ISOLATING DAMAGE FROM MECHANICAL HARVESTING OF APPLES

D. L. Peterson, B. S. Bennedsen

ABSTRACT. *This research studied the performance of the ARS fruit−harvesting concept in relationship to apple removal efficiency and damage. There were no differences in apple removal efficiency or fruit quality between a single impulse or three rapid impulses when using the rapid displacement actuator (RDA) for fruit removal. In the canopy zone ±300 mm (12 in.) from the impulse point of the RDA, removal was not significantly different between apples on short limbs and long/thin limbs. Removal outside that zone was lower and there was a significant difference between removal on short and long/thin limbs. The harvesting concept described in this article harvested 53% to 72% damage−free apples on five cultivars. Cuts and punctures were a serious problem, but bruising was also a factor limiting better quality. Apples growing inside the canopy were significantly more susceptible to damage than apples growing below the canopy. There were no significant differences in the amount of damage−free apples detached from short limbs and long/thin limbs.*

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

Researchers with the Agricultural Research Service (ARS), United States Department of Agriculture (Appalachian Fruit Research Station, Kearneysville, W.V.) developed a mechanical harvesting concept to remove apples grown on narrow−inclined trellises (Peterson and Wolford, 2003). This system had a human operator using hydraulic joysticks to position a rapid displacement actuator (RDA) to effect fruit removal and moving−energy absorbing catching surfaces to collect the fruit. Although mechanically harvested fruit quality from this concept was better than previously reported with shake−catch methods (Peterson et al., 1985; 1994), it was not as good as hand harvesting and caused too much damage to be commercially accepted. The most serious damage problem was excess cuts and punctures.

OBJECTIVES

The objective of this research was to study cultivar and fruiting characteristics in relationship to removal efficiency and damage using the ARS harvesting concept. Specific objectives were to evaluate removal and damage in relation to: 1) the number of removal impulses, 2) the fruit location in the canopy, 3) the fruiting structure, and 4) the fruit proximity to removal mechanism.

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TEST PROCEDURES

Trees used in this study were 'Rubinstar Jonagold'/B9 (fig. 1), 'Sun Fuji'/M9 (fig. 2), 'SunCrisp' /M9 (fig. 3), 'Spur GoldBlush'/M26 (fig. 4), and 'Dixie Red Delicious'/B9 (fig. 5). All trees were planted in the spring of 1999 and 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 scaffolds equally spaced [400 mm (16 in.)] on each side of the trellis arms. It was desirable to have fruiting branches extend no farther than 400 mm (16 in.) from each leader; but to get adequate fruit load, branches were often left longer.

The harvester (fig. 5) was the same unit developed by ARS (Peterson et al., 2003) to harvest sweet cherries. Peterson et al. (1999) described the rapid displacement actuator (RDA), a hydraulic cylinder that rapidly displaces scaffold−limbs to effect fruit removal. The RDA had a 29−mm (1.125−in.) bore and 50.8−mm (2−in.) stroke. A 101.6−mm (4−in.) diameter aluminum disk threaded to the end of the

Figure 1. 'Rubinstar Jonagold' trained to a "Y" trellis.

Figure 2. 'Sun Fuji.'

Figure 3. 'SunCrisp.'

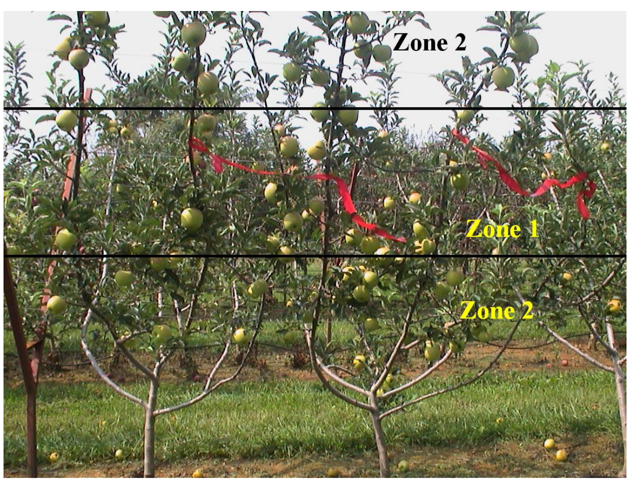

Figure 4. Fruit location zones on 'GoldBlush.'

