Research Updates

Reducing Sweet Cherry Damage in Postharvest Operations

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SUMMARY. Damage (pitting and bruising) to sweet cherries during packing line operations was evaluated in a 3-year study conducted in California, Washington, and Oregon. A large percentage of cherries sampled before packing developed damage symptoms (28% in 1992 and 35% in 1993 and 1994), suggesting that damage is imparted during growing,

harvest, or transport to the packing house. Packing line operations caused an average of 39% pitting and 10% bruising. The greatest damage was imparted by cluster cutters (20% pitting) and shower type hydrocoolers (19% pitting). Results from this study demonstrate that packing line damage can be reduced by slowing fruit speed in cluster cutters, operating cluster cutters at high fruit-throughput rates, and reducing water drop height in shower hydrocoolers.

Cherry fruit are susceptible to mechanical damage caused by impact or compression. Mechanical damage may occur during picking, transporting to the packing house, packing, or transporting to market. Several days after harvest, damaged fruit develop small sunken areas on the fruit surface, called pits, or larger flattened areas, called bruises. Pitting and bruising are leading causes of product rejection and price adjustment requests by produce receivers.

Low soluble solids concentration, low fruit temperatures, and low fruit mass are associated with susceptibility to mechanical damage in cherry, while preharvest gibberellic acid sprays have been reported to reduce cherry damage susceptibility (Crisosto et al., 1993; Facteau and Rowe, 1979; Lidster and Tung, 1979, 1980; Lidster et al., 1980; Patten and Patterson, 1985a, 1985b). Managing postharvest handling, such as minimizing drop heights, installing smooth contact surfaces, and dipping in calcium solutions can reduce damaging effects of mechanical stress (Facteau and Rowe, 1979; Lidster and Tung, 1979; Patten and Patterson, 1985a).

Limited research has been con-

ducted to identify specific orchard and packing house operations that cause damage. Over a 3 years, Kupferman and Miller (1990) surveyed packing houses in Washington and Oregon to determine fruit damage caused by orchard and packing house operations and reported that 79% of fruit was pitted and 4% bruised before entering the packing house; 95% and 58% of packed fruit were pitted and bruised, respectively. They did not identify management practices or equipment designs that could reduce mechanical damage during orchard or packing shed operations.

This project was designed to identify packing house operations that cause mechanical damage to fresh market sweet cherries and to develop specific recommendations for reducing fruit damage.

Materials and methods

PACKING HOUSE SURVEY, 1992. During the 1992 season, Bing cherries entering and exiting packing houses in California were sampled to quantify typical damage levels for orchard and packing house operations and to identify specific orchards or packing houses doing a particularly good job of fruit handling. We sampled fruit from 11 packing lines in 10 packing houses. Each line was sampled at least eight times during the 1992 season. Packing houses were visited two to three times weekly on a rotational basis and were varied occasionally to accommodate participating houses' operating schedules. This procedure ensured that our samples were representative of fruit packed over the harvest season at each site.

Four, 25- to 40-fruit samples were collected from field bins or boxes just before they entered the packing line. After waiting long enough for fruit from sampled containers to reach the end of the packing line, a second set of four 25- to 40-fruit samples were collected at the end of the packing line from fiberboard boxes packed for domestic sale or from pallet bins containing fruit to be fumigated for export. We made no attempt to analyze individual handling procedures at each facility other than to note whether fruit arrived at packing houses in bins or field boxes.

Samples were held in 1-pint polypropylene plastic berry baskets at 50 °F (10 °C) and 50% to 60% relative

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humidity for 3 d to allow visible development of pitting and bruising damage. In preliminary tests, we determined that these storage conditions would allow rapid expression of pitting and bruising damage for comparing samples. A subsample of ≈ 25 fruit (free of spurred, doubled, sutured, or decayed fruit) from each sample were evaluated for damage by a single trained evaluator. Fruit were classified as pitted if they had one or more small, distinctly sunken areas >0.08 inch (2 mm) in diameter, or bruised if they had one or more large, soft, flat, or indented areas on the fruit surface. This definition of pitting and bruising is severe, and much of the fruit we categorized as damaged was marketable.

