Fresh–Market Quality Tree Fruit Harvester Part II: Apples

D. L. Peterson, S. D. Wolford

Abstract. *A two–sided mechanical harvester was developed to remove apples grown on narrow–inclined trellises. Units were essentially mirror images. On each unit the harvester operator used joysticks to position and engage a rapid displacement actuator (RDA) on main scaffolds to effect fruit removal. Catching conveyors were designed to intercept falling fruit without damage and elevate the fruit to a collecting conveyor. Cushioned catcher pans on each unit were used to seal around the trunk and connect the two units. Fruit removal was 95% or better, and 86 to 95% of all the fruit on the trees were recovered. Tests on eight cultivars of apples yielded 59 to 84% Extra Fancy packout. Cuts and punctures were the biggest factor preventing the harvester from harvesting a higher level of fresh–market quality fruit. Stempulls with this harvesting technique ranged from 20 to 57%, depending on cultivar, and may create a decay problem. Cultivar growth habit varied greatly in their adaptability to this harvesting concept.*

Keywords. *Mechanical harvest, Apple, Trellis, Quality.*

The supply of a skilled, economical harvest labor workforce is a concern of the apple industry in the United States (Warner, 1997; Morgan, 2002). Attempts to mechanically harvest fresh–market quality apples by mass removal techniques (shake/catch) from free–standing trees have not been successful (Brown et al., 1983; Peterson et al., 1994) due to excessive fruit damage. This damage occurs from: a) excessive apple movement during detachment causing apple to apple, and apple to branch contact; b) apple to branch contact when falling, and; c) apple to apple contact on the catching surfaces since most of the apples fall in a short time period. Narrow inclined trellis systems for apples have been developed to space primary fruiting scaffolds equally along the trellis, and from the bottom to top of the wire support (Robinson et al., 1991; Robinson and Lakso, 1991). In addition to being very productive, these trellised systems have characteristics that may be compatible with mechanical harvesting such as providing sites for shaker attachment and an open non–overlapping branching pattern to minimize damage during apple fall. Upadhyaya et al. (1981a, 1981b) found that impacting inclined apple limbs from below in a direction transverse to the limb nearly eliminated fruit movement during detachment, which should reduce detachment damage.

Peterson et al. (1999) developed a robotic bulk harvester concept to remove apples grown on narrow–inclined trellises. This system combined mechanical harvesting technology with sensors and intelligent adaptive technology to identify an individual branch, determine fruit locations, position a rapid displacement actuator (RDA) and a catching surface under the apples, and execute the RDA. The RDA supplied an impulse to rapidly displace the limb away from the fruit, causing detachment. Limited field testing demonstrated feasibility of the system, with excellent removal and high fruit quality. However, they suggested that using a human operator to position and activate the RDA with hydraulic joysticks might be a simpler and more effective solution than an imaging system with controlling software. Building on this harvesting concept, Peterson and Wolford (2001, 2002) developed components for a mechanical harvesting system that had an operator using hydraulic joysticks to position the RDA, and active energy–absorbing catching surfaces to collect the fruit. This system showed promise for harvesting fresh–market quality stemless sweet cherries with quality as good as commercial hand picking. Peterson et al. (2003) developed a complete mechanical harvester utilizing this concept and demonstrated commercial potential for harvesting fresh–market quality stemless sweet cherries.

Objectives

The objective of this research was to adapt Peterson's mechanical harvesting concept for fresh–market quality apples trained to narrow inclined trellises. Sub–objectives were to: (1) identify cultivar characteristics and training schemes compatible with the mechanical harvesting concept, (2) develop components for effective fruit removal, collection, and containerization with minimum damage, and (3) field test the system to determine fruit removal, recovery, and quality

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The authors are **Donald L. Peterson, ASAE Fellow,** Agricultural Engineer, and **Scott D. Wolford,** Mechanical Engineering Technician, USDA–ARS, Appalachian Fruit Research Station, Kearneysville, West Virginia. **Corresponding author:** Donald L. Peterson, USDA–ARS, AFRS, 45 Wiltshire Road, Kearneysville, WV 25430; phone: 304–725–3451 ext. 324; fax: 304–728–2340; e–mail: dpeterson@afrs.ars.usda.gov.