RDA cylinder rod partially housed a 76.2−mm (3−in.) diameter, 2.5−mm (1−in.) thick rubber disk. This rubber disk was positioned against a scaffold to transfer the rapid displacement of the RDA to the scaffold and to minimize tree damage. Each harvester operator used a pair of hydraulic

Figure. 5. ARS experimental harvester test setup on 'Dixie Red Delicious.'

joysticks to maneuver the RDA support system to position the RDA near the middle of the scaffold.

To establish fruit location in relation to the RDA, two zones were established in the canopy (fig. 4). Zone 1 included all apples that were within the area defined by two imaginary parallel lines positioned 300 mm (12 in.) above and below the point the RDA engaged the scaffold (impulse point). All apples in this region were painted with a color. Zones 2 were all apples either above or below Zone 1, and were left unpainted to designate Zone 2. In both zones, apples that we expected to be difficult to remove on long [>400 mm (16 in.)] or thin [<5 mm (0.2 in.)] branches were painted a second color. Also apples in both zones that were resting on top of scaffolds and branches (inside the canopy) were painted a third color. From past experience we expect these apples to suffer more damage since the RDA would cause them to be propelled upward. These markings yield six identifications: Zone 1 Short (apples not on 'long/thin limbs'), Zone 1 Long, Zone 1 Inside, Zone 2 Short, Zone 2 Long, and Zone 2 Inside. Cultivars were classified as "spreading" if fruiting was predominately on long [>400 mm (16 in.)] or thin [<5 mm (0.2 in.)] branches and "compact" if fruiting was predominately on short branches or along the main scaffold.

Before harvest of each cultivar, 10 apples were picked to determine the average starch level, and three replications of 20 apples were detached with a digital force gauge (Imada DPS−11, Imada Co., LTD., Japan) to determine detachment force. After harvest the diameter of each scaffold (at RDA impulse location) was measured and recorded.

For all tests, the drivers tried to position the harvesting units such that the outer edge of the catching surfaces were at or slightly beyond the center of the trunk. The drivers then used the joysticks to position the RDA perpendicular to the impulse point in Zone 1 and activated the impulse. Two treatments were employed. In treatment one the scaffold was impulsed once. In treatment two, the scaffold was impulsed three times in rapid succession. We thought treatment two would give better removal, but might cause more damage to the apples. Apples were caught on the padded catching conveyor and on each unit a person removed the apples from the top of the conveyor and carefully placed them in trays in 0.45−m^3 (1−bu) cardboard boxes. Each replication contained the apples from four to six scaffolds, and there were five to eight replications/treatment depending on cultivar. After each row was harvested, the apples left on the trees were counted. This information was used to calculate the percent of fruit left on the tree.

During harvest, fruit removal was video taped (Sony DCR−PC100 digital video camera, Sony Corp., New York, N.Y.) to aid in the analysis of detachment damage. The detachment process in various areas on the scaffold was recorded. After harvest, the video was carefully examined in slow and stop motion to study apple movement and interactions.

The apples were stored from one to four weeks after harvest at 1°C (33°F) and then were manually separated into the six identification zones. The apples were then carefully graded according to USDA fresh market standards. “Extra Fancy” grade permits one bruise 12.7 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 damage were also counted. SAS statistical software (Version 8, 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) and fruit detachment force was in the range expected from previous research (Peterson and Wolford, 2003). There were no significant detachment or quality differences between treatments (single or three rapid impulses), so the data was pooled to analyze cultivar and location effects.