Packing damage (pitting or bruising) was calculated by subtracting percent damage before packing from percent damage after packing, dividing by percent undamaged fruit before packing, and multiplying by 100. This percentage corresponds to amount of fruit damaged during packing if all incoming fruit were undamaged, and allows comparisons among packing operations with differing levels of incoming damage. An analysis of variance (ANOVA) was used to evaluate packing lines as the main effect. Data were analyzed as the average value for damage in incoming and line-imparted damage. Mean separation of significant main effects was done using Fisher's protected least significant difference (LSD).

PACKING LINE OPERATION STUDIES, 1993 AND 1994. Damage imparted

by specific packing line operations was investigated at 10 Bing cherry packing houses in California, Washington, and Oregon. Five packing houses were located in California (one in 1993, four in 1994); three in Washington (two in 1993, one in 1994); and two in Oregon (1994). All of the packing houses used similar arrangements and types of equipment, although differences were apparent in equipment age, operation, and maintenance. We collected a 30- to 100-fruit sample at each facility before and after each major piece of packing line equipment. Our common sampling points were 1) from bins or boxes before dumping, 2) on the conveyor carrying fruit out of the bin dump, 3) after the cluster cutter (this sample included damage imparted by the leaf remover), 4) after the small fruit eliminator, 5) after hand sorting tables, 6) after the hydrocooler, 7) after the cherry sizer, and 8) after box or bin filling. Each line was sampled three times on the same day. Samples were taken while packing lines were operating under normal conditions. A marker, yellow fruit or a golf ball, was placed on the bin dump conveyor and samples were collected after the marker passed each sampling location. This procedure minimized error caused by bin-to-bin variation in fruit quality.

Samples were evaluated after 2 weeks storage in loosely sealed polyethylene bags at 33 °F (0.5 °C), and 1 d at 68 °F (20 °C). We found that fruit stored under these conditions had full expression of pitting and bruising damage and less tendency to lose moisture and soften than fruit held in the

polypropylene baskets used in our 1992 study.

Fruit evaluations were performed as described for our 1992 studies. Damage (pitting or bruising) imparted by individual line operations was calculated as the difference in the amount of fruit damaged before and after the operation, divided by the amount of undamaged fruit en-

tering that operation, and multiplied by 100.

ANOVA was used to evaluate damage imparted by packing line operations (main effect). Data were analyzed as mean percent damage ($n = 3$) for each operation. Packing houses were considered replications. Mean separation of significant main effects was done using Fisher's protected LSD.

LINE OPERATION MODIFICATIONS. Fruit throughput rate was varied in two houses to test its effect on fruit damage. Fruit throughput is defined as the rate at which fruit is processed by a packing line and is expressed as tons of fruit per hour of operation. Throughput was varied, from 4.1, 9.0, and 11.3 tons per hour in one packing house and 4.4, 6.7, and 10.2 tons per hour in another, by changing the rate of bin dumping and speed of the conveyor lifting fruit out of the bin dump. No other equipment speeds were changed. Fruit samples (100 fruit) were collected for damage evaluations at various locations along the packing line. Each line was sampled twice at each of three throughput levels.

We measured the effect of varying the cluster cutter belt speed on cherry damage in four houses. Belt speed was varied by changing belt drive gear sprockets (three houses) or by adjusting an electronic motor speed controller (fourth house). Two to three 100-fruit samples were collected before and after the operations at each speed. Fruit throughput was held constant during these tests.

We compared pitting damage with water drop height in shower type coolers at eight houses, using fruit damage data from our 1993 and 1994 line operation studies. Water drop height was measured from the shower pan to the conveyor belt. Several coolers had water diffusing screens ($\approx 0.085 \times 0.085$ -inch mesh, 2.1×2.1 mm) installed below the shower pan parallel to the conveyor belt. In these coolers, water drop height was measured from the screen to the conveyor.

Fruit damage was determined as described for the 1993 and 1994 packing house studies. Correlation and regression analyses were done to relate average fruit damage to cluster cutter belt speed, hydrocooler water drop height, and rate of fruit throughput.

Results and discussion

PACKING HOUSE SURVEY, 1992. In

Table 1. Average cherry damage levels (pitting and bruising) observed on arrival and imparted during packing at eleven California packing lines, 1992.

