

FRESH MARKET QUALITY BLUEBERRY HARVESTER

D. L. Peterson, S. D. Wolford, E. J. Timm, F. Takeda

ABSTRACT. *An experimental mechanical harvester (V45) was developed that utilized an angled double-spiked-drum shaker, a cane dividing and positioning system, and cushioned catching surfaces to harvest fresh market quality blueberries. With the V45, ground losses were reduced by 44% when compared with a commercial mechanical harvester. Fruit packout was similar between the V45 and a commercial harvester, but berry firmness and internal fruit quality from the V45 harvester were superior to that from the commercial harvester. Fruit quality from the experimental harvester was as good as quality from commercially hand harvested fruit.*

Keywords. *Mechanical harvest, Blueberry, Quality, Firmness, Bruise.*

Hand harvesting of "highbush" blueberries is labor intensive and requires as much as 1300 worker-h/ha (Brown et al., 1983). Booster (1983), Cargill and Booster (1983), Mainland (1993), and Peterson and Brown (1996) summarized the development of mechanical harvesters for blueberries destined for processing. These traditional over-the-row harvesters reduced harvest labor to 25 worker-h/ha. Peterson and Brown (1996) also described a mechanical harvester they developed that harvested significantly more fresh market quality blueberries than did conventional commercial harvesters and with quality approaching hand harvesting. The harvester included a prow and cane positioning system that divided and directed canes to the shakers with very little cane damage. This system bent the canes over the catching surfaces to reduce the distance of fruit drop. They demonstrated that a single shaker per side was as effective as a double shaker in blueberry removal and selectivity. Their experimental harvester was too wide for commercial adoption, and ground losses were higher than expected.

OBJECTIVES

The main objective of this research was to develop a commercial prototype mechanical harvester for fresh market quality blueberries. Important sub-objectives that had to be developed were: (1) a harvester layout to limit overall width to 3 m to accommodate existing plantings; (2) an angled double-spiked-drum shaker; and (3) catching surfaces, conveyors, and seals that minimized fruit losses, yet maintained quality. Another objective was to compare harvester performance on ground losses, packout, and fruit quality with commercial mechanical and hand harvesting.

HARVESTER DESIGN

The overview schematic of the prototype harvester (V45) developed in 1995 is shown in figure 1 and the experimental prototype in figure 2. Standard frame and drive components from BEI's rotary harvester (Rotary) formed the basis for the experimental prototype; except that the center bays, on each side of the tunnel, were lengthened to 2.54 m to accommodate part of the angled double-spiked-drum shaker (allowing part of the bush to be within each side bay during shaking). Due to other design changes, overall length of the new harvester was only 0.23 m longer than the Rotary, so maneuverability was similar. Inside tunnel dimensions were 1.4 m wide \times 2.0 m high. This permitted the outside width to be 3.0 m, which is typical of commercial blueberry harvesters and acceptable to growers.

The angled double-spiked-drum shaker had two spiked-drums oriented perpendicular to each other and angled 45° to the horizontal. Each spiked-drum had six whorls of nylon rods (24/whorl, 480 mm in length, 19 mm in diameter, angled 15° apart) spaced 200 mm apart on a central shaft. The central shafts of each spiked-drum were bearing supported by two arms that were bearing supported to the shaker frame. Each pair of support arms was oscillated by connecting rods that were driven by ball bearing eccentrics to generate the shaking action. The eccentrics were driven by shafts connected by a common right angle gear box. This arrangement permitted the front and rear spiked-drums to be synchronized and driven in opposite directions for dynamic

