'Redhaven' Peach Impact Damage Thresholds

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Abstract. 'Redhaven' peaches [*Prunus persica* (L.) Batsch] were dropped onto several impact surfaces to determine impact conditions that initiate bruising. After impact, the peaches were tested for flesh firmness and sorted into firm, soft, and very soft groups for bruise analysis. The drop height that did not bruise decreased as fruit softened. The peach shoulder area bruised most easily. A drop of only 8 mm onto a hard surface initiated bruising on a soft peach, whereas a Poron 15250 cushion could protect the peach for a ≤ 85 -mm drop. Impact damage threshold estimates were developed for the three flesh firmness conditions. The threshold estimates and impact history information collected by an instrumented sphere can be used to develop handling equipment design and operation guidelines that essentially avoid impact bruises on peaches.

Fruit bruising is related to the maximum deceleration and deformation of a fruit when it hits a surface and is a function of fruit mass, impact velocity, impact surface properties, and fruit tissue properties (O'Brien et al., 1983). Peach growers and packers in Michigan stated that 'Redhaven' usually presented them with serious bruising problems and therefore would be a good cultivar to study for developing bruise avoidance guidelines.

Peaches (freestone and clingstone) are characterized by dense juicy tissue, with a low volume of air-filled interstitial space (Maness et al., 1992). Bruises resulting from slight to moderate impact damage occur when tissue fracture strength is reached. Bruises generally develop somewhere below the skin surface, where the shear stress is maximum, as internal "shatter cones" with cone-shaped and radial fractures (Horsfield et al., 1972; Kunze et al., 1975; Vergano et al., 1991). Soft discolored bruises develop closer to the skin surface as the tissue softens through ripening and under severe impact conditions.

Previous research has identified the relationships of impact energy and resulting bruise response, as defined by bruise dimensions (Brusewitz et al., 1991a; Hung and Prussia, 1989; Kunze et al., 1975; Vergano et al., 1991). Peach impact bruising as a function of

cultivar, maturity, time in storage, and temperature also has been addressed (Brusewitz et al., 1991b; Fridley and Adrian, 1966; Hung and Prussia, 1989). Kunze et al. (1975) and Peterson and Colorio (1990) compared peach response to impact conditions and surfaces similar to those found during mechanical harvesting. In general, these studies evaluated either impact conditions onto thickly cushioned surfaces, resulting in negligible bruise damage, or hard-surface impacts that generally cause large bruises. Although these previous studies indicated that in some test conditions, 100% bruising was avoided, they did not identify the impact conditions (drop heights and surfaces) for which bruise initiation was avoided.

Bruise threshold response lines (conditions for which 0%, 50%, and 100% of the fruit are expected to bruise) have been developed for apples (*Malus domestica* Borkh.) (Schulte et al., 1991a), dry onions (*Allium cepa* L.) (Timm et al., 1991), potatoes (*Solanum tuberosum* L.) (Hyde and Mathew, 1992), and tomatoes (*Lycopersicon esculentum* Mill.) (Sargent et al., 1991) and have been correlated to impact data collected by the Instrumented Sphere (IS) (model IS 100; Techmark, Lansing, Mich.) described by Zapp et al. (1990). This information is useful in developing postharvest handling equipment that minimizes or avoids bruising.

Our objectives were to 1) determine the minimum impact conditions needed to initiate bruising on three impact surfaces, 2) determine the effect of fruit firmness [firm (35.6 to 53.4 N), soft (17.8 to 26.7 N), and very soft (2.2 to 13.3 N)] on the bruise response for these impact surfaces, and 3) develop a simple means of estimating the potential for bruising relative to impact data collected by the IS and to incorporate this method into the IS software.

Tests were initiated in 1990 (Schulte et al., 1991b) and were repeated with 'Redhaven' in 1992 to verify the impact bruise thresholds.

