weighed each. The result was that 75 percent of the total weight fit well into their canning process. Twenty-five percent of the total weight went into juice or puree products. This also included berries less than 3/4 inches wide.

This machine, however, did have some problems. One was that the feeder would not feed properly to all 10 cups, and although the machine is capable of decapping 10 berries a second, only an average of 5 to 6 berries per second would feed. Second, the vacuum tubes would plug, lowering the percentage.

In 1977, both these problems were solved. We also found that 2 small berries would fall into one cup. Naturally, one one would cap, while the uncapped berry just lowered the percentage. After these problems were solved, we improved production to as high as 80 percent with berries sized 1 inch and up. Remember, we are talking about total percentage of field weight.

Basically, this is the principle on which the decapper operates. A drum revolves over a drum valve. On the revolving drum there are 6 rows of 10 cups mounted on the drum. As the drum revolves, air enters the cup and jets around the berry. As the air flows with little resistance until it hits the flower part of berries, resistance stiffens. The flower part tends to open and the berry stands vertical, more or less. The revolving drum stops, vacuum tubes lower as vacuum overcomes the air flow. It creates a stream of air that the berry follows, directly into the vacuum hole. Since berries come in all sizes, each berry will go in the vacuum tube precisely when the vacuum overcomes the flow of air--large berries first and so on. As the vacuum tubes lower and also as the vacuum tubes are being filled with berries, vacuum increases on remaining tubes, so that small berries that take less volume in the cup are compensated by more volume of vacuum. The vacuum tubes and drum begin moving forward again. Vacuum tubes along with berries wipe past a razor sharp blade that separates the sepal and stem. The berry falls back into the cup and then is vacuumed into a stainless steel tank for juice.

Vacuum tube continues forward enough to go past a clean out and then snaps back for a position for next cycle, while drum rotates with more berries and then stops.

The vacuum cups at the present time have 23/32 holes, slightly less than 3/4 inch. Therefore, any berry smaller will be sucked into the vacuum tank for juice. Ideally, berries with a diameter of 1 to 1-3/4 inches work best. Big king berry or doubles work fairly well. No stem is needed. The machine works best with no stems or stems 1/2 inch long. Longer stems have a tendency to tip the berry slightly. A berry with no stem or flower will go through normally, but a slice will be taken off; since there is no flower to orient the berry, the slice could occur anywhere on the berry.

The machine is designed for in-line installation. One can have as many as 10 machines in a line, using one conveyor to feed and one conveyor exhausting. With one machine, one person can feed strawberries and still have time to remove uncapped berries. With multiple installation, probably one person per two machines would be adequate. Feeding strawberries for 10 machines would require one person, which would be adequate. I talked to a field man at the Sortex Machine Company, and he felt that a Sortex would work well for sorting uncapped berries. This machine is built very rugged for long years of wear and has very few wearing parts. Once adjusted to proper air flow, very little can go wrong--unless someone tries to decap a pipewrench.

I believe this machine is ready to be used in industry. It has been tested for more than 5 years and continues to operate efficiently. The machine is easy to wash down after use. Its size at present is 3 feet wide by 42 inches long and 54 inches high. Its capacity is 10 berries per second or 600 berries per minute. With an average of 70 berries per pound, that would be 8.57 pounds per minute. Thus 514 pounds of berries pass through the machine each hour.

CONFERENCE SUMMARY AND OBSERVATIONS

Lloyd W. Martin

The following notes are not intended as a detailed summary of all the papers presented but are instead a brief, general summation of the author's personal observations and thoughts. Comments are grouped according to topics discussed at the conference.

Culture

Cultural practices designed to enhance mechanical harvesting will be accepted only after the harvester has been developed and ensuing problems have come into clear focus. The problems of mechanization that result from cultural practices, however, are minimal when compared to the other problems of harvesting and handling. Growers who are experimenting with mechanical harvesting have sufficient technical knowledge and know-how to tailor their cultural practices to fit the particular needs of their harvesting equipment. Roller-packer and bed shaping machines, coupled with long-life herbicides are tools of the trade that will become more commonplace.

Educational programs, which stress the importance of good cultural practices, are needed in areas where harvest mechanization is developing. Once a grower has had experience with mechanical harvesting he can readily appreciate the necessity of bed shaping, weed control, and uniformity of the plant bed.

Applying growth regulators or other chemicals to concentrate the fruit-ripening period, alter the fruit-supporting structure, or delay ripening is a promising area of research that could directly impact mechanical harvesting. However, work of this type was not reported at the conference, leaving the major research and development activities in the hands of engineers, plant breeders, and growers who implement mechanical harvesting.