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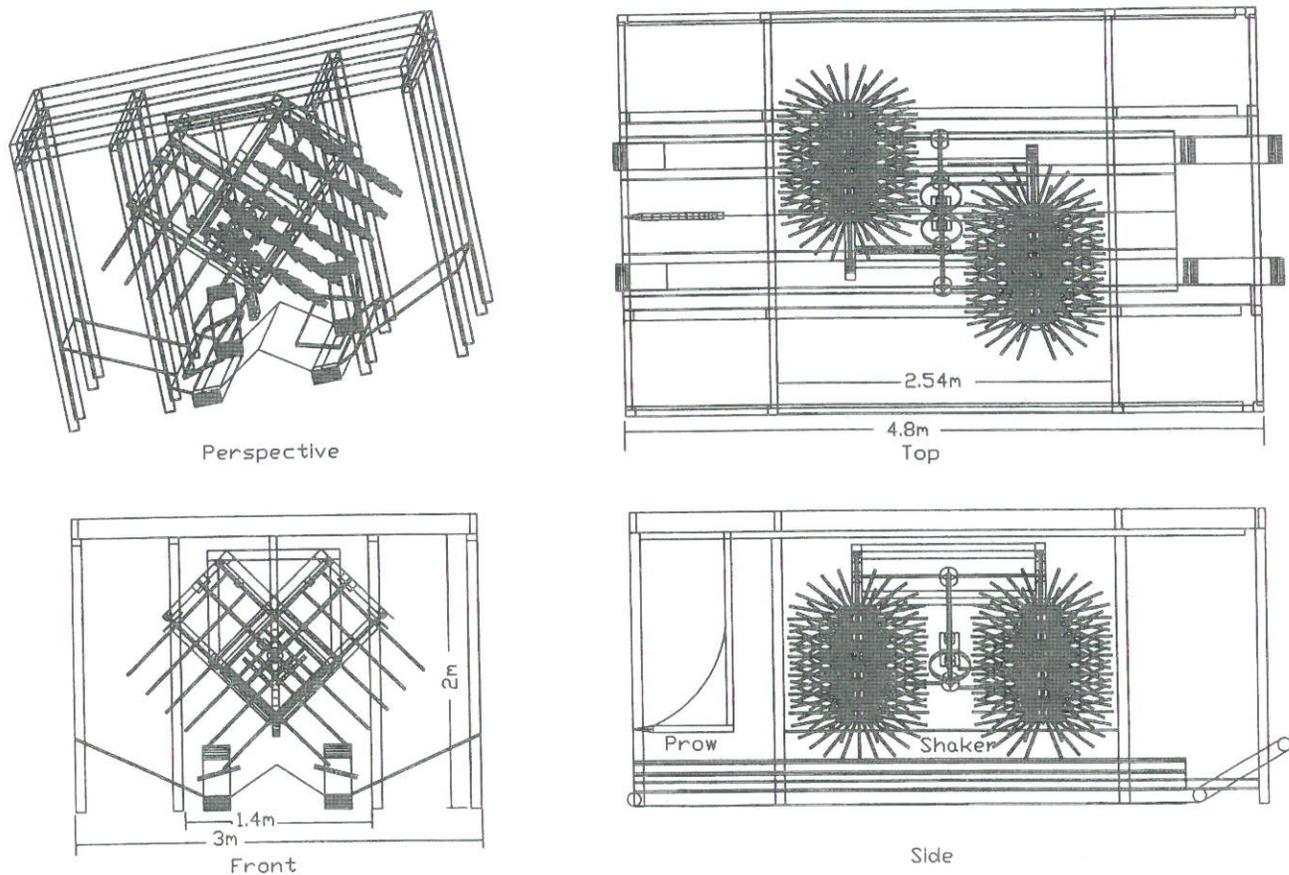
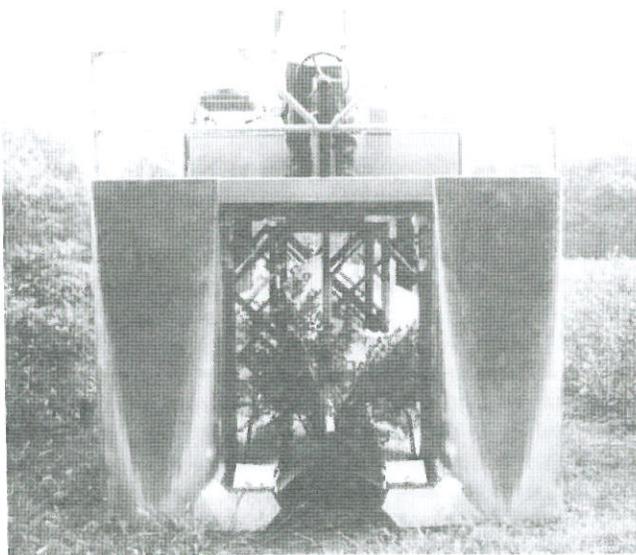