Packing house (line)	Fruit damaged (%)	
	Before packing	During packing
1	24.5	46.1
2	31.4	34.9
3	30.7	30.7
4	26.3	25.6
5	37.8	25.2
6	25.5	24.8
7	29.8	24.0
8	22.6	12.7
9	32.0	3.7
10(a)	22.1	20.2
10(b)	22.6	6.1
LSD _{0.05}	NS	16.5

^{NS}Nonsignificant.

our survey, an average of 27.8% of fruit was damaged before packing house arrival (Table 1). There was no statistically significant difference among packing houses ($P > 0.05$) in the amount of fruit damaged before house arrival. Fruit transported to packing houses in bins and boxes had similar ($P > 0.05$) damage levels (27.4% and 29.5%, respectively, data not shown).

The amount of fruit damaged during packing varied significantly among packing lines ($P < 0.05$), with one line causing only 3.7% average damage and another causing 46.1%. The two packing lines with the lowest damage during packing (lines 9 and 10b) had different equipment designs. Equipment in packing line 9 was relatively old with a dry box dump and dry conveyor belt transfers. It used a saw type cluster cutter operated at a low belt speed (≈ 1.5 feet per second, $0.5 \text{ m}\cdot\text{s}^{-1}$) and low fruit throughputs (4 to 5 tons per hour). Line 10b was in its second year of operation in 1992, and used water flumes to move fruit between operations. It had a saw type cluster cutter operated at a relatively high belt speed (≈ 2.7 feet per second, $0.8 \text{ m}\cdot\text{s}^{-1}$) and throughputs (10 to 14 tons per hour). Neither line included a hydrocooler. These results suggest that old and new packing house equipment can be operated with low levels of fruit damage.

PACKING LINE OPERATION STUDIES, 1993 AND 1994. Fruit arriving at packing houses had an average of 35% pitting and 19% bruising (data not shown). Line operations caused an additional average of 39% pitting and

10% bruising damage, resulting in a total average of 58% pitting and 27% bruising. These prepacking house damage levels support results of our 1992 survey and those of Kupferman and Miller (1990).

Cluster cutting and hydrocooling caused significantly more pitting than other line operations (Table 2). Bin dumping, deleafing, small fruit elimination, sizing, hand sorting, and box filling imparted relatively little pitting damage. Bruising damage did not differ significantly among line operations, but tended to be greatest in operations that caused the greatest pitting damage.

Cluster cutters in the 10 sampled houses were saw-type units, in which fruit is conveyed on a rubber or plastic belt past plastic tines positioned at a narrow angle to the belt and pointed against the direction of fruit flow. Clusters of fruit are caught on the tines and the moving belt causes stems to move into rotating saws which sever the stems. Cluster cutters imparted pitting damage to an average of 20.3% of fruit and bruised 3.4% of fruit. Video footage taken at several houses revealed that cherries passing through cluster cutters sometime strike the ends of the plastic tines. When cherries hit tines directly, they bounce back and momentarily move against the flow of fruit. We hypothesized that the impact on the tines was the principle source of damage in cutters, and that those packing houses with slow belt speeds would have low tine impact forces and cause less damage than those with faster belt speeds. Cherries dropped 1 inch (25 mm) onto the tip of a tine fell at a speed of 2.3 feet per second ($0.7 \text{ m}\cdot\text{s}^{-1}$) and developed 90% pitting damage (Thompson and Grant, unpublished). Cluster cutters typically operate at belt

speeds greater than 2.7 feet per second ($0.8 \text{ m}\cdot\text{s}^{-1}$).

Hydrocoolers are continuous, in-line units that remove heat either by showering fruit with cold water or by moving immersed fruit through a cold water bath. Shower type coolers used at seven of the 10 packing houses caused an average of 18.6% pitting damage and 9.6% bruising damage. Immersion coolers (two houses, not included in Table 2) caused relatively little damage (3.5% pitting, -2.5% bruising).

Bin dumping and deleafing caused an average of 4.4% pitting and -0.8% bruising. Eight of the 10 houses had water bath bin dumps, in which fruit bins were tilted and emptied into water-filled tank, where flighted inclined conveyors lifted the fruit out of the bath to the next operation. Dry bin or field box dumps onto flat belt conveyors were used in the other two houses. Deleafing uses an air stream blowing up through a bar conveyor to separate leaves from fruit. Our sampling locations were such that this operation was combined with a transfer from the inclined conveyor from the bin dump to the deleafing bar conveyor. In three lines, we sampled this operation separately and found it caused no significant damage (data not shown). This seemed reasonable because fruit moves slowly through deleafers and drops are short.