Breeding

Breeding probably holds the greatest opportunity for major advancements of mechanical harvesting. There is need for continuing work in this area. Firmness, concentrated ripening, and easy capping are some fo the characteristics that are needed.

Fortunately, the peculiar plant and fruit characteristics that enhance mechanization are all available in the genetic pool. Getting these characteristics together while also maintaining acceptable fruit quality, pest tolerance, and acceptable yield levels is a major time-consuming problem.

The conference noted that plant breeders are needed in each production area considering mechanization. Transfer of information from one breeding program to another has limited application since strawberries are usually adapted to relatively small geographic areas.

Progress is being made as evidenced by numerous reports. Recovery rates of 90 percent and selections with 80 percent of their fruit ripe at one time were reported. A major breakthrough in plant breeding, however, has not yet occurred. The cultivar 'Linn,' and numerous selections, has characteristics amenable to mechanical harvesting, but other weaknesses have kept them from being generally acceptable. The lack of suitable cultivars was identified by researchers and industry representatives alike as the major obstruction to successful harvest mechanization.

Harvesting

Development of the total harvesting unit is now in the hands of industry. Three manufacturers offer mechanical harvesters for sale: (1) Blueberry Equipment, Inc. BEI, South Haven, Michigan; (2) Canners Machinery, Ltd. (CML), Simco, Ontario, Canada; and (3) SKH&S, Stayton, Oregon. Their acceptance and further development will likely depend on how the concept of a mechanization system is accepted by the berry processing industry.

The harvest machines remove the fruit from the plant by either stripping the plant with a metal combing device (BEI) or by mowing off the entire plant (OSU, CML, and SKH&S). The effectiveness of the machines in terms of fruit recovery and damage to the fruit varies widely depending on field condition and stage of fruit development.

Growers experiencing hand labor problems are eager to try mechanization. Manufacturers are eager to sell machines and recoup research and development costs. The immediate obstacle for growers is finding buyers who can handle fruit that has been mechanically harvested.

Inplant Machinery

Inplant machinery presents one of the greatest immediate engineering problems that will be necessary for mechanization. More efficient machines with greater capacity are needed. The task is complicated by the difference in cultivars and the different ways in which they respond to the capping and cleanup equipment.

Removal of leaves and long stem clusters from mechanically harvested fruit does not present a major problem. However, detaching and removing short stems and caps (leaflets that grow at stem end of berry) are the primary challenge. Stems and caps are removed mechanically by pulling off with counter-rotating rollers (OSU and BEI cappers) or by cutting off with a saw-like blade (CML capper). Both these removal systems require that each berry has a stem or cap sufficiently long to be caught by the rollers. Berries stripped from the plant are more difficult to cap than those that are mowed because of the high percentage of fruit without a stem.

Quality and Utilization

Use of mechanically harvested fruit should not be a problem so long as product supply is kept within limits of existing markets. Once the fruit has gone through the processing line and been sorted according to grade, there is not a distinguishable difference between hand and mechanically harvested fruit.

Economics

Economics are constantly changing; however, from the data presented it would seem there is reason for optimism. The economics of mechanical harvesting likely will improve with time. Handpickers are likely to be more expensive; and, if the trend continues, handpickers may become less efficient. Conversely, mechanical harvesters will become more efficient as experience is gained by the operators.

Concluding Notes

Research and development of strawberry mechanization are a systems problem. Solution will require a continued team effort from engineers, food technologists, plant breeders, horticulturists, and economists working in concert with the strawberry industry and the consuming public.

Universities should consider the logic of more interdiscipline and inter-state research. Potentially productive areas of interstate research are in plant breeding and development of stemming and capping equipment. Cooperation between early and late season areas also could extend the period when ripe fruit is available for research.

Capping equipment that will work on the fruit from one area may work very well on varieties or selections from another area. As indicated earlier, strawberry cultivars usually are adapted to very small areas. However, selections that are being discarded in one area may be adapted to another area.

The strawberry industry needs to be working towards reducing the information gap between the producer and the consumer. The industry should have answers ready for those concerned about the impact of mechanization. What about labor displacement? What about quality and flavor of mechanically harvested fruit? What does mechanization do to the small farm?

The strawberry industry needs to develop some positive thoughts about mechanization. What about stabilizing the labor need? Is it not better to provide year-round labor for a few rather than for a larger number but for a very short period of time? What about retrieving fruit late in the season that would otherwise be lost in the field? And, is that late season fruit not superior in color, sugar and flavor?

Lastly, what are the benefits to society for maintaining an industry that may otherwise be lost?

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