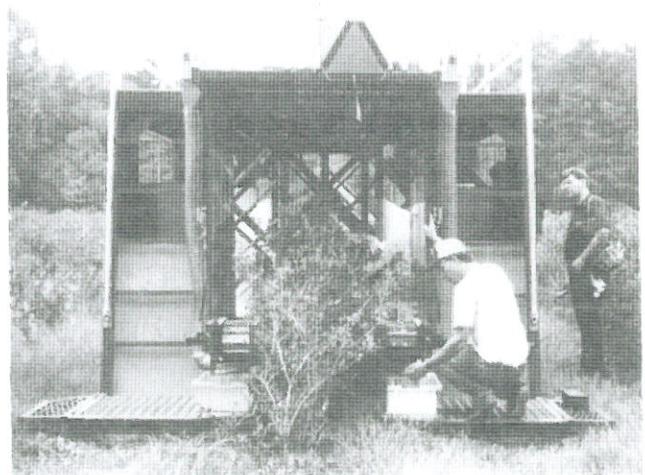
Figure 1-Schematic of V45 prototype blueberry harvester using the angled double-spiked-drum shaker.

balance. Outside diameter of each spiked drum was 1 m. Exposed shaking length of the rods was 380 mm and maximum displacement at the tip was 100 mm. Flywheels were added to the eccentric drive shafts to maintain momentum and uniform shaking frequency.

The prow to divide the bush was developed from a 38-mm square tube extending 920 mm in front of the shaker. At the leading end of the tube (positioned at the front edge of the harvester) was a 150 mm long cone shaped wedge. Starting at the end of the cone and arcing up 920 mm over the length of the tubing was a curved piece of 38 mm wide × 25 mm thick UHMW plastic bar (Polihi



(a)



(b)

Figure 2-V45 blueberry harvester (a) front and (b) rear views.

Solidur, Scranton, Pa.). The prow was supported by a vertical 50 mm² steel tube fastened to the over-the-row frame. The space among the three members that made the prow was covered with UHMW plastic sheet. The smooth UHMW bar and sheeting reduced cane abrasion and prevented canes and fruit clusters from snagging on exposed edges. From the prow support tube, four 35-mm angled-positioning pipes diverted the right (orientation, rear of harvester facing forward) divided canes into the right spiked-drum. After the canes passed the right drum, positioning pipes guided the canes out the rear of the harvester. Also originating from the prow support tube, positioning pipes diverted the left divided canes to pass by the right spiked-drum and feed into the left spiked-drum. On each side of the harvester, four 35-mm cane-support pipes were placed above the primary catching surface to force low hanging canes into the shaker. The cane-support pipes were covered with 6-mm thick Poron (Rogers Corp., East Woodstock, Conn.). All cane positioning pipes and any abrupt edges on the harvester that might come in contact with canes were covered with UHMW to provide a smooth transition.

The primary catching surfaces were constructed of sheet metal and angled at 25° above the horizontal. These surfaces were covered with 12 mm thick "Double Soft NoBruze" (Connecticut Valley Corp., Shelton, Conn.) attached by contact cement and directed the berries into BEI's standard horizontal bucket conveyors. Above each conveyor was a similar cushioned catching surface angled at 15° above the horizontal and toward the primary catching surfaces. Standard fiberglass "fishscale" angled at 15° completed the catching surface between the conveyors. The fishscales were also covered with 6-mm thick Poron, which meant that all surfaces where falling berries might land were cushioned. BEI's undershot cleaners (berries dropped through a horizontally moving air-stream) and lug fillers were used on each side of the harvester.

In 1996, the angled double-spiked-drum shaker was lowered 75 mm so that the lowest whorls could better engage short canes. The shaker support frame was also strengthened to reduce unwanted vibration. Two upper cane-support pipes on each side of the shaker were replaced with four tensioned 6-mm cables that supported 17 mm OD. PVC pipes. The PVC pipe provided a smooth surface for canes to slide on, and the cables were easy to position and support. Lowering the angled double-spiked-drum shaker positioned the cane support pipes about 50 mm inside the shaker's whorls.