TRELLIS AND TREE DESIGN

Trees used in this study were 'Empire'/M9 planted in May 1994; 'AceSpur Delicious'/M7 and 'Pink Lady'/M9 planted in the spring 1997; and 'Crimson Gala'/B9, 'SunCrisp' /M9, 'Spur GoldBlush'/M26, 'Sun Fuji'/M9, and 'Rubinstar Jonagold'/B9 all planted in the spring of 1999. Trees were trained to a Y–trellis. The trellis had a vertical post 700 mm (27 in.) in height, and each 2–m (78–in.) arm was set at 50° from the horizontal. The rows were spaced 4.9 m (16 ft). The training system had trees spaced 1.2 m (4 ft.) in the row with three leaders equally spaced [400 mm (16 in.)] on each side of the trellis arms (fig. 1). It was desirable to have fruiting branches extend no farther than 300 mm (12 in.) from each leader; but to get adequate fruit load, branches were often left longer. The diameters of the leaders range from 19 to 64 mm (0.75 to 2.5 in.). Fruiting branches directly above or below the leader were eliminated.

HARVESTER DESIGN

The harvester (figs. 2 and 3) was the same unit used by Peterson et al. (2003) to harvest sweet cherries, but with some modifications of the catching conveyor and bin filler on the right–hand unit (at rear—facing forward, fig. 2). The catching conveyor on the right side had pockets spaced at 190 mm (7.5 in.) and was inclined 45° to the horizontal instead of 127–mm (5–in.) spaced pockets and an inclination of 30° as on the left–side unit. The right–side conveyor carefully discharged the fruit onto a transfer incline (fig. 4). This incline was covered with 12–mm (0.5–in.) thick Poron (Rogers Corp., East Woodstock, Conn.) and transferred the fruit to a 460–mm (18–in.) wide collecting conveyor. Assisting the transfer to the collecting conveyor was a 356–mm (14–in.) diameter 2.93–m long (115–in.) soft bristle brush (Industrial Brush Corporation, Lakeland, Fla.) whose axis was parallel to the drive axis of the catching conveyor. The brush was positioned so that the outer diameter lightly touched both the catching and collecting conveyors. The brush was rotated in the direction of the collecting conveyor and acted to decelerate the fruit during transition. The collecting conveyor used a series 900 Flush Grid plastic perforated belt (Intralox, Harahan, La.) that transported the fruit to the rear of the harvester and into an automated bin filler (Peterson and Wolford, 2003). Before the conveyor delivered the fruit to the bin filler, a fan pulled air through the conveyor to remove leaves and other light trash.

All moving mechanisms were properly shielded to prevent accidents to the operators and onlookers whom may be in contact with the harvesters during field testing or demonstrations. Displaced components of the RDA were designed to maintain their integrity during rapid acceleration. During field evaluations onlookers were advised to stand clear of the front of the harvesters, since the harvester's operators could often have restricted visibility.

Figure 1. Side view of "Y" trellis showing orientation of scaffolds.

TEST PROCEDURES

The day before harvest of each variety, 10 apples were picked and used to determine the average Magnus Taylor

Figure 2. Rear view of experimental apple harvester.

Figure 3. Front view of experimental apple harvester.

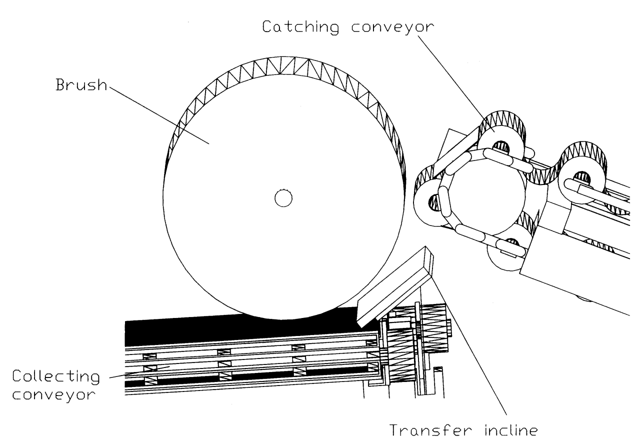

Figure 4. Schematic of fruit transfer components.

pressure, starch level, and soluble solids. Just prior to harvest 60 apples were detached with a digital force gauge (Imada DPS–11, Imada Co., LTD., Japan) to determine detachment force.

For all tests, the drivers tried to position the outer edge of the catcher pans at or slightly beyond the center of the trunk. The drivers then used the joysticks to position the RDA perpendicular to a scaffold and activated the impulse [51–mm (2–in.) stroke] Peterson et al. (2003). Each scaffold was impulsed two to three times at one to two locations. The drivers tried to keep the scaffold being harvested near the center of the inclined catching conveyor. Often two adjacent scaffolds could be harvested before the operator move to the next position. Both drivers tried to keep the units together, since detached fruit could land on either catching conveyor. On the right side, fruit was collected in a bin using the automated bin filler. On the left side, a person removed harvested apples from the collecting conveyor and carefully placed them in 0.45–m^3 (1–bu) cardboard boxes. After each row was harvested, the apples left on the trees and lost to the ground were counted. This information was used to calculate the percent of fruit left on the tree, lost to the ground, and collected by the harvester.