Small fruit eliminators consist of banks of paired, smooth, counter-rotating rollers that slope downward so fruit slides between them. The gap between roller pairs increases slightly in the direction of fruit travel. Small fruit drops between the rollers and is not packed. Larger fruit is carried down the rollers and drops onto belts or into water flumes that carry it to hand

Table 2. Pitting and bruising damage caused by individual operations in ten Bing cherry packing houses in California (5), Washington (3), and Oregon (2), during 1993 and 1994.

Operation	Fruit damaged (%)	
	Pitting	Bruising
Bin dump and deleafing	4.4	-0.8
Cluster cutter	20.3	3.4
Small fruit eliminator	1.0	-0.6
Hand sorting	0.0	-1.9
Hydrocooler	18.6	9.6
Sizer	-7.1	3.5
Box filling	-0.1	1.3
LSD _{0.05}	11.5	NS

^{NS}Nonsignificant.

Table 3. Effect of fruit throughput rate on damage (pitting and bruising) imparted to Bing cherries processed at two packing houses.

Packing house	Throughput rate (tons/h) ^a	Fruit damaged (%)	
		All operations	Cluster cutter
1	4.1	70.4	43.1
	9.0	74.2	25.4
	11.3	63.5	1.7
2	4.4	90.0	53.7
	6.7	87.5	45.2
	10.2	93.0	41.8
r^2		0.06 ^{NS}	0.58 [*]

^aAverage of two tests at each site.

^{NS}, ^{*}Nonsignificant or significant at $P \leq 0.05$, respectively (one-tailed test).

Fig. 1. Effect of cluster cutter belt speed on cherry pitting damage for saw-type cluster cutters. Regression based on belt speed in feet per second: $y = -29.57 + 0.36x$, $r^2 = 0.52$, $P = 0.0008$.

sorting tables. Eliminators caused an average of 1.0% pitting damage and appeared to reduce bruising damage slightly. Sizers are similar in design and operation to eliminators, except that fruit is separated by size as it falls between rollers, and is subsequently packed by size category. Sizers caused low levels of pitting damage but bruised an average of 4% of fruit. Damage susceptibility is negatively correlated with fruit size and maturity (Facteau and Rowe, 1979), and the removal of small fruit by eliminators and sizers may account for observed reductions in damage at these line operations. Samples collected after eliminators and

sizers typically did not include the small fruit removed by these operations. Damage evaluations performed on separate samples of small and large fruit exiting sizers at three houses confirmed this hypothesis. Small fruit averaged 14.8% bruising, compared to 2.8% for large fruit (significant F test, $P < 0.05$).

During hand sorting, fruit is distributed over a flat conveyor belt and manipulated by human sorters. Immature, misshapen, and damaged fruit are removed and discarded. Pitting damage was not affected by hand sorting. Bruising was reduced slightly, possibly due to the elimination of small fruit. Negative damage values for other operations are attributed to sample variability.

LINE OPERATION MODIFICATIONS. There was no effect of rate of fruit throughput on damage imparted by all packing operations combined (Table

3, $P > 0.05$). The only individual operation that showed an effect of fruit throughput was the cluster cutter. Fruit damage decreased as fruit throughput in the cluster cutter increased. We speculate this occurred because high throughput rates decrease the probability of direct and damaging fruit-time impacts. Cluster cutters should not be operated at low fruit throughput rates for prolonged periods, unless belt speed is low. The low damage levels at line 10b in our 1992 survey suggest that low damage is possible at higher speeds, providing fruit throughput is high.

Slowing cluster cutter belt speed reduced pitting (Fig. 1). Low damage levels were obtained at speeds close to 1.3 feet per second ($0.4 \text{ m} \cdot \text{s}^{-1}$). Two packing house managers indicated that they would have trouble keeping cluster cutters free of clogged fruit at speeds as low as 1.3 feet per second, although we have occasionally observed cluster cutters operating near this speed. In practice, it may be best to equip cluster cutter belts with electronic speed controls and adjust them to operate as slowly as possible without causing clogs.

Because we held fruit throughput constant, belt loading rates (number of fruit per unit belt area) increased with decreasing belt speed during our tests. In our fruit throughput tests, cluster cutter fruit damage decreased with increased fruit throughput, and we speculate that this was due to higher fruit loading rates. It is possible that some of the damage reduction associated with slower belt speeds was caused by increased fruit loading rates. How-

Fig. 2. Effect of hydrocooler water drop height on pitting damage to Bing cherries. Regression based on water drop measured in inches: $y = 1.39 + 1.04x$, $r^2 = 0.41$, $P = 0.062$.

ever, we believe it is reasonable to attribute at least a portion of the damage reduction at slower speeds to lower fruit-time impact forces caused by slower belt speeds.