TEST SETUP

In 1995, a field test was conducted on 15-year-old 'Elliott' bushes at a commercial blueberry farm near South Haven, Michigan. The experimental V45 harvester was compared with a BEI rotary blueberry harvester (Rotary) to represent conventional mechanical harvesters. The Rotary also had an angled-cushioned catching surface above each conveyor to prevent berries from falling directly into the conveyor. Prior to the test, the V45 harvester was operated to determine optimum operating characteristics. Shaking frequency was set at 375 cpm and ground speed was 0.8 kph. The Rotary harvester was operated by the cooperating grower under normal procedures for maximum fruit quality. Shaker frequency was 300 cpm and ground

speed was 0.8 kph. Tests were conducted on 6 September between 8:30 A.M. and 12:00 M. Temperature was 26°C. Four side by side rows were selected for the test and alternate rows were harvested with either the V45 or the Rotary harvester. For each row, two sets of 50 continuous plants were selected as replications (4 reps/treatment). Preharvest berry samples (2 pints/replication) were taken to determine initial firmness and internal damage. During each test, blueberries were randomly sampled by hand as they dropped between the conveyor and the lug boxes, and then carefully placed in plastic buckets. After the field tests were completed, each sample bucket was sorted and six random samples (pints) of marketable fruit were selected and placed in cold storage (0°C) for later evaluation of internal damage and firmness. Fruit in the lug boxes were weighed and graded in the cooperating grower's sorting line (clusters, undersized, natural and machine defects, and marketable) to determine fresh market packout.

The stored fruits were evaluated for internal quality using a grading system established by Brown et al. (1996) to evaluate internal bruise damage. After storage, berries were cut in half and categorized for bruising as: (1) None, no bruising; (2) Slight, less than 25% of the berry area bruised; (3) Moderate, between 25 and 50% of berry area bruised; and (4) Severe, more than 50% of berry area bruised. Previous studies showed that fruit in the None and Slight categories would have long term shelf life, and therefore be excellent for the fresh market.

Brown et al. (1996) also established a relationship between berry firmness and average bruise severity. Using instrumentation developed by Timm et al. (1996) to nondestructively measure berry firmness (gm/mm), they found that higher firmness translated into better fruit quality. A commercial automated version of this instrumentation (FirmTech1, Bioworks, 1621 W. University, Stillwater, Okla.) was used in our tests to determine relative berry firmness.

After nine days in cold storage, two pints of berries from each replicated sample were randomly selected and placed in CA (controlled atmosphere, 0°C, 95% RH, 4% O₂, and 8% CO₂) for 42 days. The remaining samples were kept one day at room temperature and then tested for internal fruit bruising (n = 150) and firmness (n = 150). After 42 additional days, the fruits in CA were removed and kept one day at room temperature. Berries from each replication were then tested for firmness (n = 50) and internal fruit bruising (n = 50).

In 1996, a similar field test was conducted on 20-year-old 'Bluecrop' on the same farm and with the same two harvesters. Four harvests were conducted at 7-day intervals beginning on 31 July. Four side by side rows were selected and alternate rows were harvested with either the V45 or the Rotary harvester. For each row, two sets of 35 continuous plants were selected as replications (4 reps/treatment). Fruit sampling techniques were the same as described above. In each replication, two sets of three adjacent plants were selected to collect ground loss data. For these plants, suckers were removed to increase visibility into the crown, the grass around these plants was mowed close to the ground, and the area raked clean. Two plastic sheets (1 m × 4.5 m, plant spacing 1.5 m) were used to cover the ground under each three-plant group. Sheets were carefully cut to fit around the plant crown and joined

at the row center with VELCRO strips (sheets stayed in place for total harvest period). Outer edges of the sheets were held in place with plastic pins. After each harvest, the fruit in the crown and on the plastic sheets were collected and weighed. The percentage of fruit loss to the ground was calculated based on the total fruit harvested and lost on the ground from each three-bush replication.