Materials and Methods

'Redhaven' peaches were harvested on two separate dates in 1992, 1 week apart, at the Clarksville Horticultural Expt. Station (CHES), Clarksville, Mich. A total of 800 fruit were randomly harvested on each date. The first harvest date was intended to represent firm fruit for long-distance shipments (35.6 to 53.4 N) and the second was to represent soft fruit for short-term storage and local sales (17.8 to 26.7 N). The larger fruit on selected trees were carefully hand-harvested and placed in polystyrene soft trays (24 cells per tray) and cellmaster cartons (96 fruit per carton) in the orchard to minimize handling and transport damage. The fruit remained at nominal ambient temperature (21°C) throughout the experiment. Before testing at CHES, fruit with obvious defects, excessive shape irregularities, and split pits were discarded. The remaining fruit were randomly placed into 20-fruit test groups. Impact testing was completed within 4 h of harvest.

Schulte et al. (1991b) indicated that the peach shoulder and suture areas were more sensitive to bruise initiation than the cheek, so only these two areas were tested.

Three flat impact surfaces used in these tests (Table 1) were characterized with the IS as described by Brown et al. (1990). Each impact test involved dropping the 20 peaches in a test group separately on their shoulder and suture areas onto each of the surfaces. A free-fall impact test stand similar to the system designed and described by Timm et al. (1989) was used for the impact tests. Each fruit was carefully oriented in a suspended fruit ring that was guided in a free-fall drop to the impact surface. Correct fruit orientation was always maintained.

The drop height (distance from the bottom of the fruit to the impact surface) was set within ± 0.5 mm using a horizontally positioned, visible laser diode (Power Technology, Little Rock, Ark.). Correct drop height

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Table 1. Impact surface descriptions.

Surface type	Thickness (mm)	Manufacturers code	Density kg·m ⁻³	Stiffness kPa ²
Steel	13	Cold rolled steel	7833	∞
Poron ³	3.17	4701-05-20125-1637	320	18 $\pm$ 5
Poron	6.35	4701-05-15250-1637	240	11 $\pm$ 3

²Expressed as force per unit area at 25% cushion deflection per American Society for Testing and Materials 3574.

³Poron urethane microcell sponge (Rogers Corp., East Woodstock, Conn.).

was determined when the bottom of the suspended fruit just began to interrupt the collimated light beam. A light dusting of chalk, transferred from the surface to the fruit, marked each impact site. A series of drop heights were selected to cover a range of 0% to 100% probability of bruise occurrence. Peaches were dropped on steel and cushions of Poron urethane microcell sponge (Poron; Rogers Corp., East Woodstock, Conn.) over steel. Based on earlier findings and a limited number of trial impacts on fruit similar to the test fruit, the range of drop heights were as follows (in mm): steel, 10 to 120; Poron 20125, 40 to 320; Poron 15250, 200 to 800.

Flesh firmness was measured adjacent to each impact site shortly after impact testing using a Magness-Taylor firmness tester with a 7.8-mm-diameter probe (model FT-327; Effegi, Alfonsine, Italy). The average fruit mass for these tests was 127 ± 14 g.

After testing, all fruit were held at 21°C and 75% to 80% relative humidity for 1 to 2 days and then evaluated for bruise presence (percentage of fruit that bruised at each drop height) and the corresponding bruise size. A thin layer of skin and a vertical wedge of tissue were removed from each impact site to determine the presence of discolored or fractured tissue.

Due to the flesh firmness range of the harvested peaches, it became obvious that the impact results for both harvest dates should be sorted into three categories based on flesh firmness adjacent to the site of impact. Therefore, the data from two 20-fruit groups per drop was pooled and resorted. The final flesh firmness categories were as follows (in N): firm, 35.6 to 53.4; soft, 17.8 to 26.7; and very soft, 2.2 to 13.3. Fruit having firmness outside of these ranges were discarded. At least five fruit of similar firmness were present in each category. The maximum number of fruit in each category was 25, but 15 was more typical. Then, the impact results were analyzed relative to impact orientation (suture or shoulder), impact surface, and drop height.