After harvest the apples were carefully manually separated into two categories, stem and stemless, and then counted. From each category four groups of 60 apples (30 apples for ‘SunCrisp’ and ‘GoldBlush’ because of limited yield) were randomly selected and placed in 20 cell tray packs and placed in cardboard boxes. These apples were held at room temperature for one week and then carefully graded according to USDA fresh market standards. “Extra Fancy” grade permits one bruise 13 mm (0.5 in.) in diameter or several bruises with a total area not to exceed 127 mm^2 (0.2 in.^{2}); “Fancy” grade permits one bruise not to exceed 19 mm (0.75 in.) in diameter or several bruises with a total area not to exceed 285 mm^2 (0.44 in.^{2}). All other bruised apples were classified as “Bruised.” Apples with any skin breaks were classified as “Cuts and Punctures.” In the “Extra Fancy” category, apples with no bruising were also counted. For all apples except ‘Empire’ we did not distinguish between the two sides of the harvester. ‘Empire’ apples were sampled as described above from the left–hand side of the harvester. ‘Empire’ apples placed in a bin on the right side were also held at room temperature for one week and then graded as three replications in–order to give a comparison between the two halves. SAS statistical software (Version 7, SAS Institute Inc., Cary, N.C.) was used to analyze the data.

TEST RESULTS

All the cultivars were harvested at an appropriate stage of maturity (table 1); except ‘Rubinstar Jonagold’ was slightly over mature. All machine components operated reliably. The driver on the left–side unit could easily control the positioning of the RDA; where space between the tree canopy and the catching conveyor was adequate. The driver on the right side had more difficulty controlling the positioning of the RDA since the space between the tree canopy and the catching conveyor was restricted and scaffold visibility was obstructed. Fruit left on the tree was always less than 5% (table 2). Fruits left on the tree were generally on long thin limbs. Fruit lost to the ground was normally beyond the ends of the catching conveyor. The steep catching conveyor on the right–hand unit had more fruit cascading down it and jumping off the ends. ‘Empire’ had a lot of fruit knocked off to the ground by the leading edge of the right–side catching conveyor. Making the catching conveyor longer would probably eliminate most of the fruit lost to the ground.

Table 1. Preharvest apple parameters.

Cultivar	Pull Force (kg) [a]	Starch[b]	Soluble Solids (%)	Magnus Taylor (N) [c]
‘Crimson Gala’	2.4a	6.4	16.4	100
‘Empire’	1.9b	4.9	12.2	82
‘Ace Spur Delicious’	1.9b	5.4	12.0	73
‘Rubinstar Jonagold’	1.7bc	7.5	15.3	73
‘Sun Fuji’	1.6bc	4.8	14.5	83
‘SunCrisp’	1.9b	6.6	15.2	73
‘GoldBlush’	1.4c	5.8	14.2	82
‘Pink Lady’	1.7bc	4.9	15.2	82

[a] Mean separation within columns by Duncan’s multiple range test, P = 0.05, df = 452 (numbers with the same letters are not significantly different).

[b] Harvest criteria; 1–3 is immature, 4–6 is acceptable, and 7–9 overripe.

[c] Readings taken with a 11–mm tip.

Stem pulls ranged from 20.2 to 57.2% for the different cultivars and is a potential serious problem for this harvesting technique. Stem pulls may increase the decay risk for apples during long–term storage. In a companion study, Janisiewicz and Peterson (data not published yet) are studying this risk and ways to minimize it. Preliminary results suggest that when decay is a problem with certain cultivars, bio–control agents may be used to minimize or eliminate the decay.

Before grade analysis between the individual cultivars, all the data were pooled and analyzed to determine if there was a difference in grade between apples with stem or stem pulls. The analysis showed no significant differences (P = 0.05, df = 62) in any of the grade categories; therefore the stem and stem pull data for each cultivar was pooled. The fruit quality grades are shown in table 3. Extra Fancy fruit range from 59 to 84% and there were significant differences among cultivars. ‘Crimson Gala’ was the first cultivar harvested and we identified several areas on the harvester that we felt were causing damage. These areas were corrected before the remaining harvests. ‘Pink Lady’ yielded the lowest amount of extra fancy fruit and probably had the most dense canopy and most fruit on long thin hanger limbs. Long thin hanger limbs result in the most apple movement during detachment and therefore more damage. On four cultivars (‘Empire,’ ‘Ace Spur Delicious,’ ‘Sun Fuji,’ and ‘GoldBlush’) fresh–market quality fruit (Extra Fancy + Fancy) ranged from 86 to

Table 2. Harvester efficiency.