For the spreading cultivars, ‘Rubinstar Jonagold,’ ‘Sun Fuji,’ and ‘SunCrisp’ (table1), the number of fruit left on the tree was higher than in previous years (table 2) (Peterson and Wolford, 2003). But this lack of removal was expected since only one impulse location/scaffold was used, and during normal harvest each scaffold would be impulsed at multiple locations to ensure maximum removal. Significantly fewer apples were left on the trees with the compact cultivars, ‘GoldBlush’ and ‘Dixie Red Delicious,’ since these cultivars have more compact growth habit, and fruiting was concentrated around the scaffold; which permitted more efficient transmission of the impulse force.

Table 1. Harvester parameters.

Cultivar	Detachment Force (kg)[a]	Starch Reading[b]	Scaffold Diameter at Impact Position (mm)[c]	Fruiting Type[d]
‘Rubinstar Jonagold’	−1.8a	6.7	20.5a	Spreading
‘Sun Fuji’	−2.3b	4.7	19.0b	Spreading
‘SunCrisp’	−2.2b	4.7	17.4cd	Spreading
‘GoldBlush’	−1.5a	4.1	18.4bc	Compact
‘Dixie Red Delicious’	−2.2b	4.5	16.6d	Compact

[a] Mean separation within columns by Duncan’s multiple range test, P = 0.05, df = 10 (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] Mean separation within columns by Duncan’s multiple range test, P = 0.05, df = 239 (numbers with the same letters are not significantly different).
[d] Spread defined as predominate fruiting on long (>400 mm) or thin (<5 mm) branches. Compact defined as predominate fruiting on short (not long or thin) or along the main scaffold.

Table 2. Harvester efficiency versus cultivar.

Cultivar	Fruit Left on Tree (%)[a]	Zone 1 Short (%)	Zone 1 Long (%)	Zone 2 Short (%)	Zone 2 Long (%)
‘Rubinstar Jonagold’	11.2b	1.4ab	0.5b	3.3b	6.1a
‘Sun Fuji’	14.4ab	1.1a	3.6a	1.8bc	8.0a
‘SunCrisp’	19.5a	1.3ab	1.5b	8.1a	8.7a
‘GoldBlush’	6.3c	1.1a	1.0b	1.5b	2.7b
‘Dixie Red Delicious’	1.2d	0.0b	0.4b	0.2c	0.6c

[a] Means are from the raw data, but transformed with arcsin transformation for analysis. Mean separation within columns by Duncan’s multiple range test, P = 0.05, df = 63 (numbers with the same letters are not significantly different).

We had expected that removal on long/thin branches would be less efficient than on shorter branches, but analyzing removal of ‘Rubinstar Jonagold,’ ‘Sun Fuji,’ and ‘SunCrisp’ (inefficient removal cultivars) yielded no significant differences in removal in Zone 1 (table 3) between short and long branches. However, as expected, removal in Zone 2 was significantly less effective than in Zone 1, and there was a significant difference between removal on short and long branches.

The fresh market apple industry is only interested in damage−free fruit. In this study, 53.1% to 72.6% of the apples were damage free (table 4). ‘Sun Fuji’ had the highest number of damage−free apples and ‘GoldBlush’ the least. Both compact cultivars, ‘GoldBlush’ and ‘Dixie Red Delicious,’ were more susceptible to small bruises (Extra Fancy Bruised) than the other three cultivars. There were no strong trends between cultivars in moderate (Fancy) and severe bruising (Bruise). ‘Dixie Red Delicious’ had significantly less cuts and punctures than the other four cultivars and is known to be a damage resistant cultivar.

Analyzing apple quality by location and fruit structure (table 5) shows that there were significantly less damage−free apples in both Zones 1 and 2 on apples inside the canopy. Apples in this location have significantly more cuts and punctures in Zone 1 and trending to that in Zone 2. Analysis of the video clearly shows that during detachment, apples growing inside the canopy are removed with much higher velocity and are propelled through more canopy before they reach the catching conveyor. Since our training technique tries to avoid apples growing on the inside of the canopy, only 7% of all the apples in this study were inside the canopy. Video analysis of apples hanging below the canopy showed that they fall at lower velocity, with less fruit rotation, and

Table 3. Harvester efficiency verses location and structure for ‘Rubinstar Jonagold,’ ‘Sun Fuji,’ and ‘SunCrisp.’