Exploratory impact tests were conducted in 1990 on two groups of 'Redhaven' peaches, using similar methods. The peaches were harvested ≈ 1 week apart in a commercial orchard to obtain firm and soft fruit. Average fruit mass for these tests for firm fruit and soft fruit was 143 ± 20 and 157 ± 20 g, respectively. Shortly after testing, flesh firmness was measured on 25 randomly selected fruit adjacent to each impact site. It was assumed that the average flesh firmness value would represent all fruit harvested on each date. The average values were as follows (shoulders, suture; in N): firm fruit, 47.6, 49.4; soft fruit, 24.5, 20.0. The two impact surfaces used were steel and a Poron 20125 cushion over steel. Ten fruit were selected for each drop height.

Results and Discussion

In general, once bruising began, the probability of bruising increased with an increase in drop height (Fig. 1). The variability of the data suggests that slight differences in fruit maturity (flesh firmness) and fruit curvature

may have an effect on a peach's bruise response. Peach tissue properties are not homogeneous around its surface, partly due to its orientation relative to sun (blush side) and shade (green side). Brusewitz et al. (1991a) showed that the peak impact force : time ratio to peak force for peaches was low for ripe peaches and red sides but higher for less ripe peaches and green sides. We attempted to compensate for the inconsistency by grouping fruit into final firmness categories relative to the impact area. Despite the variability, we believe that the practical impact conditions at which bruising begins (0% to 10% bruise occurrence) and the potential that all fruit will bruise (100% bruise occurrence) can be estimated. To achieve this goal, bruise occurrence lines (covering the 0% to 100% range) were visually placed on the results so that they represented conservative estimates of the minimum drop height that can be expected to result in a certain level of bruise occurrence. At any bruise probability level, each line defines an allowable drop height that cannot be exceeded without experiencing greater bruising. If regression lines had been fit to these bruise results, they would be located further to the right on the graphs and would imply that greater drop heights can be tolerated before a given bruise probability level is experienced. We propose that peach packers should strive to avoid bruising on their packing lines. Using the allowable drop height lines, we constructed safe drop heights for cushioning materials that enable peach packers to avoid bruising on packing lines (Fig. 1), and estimate the consequences of greater drop heights or inadequate cushioning.

As expected, the drop height above which bruising was initiated on a cushioned surface decreased as maturity increased (Fig. 1E), but it was much lower and nearly equivalent for firm and soft shoulders when dropped on a hard surface (Fig. 1A). Bruising was initiated close to a zero drop height for very soft fruit on steel (Fig. 1G and H), and adding a Poron 20125 cushion to the impact surface gave little or no protection to very soft fruit. The range of drop heights chosen for these tests did not allow us to define the drop height where bruising initiated for very soft fruit on the Poron 15250 cushion, but the height limit appeared to be in the 10- to 20-mm range. More protection probably was required than was available from this cushion.

Thai and Shewfelt (1990) observed that even well-trained pickers in Georgia are not capable of picking peaches of consistent maturity, as represented by ground color hue angle. In these Michigan tests, fruit harvested either firm (early) or soft (late) had 36% to 63% very soft sutures, respectively (Table 2). The inherent problems of nonuniform ripening on the tree and less than adequate determination of firmness during harvest predisposes any harvest operation in the eastern United States to a certain percentage of very soft fruit. The high probability of impact damage to very soft fruit during handling will significantly decrease the apparent quality of a finished pack unless gentle handling practices are followed.

The range of drop heights that resulted in 0% to 100% bruising were 9% to 74% lower for a shoulder than for a suture of equivalent firmness. Although not measured for exact fruit surface curvatures, the tested fruit's sutures appeared fairly flat and not as sharply curved as the shoulders, which may account for the differences in test results. Pronounced sutures on other peach varieties may be more sensitive to impact bruising and respond similarly to the shoulders in this test.