Harvesting parameters for each harvest were set by the cooperating grower. Shaking frequencies for the V45 for the four harvests were 275, 300, 330, and 390 cpm, and ground speeds were 1.1, 0.7, 0.7, and 0.7 kph, respectively. Shaking frequencies for the Rotary for the four harvests were 500, 500, 500, and 700 cpm, and ground speeds were 1.1, 0.7, 0.9, and 0.9 kph, respectively.

Berry firmness was determined on the day of harvest. Internal bruising was evaluated 8 days after storage at 1° C.

RESULTS AND DISCUSSION

Nearly all V45 harvester components operated reliably. Occasionally a bearing on the shaker would vibrate loose or break. Changes after the 1996 harvest season that increased shaft and bearing sizes, and alterations in the support configuration were expected to eliminate this problem. Unbalanced shaker vibration to the harvester frame was minimal and deemed not to be a problem. The bush-dividing prow did an excellent job of penetrating and dividing the canes. The cane-support pipes and UHMW surfaces did a good job positioning the canes into, through, and around the shakers. Only low-hanging side limbs were difficult to feed into the shaker and not always effectively shaken. Having the upper section of the shaker in the center-side bays was workable. On 'Elliott' observed cane damage was minimal and not considered a serious problem. More cane damage was observed on 'Bluecrop'. The increase in cane damage to 'Bluecrop' was probably due to the increase number of harvest. More serious cane damage was observed with the V45 than with the Rotary. Cane damage by the V45 was mainly on old canes and could have been caused by having the lowest whorls too low and/or forcing the canes too tightly into the shaker. Refinements in shaker configuration and cane support structure may be necessary to reduce cane damage. Long-term observation of plant health and yield will be necessary to determine if cane damage will become a serious problem with the V45.

The V45 lost significantly less fruit both to the ground and in the crown (table 1) than did the Rotary. On average, the V45 reduced total fruit loss by 44% compared to the Rotary. Design changes for the V45 harvester that included moving the prow back into the harvester, shielding the prow supports, placing the shaker farther from the ends of the harvester, and reducing the angle of the catching surfaces to 25° all combined to reduce ground losses to only 8.7% as compared to 15% from the previous experimental design (Peterson and Brown, 1996). The only observable area of loss for the V45 was at the front of the harvester where low hanging canes are lifted and fed into the tunnel.

Michigan experienced an unusually hot growing season in 1995 and an unusually dry growing season in 1996 which caused the mature blueberries to be difficult to detach. However, the cooperating grower was pleased with the selectivity and removal abilities of the V45 harvester. When harvesting 'Elliott', the V45 harvester had

Table 1. Average harvester fruit loss for 'Bluecrop' in 1996

Harvest Technique	Harvest Date	Fruit Loss (%)		
		Ground	Crown	Total
V45	7/31/96	10.0 a	1.6 c	11.6 b
	8/07/96	7.1 b	1.2 c	8.3 c
	8/14/96	6.6 b	1.6 c	8.3 c
	8/21/96	5.4 b	1.2 c	6.6 c
Rotary	7/31/96	11.8 a	4.5 a	16.5 a
	8/07/96	10.2 a	3.7 ab	13.9 ab
	8/14/96	12.3 a	4.3 ab	16.6 a
	8/21/96	12.0 a	3.4 b	15.4 a
V45	Average	7.3	1.4	8.7
Rotary	Average	11.6	4.1	15.6
Analysis of variance				
Harvest technique		**	**	**
Harvest date		*	*	**
Harvester × harvest date	*	NS	NS	

NS, *, ** = Nonsignificant or significant at P < 0.05 or 0.01, respectively. Mean separation within columns by Duncans multiple range test, P = 0.05 df = 21.