Shower-type hydrocoolers are known to damage leafy vegetables because of water falling onto product from excessive distances (R.F. Kasmire, personal communication). Pitting was low when water drop was <8 inches (20 cm) (Fig. 2). Diffusing screens made only of expanded metal did not reduce damage as much as those made of expanded metal covered with plastic screening. Shower coolers that caused high levels of pitting damage also bruised a large percentage of fruit (Table 2), and reducing water drop height should reduce cherry bruising damage. Several types of screening are available and have been used successfully in hydrocoolers. The mesh size of screening used in this application must be small enough to intercept and reduce the velocity (but not the flow rate) of water droplets falling from the distribution pan.

Most prior work focusing specifically on packing house sources of damage has emphasized reducing the number and height of fruit drops to hard surfaces, or cushioning these drops at equipment transitions. Recent packing house designs have made increasing use of water flumes in place of conveyor belts and water troughs to receive fruit at elevators to accomplish these objectives. We have identified operations most likely to cause damage and have recommended design or operational changes that will help reduce damage.

Literature cited

Crisosto, C.H., D. Garner, J. Doyle, and K.R. Day. 1993. Relationship between fruit respiration, bruising susceptibility, and temperature in sweet cherries. *HortScience* 28:132-135.

Facteau, T.J. and K.E. Rowe. 1979. Factors associated with surface pitting of sweet cherry. *J. Amer. Soc. Hort. Sci.* 104:706-710.

Facteau, T.J. 1985. Postharvest bruising, GA or Ca. *Proc. 81st Annu. Washington State Hort. Assn.*

Kupferman, E.M. and K. Miller. 1990. Cherry warehouse survey report. Washington State Univ.

Lidster, P.D. and M.A. Tung. 1979. Identification of deformation parameters and fruit response to mechanical damage in sweet cherry. *J. Amer. Soc. Hort. Sci.* 104:808-811.

Lidster, P.D. and M.A. Tung. 1980. Effects of fruit temperatures at the time of impact damage and subsequent storage temperature and duration on the development of surface disorders in sweet cherries. *Can. J. Plant Sci.* 60:55-559.

Lidster, P.D., K. Miller, and M.A. Tung. 1980. Effects of maturity on fruit composition and susceptibility to surface damage in sweet cherries. *Can. J. Plant Sci.* 60:865-871.

Mitchell, F.G., G. Mayer, and A.A. Kader. 1980. Injuries cause deterioration of sweet cherries. *California Agr.* 34:14-15.

Patten, K.D. and M.E. Patterson. 1985. Fruit temperature effects on mechanical damage of sweet cherries. *J. Amer. Soc. Hort. Sci.* 110:215-219.

Patten, K.D. and M.E. Patterson. 1985. Fruit moisture status effects on mechanical damage of sweet cherries. *J. Amer. Soc. Hort. Sci.* 110:537-541.

Bell Pepper Yields Not Affected by Stand Deficiencies or Replanting

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ADDITIONAL INDEX WORDS. transplant, polyethylene mulch, missing plants, plant population, early yield, stand establishment

SUMMARY. Field studies were conducted in Spring 1991, 1992, and 1993 to determine if stand deficiencies of 10%, 20%, or 30% affected bell pepper (*Capsicum annuum* L.) yield and fruit size. Subsequent replanting to a 100% stand and timing of replanting also were evaluated for effects on fruit yield. Stand deficiencies of up to 30% and replanting to a complete stand 2 or 3 weeks after initial transplanting did not affect yield per acre and average weight per fruit of bell pepper plants grown on polyethylene-mulched beds during 3 years of tests. Bell pepper plants grown in 10%, 20%, or 30% deficient stand had greater marketable yield per plant than plants grown in 100% stand. Replanting to a complete stand 3 weeks after initial transplanting decreased early marketable yield and production per plant over replanting 2 weeks after initial transplanting.

Bell pepper is grown extensively in southeastern Louisiana on fumigated, raised beds, covered with polyethylene mulch, with irrigation and using transplants. Due to the intensive system of production, cost of establishing the crop is estimated at \$1600 per acre (\$4000 per ha) (Boudreaux et al., 1992). Plant losses occurring during or shortly after

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