Location and Structure	Fruit Left on Tree (%)[a]
Zone 1 Short	1.3a
Zone 1 Long	1.9a
Zone 2 Short	4.2b
Zone 2 Long	7.3c

[a] Means are from the raw data, but transformed with arcsin transformation for analysis. Mean separation within columns by Duncan’s multiple range test, P = 0.05, df = 140 (numbers with the same letters are not significantly different).

generally in a direct downward direction than apples inside the canopy. Video analysis also showed more interactions than expected between some detached apples and trellis components (wires and frame), other apples, and the tree−seal on the harvester. All of these interactions can lead to damage. There was no significant difference in the amount of damage−free apples detached from long/thin limbs or short limb in both zones 1 and 2. This result was a little surprising since we expected that apples on long/thin limbs would have more movement (and therefore more damage) during detachment than apples on short limbs. Video analysis confirmed that was not the situation.

Conclusions and Discussion

There were no differences in apple removal efficiency or fruit quality between a single impulse or three rapid impulses when using a RDA for fruit removal. In the canopy zone ±300 mm (12 in.) from the impulse point of the RDA, removal was not significantly different between apples on short limbs or on long/thin limbs. Removal outside that zone was lower and there was a significant difference between removal on short and long/thin limbs. Therefore to improve removal, the RDA would have to be impulsed at more than one position on some scaffolds.

The harvester described in the report harvested 53% to 72% damage−free apples on five cultivars. Cuts and punctures seem to be the most serious problem, but bruising was also a factors limiting better results. Apples growing inside the canopy were significantly more susceptible to damage than apples growing below the canopy. A training system should eliminate apples growing inside the canopy, but this objective is difficult to achieve. There were no significant differences in the amount of damage−free apples detached from long/thin limbs or short limbs. Video analysis of apple detachment did not identify modifications in either training system or detachment principle that might significantly result in reduced damage. It seems unlikely that this harvesting concept has strong commercial potential if nearly 100% damage free fruit is required.

Table 4. Apple quality[a] of mechanically harvested apple cultivars.

Cultivar	Extra Fancy Damage−Free[b] (%)	Extra Fancy Bruised (%)	Fancy (%)	Bruised (%)	Cuts and Punctures (%)
'Rubintar Jonagold'	61.8b	9.4c	6.5	8.9a	13.4ab
'Sun Fuji'	72.6a	6.9c	5.9	5.1ab	9.6bc
'SunCrisp'	62.6b	9.8c	6.6	6.2ab	14.8a
'GoldBlush'	53.1c	22.5a	10.1	6.6ab	7.6c
'Dixie Red Delicious'	67.7ab	17.7b	6.3	4.5b	3.9d

[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] Means are from the raw data, but transformed with arcsin transformation for analysis. Mean separation within columns by Duncan's multiple range test, P = 0.05, df = 63 (numbers with the same letters are not significantly different).

Table 5. Apple quality[a] in relation to location and structure.

Location	Extra Fancy Damage−Free[b] (%)	Extra Fancy Bruised (%)	Fancy (%)	Bruised (%)	Cuts and Punctures (%)
Zone 1 Short	63.6a	13.0	6.7	7.2	9.5b
Zone 1 Long	70.6a	9.6	6.7	3.8	9.3b
Zone 1 Inside	29.2c	15.7	12.5	9.8	32.8a
Zone 2 Short	65.2a	13.8	5.4	5.6	10.0b
Zone 2 Long	72.1a	9.5	5.8	5.5	7.0b
Zone 2 Inside	42.6b	19.5	13.5	8.2	16.1b

[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 12.7 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 "Cut and Punctures."

[b] Means are from the raw data, but transformed with arcsin transformation for analysis. Mean separation within columns by Duncan's multiple range test, P = 0.05, df = 317 (numbers with the same letters are not significantly different).

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