Table 2. Total harvest weight and average packout for 'Elliott' in 1995

Harvest Technique	Harvest Wt. (kg)	Packout (%)			
		Market-able	Clusters and Soft	Under-size	Natural and Machine Defects
V45	102.5	79.8	4.4	14.7	1.1
Rotary	104.0	71.3	3.6	23.4	1.6
Analysis of variance					
Harvester	NS	*	NS	*	**

NS, *, ** = Nonsignificant or significant at P < 0.05 or 0.01, respectively, df = 6.

significantly more marketable fruit packout than did the Rotary harvester (table 2). This difference was due to fewer undersized berries, and fewer berries removed from the sorting belt (natural and machine defects) with the V45 harvester than with the Rotary. The exterior quality of the fruit from the V45 harvester was so good that the cooperating grower included it in an overnight shipment of fresh market fruit to Europe. On average, there was no significant difference in the commercial packout between the V45 and Rotary when harvesting 'Bluecrop' (table 3). There were also no significant differences in the average fruit weight harvested by both harvesters, although there was week to week differences.

There were considerable differences in internal fruit quality and berry firmness between the two harvesters with both 'Elliott' and 'Bluecrop'. After nine days in cold storage and 42 additional days in CA storage, the V45 harvester had 20% and 37% more 'Elliott' berries in the None and Slight bruise categories, respectively, than did the rotary harvester (table 4). For these categories (long term fresh market quality), there were no significant differences for either storage treatment between the V45 harvester and the preharvest sample; although the preharvest sample averages tended to be slightly higher. Berry firmness for all harvest techniques followed the same trends as internal fruit quality. On average for 'Bluecrop', the V45 harvester had 64% more berries in the None and Slight bruise categories than the Rotary harvester and

Table 3. Average harvest weight and packout for 'Bluecrop' in 1996

Harvest Technique/ Harvest Date	Harvest Wt. (kg)	Packout (%)			Natural and Machine Defects
		Market-able	Clusters and Soft	Under-size	
V45					
7/31/96	21.5 cd	70.5 d	17.8 a	1.7 b	10.0 a
8/07/96	29.7 b	85.8 ab	10.9 bc	0.5 b	2.8 c
8/14/96	25.0 bc	79.7 bc	12.8 bc	0.7 b	6.8 b
8/21/96	13.2 ef	79.0 c	9.9 c	5.2 a	5.9 b
Rotary					
7/31/96	38.0 a	86.7 a	8.9 c	0.7 b	3.8 c
8/07/96	30.1 b	80.2 bc	15.6 ab	0.8 b	3.4 c
8/14/96	17.1 de	77.1 c	12.6 bc	1.3 b	9.0 a
8/21/96	8.5 f	78.3 c	10.7 bc	4.9 a	6.1 b
V45					
Average	22.3	78.8	12.8	2.0	6.4
Rotary					
Average	23.4	80.6	11.9	1.9	5.6
Analysis of variance					
Harvest technique	NS	NS	NS	NS	*
Harvest date	**	NS	NS	**	**
Harvester × date	**	**	**	NS	**

NS, *, ** = Nonsignificant or significant at P < 0.05 or 0.01, respectively. Mean separation within columns by Duncans multiple range test, P = 0.05 df = 21.

significantly higher firmness (table 5). On average, there was no significant difference in the percentage of 'Bluecrop' berries in the None and Slight bruise categories between the V45 harvester and commercial hand harvesting. However, the V45 harvester maintained berry firmness better than did the commercial hand harvesting.

The cooperating grower used the V45 harvester to harvest other blueberry plantings. All of the harvested fruit was sorted in their grading line, and marketable fruits were packed and sold on the fresh market (some were even held in CA storage before sale).

CONCLUSIONS

1. A commercial prototype mechanical harvester, V45, was developed with the size and maneuverability similar to conventional harvesters.