Cultivar	Fruit Left on Tree (%)	Fruit Lost to Ground (%)	Fruit Collected (%)	Stem Pulls (%)
‘Crimson Gala’	1.4	3.8	94.8	48.7
‘Empire’	2.9	11.1	86.0	43.6
‘Ace Spur Delicious’	4.3	3.1	92.6	42.8
‘Rubinstar Jonagold’	3.4	5.9	90.7	57.4
‘Sun Fuji’	1.7	2.9	95.3	49.5
‘SunCrisp’	4.8	5.0	90.2	20.2
‘GoldBlush’	0.7	7.3	92.0	36.2
‘Pink Lady’	4.8	6.3	88.9	51.1

Table 3. Apple quality grade[a].

Cultivar	Extra Fancy (%)[b]	Fancy (%)	Bruised (%)	Cuts and Punctures (%)
'Crimson Gala'	68.2(88)[c]d	3.2b	3.3bc	25.3a
'Empire'	80.4(90)ab	5.6ab	1.6c	12.4cd
'Ace Spur Delicious'	83.0(93)a	5.5ab	4.7ab	6.8f
'Rubinstar Jonagold'	76.2(95)bc	3.6b	2.5bc	17.7b
'Sun Fuji'	84.0(96)a	2.8b	2.6bc	10.6de
'SunCrisp'	72.1(86)cd	4.7ab	7.6a	15.6bc
'GoldBlush'	82.6(87)a	7.5a	2.1c	7.8ef
'Pink Lady'	59.1(65)e	7.8a	5.9ab	27.2a

[a] USDA fresh market standards; "Extra Fancy" grade permits one bruise 13 mm in diameter or several bruises with a total area not to exceed 127 mm^2; "Fancy" grade permits one bruise not to exceed 19 mm in diameter or several bruises with a total area not to exceed 285 mm^2. All other bruised apples were classified as "Bruised." Apples with any skin breaks were classified as "Cuts and Punctures."
[b] Mean separation within columns by Duncan's multiple range test, P = 0.05, df = 56 (numbers with the same letters are not significantly different).
[c] Number in parenthesis is proportion of Extra Fancy fruit that is bruise free.

90%. In general, minor bruising (represented in the Fancy grade) and severe bruising were not the major reasons preventing a higher percentage of Extra Fancy fruits. The cuts and punctures category represented the most damage to the apples. This fact is somewhat puzzling to the authors since initial results with the RDA (Peterson et al., 1999) showed very low numbers of cuts and punctures on harvested apples. Differences from those tests and results reported here are a more mature/dense canopy, and apples falling farther to a padded conveyor. More detailed analysis and testing of the removal and catching operational will be required to identify the reason for increased damage during harvest.

The data in table 4 show that there were no differences in the packout of 'Empire' from either the left or right side of the harvester. This data indicates that the bin filler was not causing additional damage to the harvested apples.

Conclusions and Discussion

Cultivar growth habit varied greatly in their adaptability to this harvesting concept. 'SunCrisp,' for example is very compact in its growth habit, requires minimum training, and has short fruitful laterals. On the other hand, 'Pink Lady' has much more growth, a denser canopy that takes more training effort, and has longer thinner fruiting laterals than 'Sun-Crisp.'

Table 4. 'Empire' grade[a] comparison for left and right side of harvester.

Treatment	Extra Fancy (%)[b]	Fancy (%)	Bruised (%)	Cuts and Punctures (%)
Right side	79.8	3.9	4.0	12.2
Left side	80.4	5.6	1.6	12.4

[a] USDA fresh market standards; "Extra Fancy" grade permits one bruise 12.7 mm in diameter or several bruises with a total area not to exceed 127 mm^2; "Fancy" grade permits one bruise not to exceed 19 mm in diameter or several bruises with a total area not to exceed 285 mm^2. All other bruised apples were classified as "Bruised." Apples with any skin breaks were classified as "Cuts and Punctures."
[b] Mean separation within columns by Duncan's multiple range test, P = 0.05, df = 9; no significant differences.

The harvesting prototype functioned reliably with good removal and recovery of the fruit. The setup of the left–hand unit was preferable since it enabled better visibility for the operator (potential for faster operation), with less fruit cascading down the catching conveyor. On a commercial prototype the catching conveyor would have to be longer to reduce ground loses.

On four cultivars ('Empire,' 'Ace Spur Delicious,' 'Sun Fuji,' and 'GoldBlush') fresh–market quality fruit (Extra Fancy + Fancy) ranged from 86 to 90% and demonstrated that this harvesting technique may have commercial potential. Cuts and punctures were the biggest factor preventing the harvester from harvesting a higher level of fresh–market quality fruit. More detailed analysis of fruit detachment and catching will have to be conducted to determine reasons for this high level of damage. The large number of stem pulls with this harvesting technique may create a decay problem during storage and also needs farther study.

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