Table 5. Average firmness and internal bruising for 'Bluecrop' in 1996

Harvest Technique/ Harvest Date	Firmness (g/mm)	Bruising (%)				
		None	Slight	None + Slight	Moderate	Severe
Pre-harvest control						
7/31/96	157 a	97.5 a	1.5 i	99.0 a	1.0 g	0.0 g
8/07/96	141 b	89.0 ab	7.3 hi	96.3 ab	1.0 g	2.8 g
8/14/96	139 bc	75.3 bc	15.8 efg	91.0 abc	3.8 fg	5.3 fg
8/21/96	143 b	77.5 bc	12.0 gh	89.5 abc	6.5 efg	4.0 g
V45						
7/31/96	131 cd	57.3 de	28.8 ab	86.2 abcd	8.2 def	5.7 fg
8/07/96	128 de	65.2 cde	19.5 cdefg	84.7 bcde	5.7 efg	9.7 defg
8/14/96	121 ef	42.8 fg	27.0 bc	69.8 f	10.5 cde	19.7 cd
8/21/96	128 de	38.3 g	18.8 defg	57.2 g	16.2 abc	26.7 bc
Rotary						
7/31/96	112 gh	19.8 h	35.0 a	54.8 gh	20.8 a	24.3 c
8/07/96	107 gh	21.2 h	23.8 bcde	45.0 ghi	18.3 ab	36.7 ab
8/14/96	105 h	23.8 h	19.8 cdefg	43.7 hi	18.0 ab	38.3 a
8/21/96	116 fg	20.8 h	17.3 efg	38.2 i	20.2 a	41.7 a
Commercial hand						
7/31/96	110 gh	53.0 ef	26.0 bcd	79.0 cdef	13.0 bcd	8.0 efg
8/07/96	115 fg	71.0 cd	15.0 fg	86.0 abcd	5.0 efg	9.0 defg
8/14/96	109 gh	56.0 ef	16.0 efg	72.0 ef	9.0 def	19.0 cde
8/21/96	113 fgh	55.0 ef	21.0 cdef	76.0 def	8.0 def	16.0 cdef
Pre-harvest control						
Average	145 a	84.8 a	9.1 c	93.9 a	3.1 c	3.0 c
V45						
Average	127 b	50.9 c	23.5 a	74.4 b	10.1 b	15.4 b
Rotary						
Average	110 c	21.4 d	24.0 a	45.4 c	19.3 a	35.3 a
Commercial hand						
Average	112 c	58.8 b	19.5 b	78.3 b	8.8 b	13.0 b
Analysis of variance						
Harvester	**	**	**	**	**	**
Harvest date	**	**	**	**	**	**
Harvester × date	*	*	**	NS	NS	NS

NS, *, ** = Nonsignificant or significant at P < 0.05 or 0.01, respectively. Mean separation within columns by Duncans multiple range test, P = 0.05 df = 45.

2. An angled double-spiked-drum shaker was developed and demonstrated potential for commercial reliability and effectiveness in removing mature blueberries.
3. The V45 harvester was effective in harvesting 'Elliott' and 'Bluecrop' blueberries for the fresh market. Packout of marketable fruit was as good as or better than that from the Rotary harvester.
4. Berry firmness and internal fruit quality that is needed for long-term shelf life was significantly better from the V45 harvester than from the Rotary harvester, and at least as good as commercial hand harvested fruit.

Table 4. Average firmness and internal bruising for 'Elliott' in 1995

Harvest Technique	Storage Conditions	Firmness (g/mm)	Bruising (%)				
			None	Slight	None + Slight	Moderate	Severe
Pre-harvest control							
V45	9 days cold	111 b	95.0 b	3.5 a	98.5 c	1.5 a	0.0 a
Rotary	9 days cold	99 ab	82.7 b	13.8 b	96.5 c	2.0 a	1.5 a
		92 a	47.2 a	33.2 d	80.3 b	9.3 c	10.3 ab
Pre-harvest control							
V45	9 days cold	100 ab	94.5 b	1.0 a	95.5 c	1.5 a	3.5 a
	42 Days CA						
Rotary	9 Days cold	97 a	84.0 b	6.0 a	90.0 bc	2.0 a	8.0 a
	42 Days CA						
Rotary	9 Days cold	90 a	49.5 a	16.0 bc	65.5 a	3.0 ab	31.5 c
Analysis of variance							
Harvest technique		*	**	**	**	**	**

NS, *, ** = Nonsignificant or significant at P < 0.05 or 0.01, respectively. Mean separation within columns by Duncans multiple range test, P = 0.05 df = 15.

5. Modifications made to the prow and cane positioning system of the V45 were effective in reducing fruit loss, and total ground losses were reduced by 44% compared to the Rotary.

RECOMMENDATIONS

Continue development and refinement of V45 commercial prototype with extensive testing on a wider range of fresh market blueberry cultivars.

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