In an earlier study (Schulte et al., 1991b), we concluded that 'Loring' had a 20% lower drop height that initiated bruising than 'Redhaven' peaches. That conclusion may be an artifact of the experimental procedure, because the 'Loring' fruit were heavier and softer than the 'Redhaven' fruit. A soft 'Loring' peach (shoulder, 8.0 N) began bruising on the steel at ≈ 18 mm and reached 100% bruise occurrence at 35 mm. In 1992, 'Redhaven' peaches of similar firmness (very soft shoulder, 2.2 to 13.3 N) had a 0% to 100% bruise occurrence range of near zero to 55-mm drop height on steel. When flesh firmness was similar for the two varieties, there did not appear to be clearly defined differences in the bruise threshold response ranges. Consequently, varietal differences in bruise thresholds may be primarily a matter of fruit size (mass) and shape (i.e., pronounced sutures) rather than flesh firmness or browning differences.

The average bruise size on 'Redhaven' for impact conditions that were approaching 100% bruise probability on steel (50-mm drop) were 6.9 mm diameter $\times$ 4.6 mm deep for soft shoulders, and 6.3 mm diameter $\times$ 4.5 mm deep for firm shoulders (Fig. 1A and B). The corresponding results for the Poron 20125 cushion (190- to 275-mm drop) were 10.4 mm diameter $\times$ 8.3 mm deep for soft shoulders, and 6.3 mm diameter $\times$ 7.5 mm deep for firm shoulders (Fig. 1C and D). The U.S. standards for grades of peaches (U.S. Dept. of Agriculture, 1952) state that fancy and no. 1 grade peaches are free from bruises that materially affect their appearance or edible quality. Our peach bruises sizes and larger will reduce overall grade and consumer appeal. The Poron 15250 cushion avoided bruising on soft shoulders for drop heights ≤ 85 mm. There is no need for drops to exceed this height on any well-designed packing line, but 25- to 75-mm drops are common. Therefore, the Poron 15250 cushion (or its equal) is an essential requirement on packing lines for peaches.

Impact surface characterization lines derived from the IS (velocity change vs. peak acceleration) were combined with the bruise threshold response lines (0% or 100% probability of bruising) for 'Redhaven' peaches. Peak acceleration (G) is the maximum acceleration value ($1G = 9.8 \text{ m}\cdot\text{s}^{-2}$) recorded during the impact pulse. Velocity change (Δv) is the area under the acceleration-time curve for the impact pulse and is calculated by integration. The result (Δv , G) defines the amount of cushioning that is provided by a surface when it is hit by the IS or a peach. Figure 2 combines this information with impacts recorded when an IS was passed over a commercial peach

packing line 10 times. Two flesh firmness conditions (soft shoulder, 17.8 to 26.7 N; firm shoulder, 35.6 to 53.4 N) are presented. Firm peaches begin bruising at 69 G (8-mm drop

height) on steel, whereas the same peaches would be protected at ≤ 232 G (510-mm drop height) by adding a Poron 15250 cushion. Soft peaches begin bruising at 45 G (5-mm drop

height) on steel, but the same cushion will provide protection at a ≤ 85 -mm drop height. The bruise thresholds are further diminished for very soft fruit, but we could not establish

Fig. 1. Bruise probability for 'Redhaven' peach when dropped: (A) shoulder on steel; (B) suture on steel; (C) shoulder on Poron 20125; (D) suture on Poron 20125; (E) shoulder on Poron 15250; (F) suture on Poron 15250; (G) very soft shoulder on all surfaces; (H) very soft suture on all surfaces.

bruise occurrence lines for the Poron 15250 cushion as discussed earlier. With this in mind, it seems that a significant number of impacts recorded by the IS on the packing line indicated that bruising would occur on soft fruit. Adding Poron 15250 at all packing line transfers that have hard or Poron 20125 surfaces and reducing some drop heights would quickly change this packing line to a relatively bruise-free environment for soft and firm fruit (firmness 17.8 N). Very soft fruit need cushioning that requires substantially less force to be indented than that necessary to bruise the fruit, thereby avoiding bruise initiation.

Table 2. Distribution of firmness for 'Redhaven' peaches picked firm (early) or soft (late), 1990.

Harvest time	Test area	% Fruit in each firmness ^z		
		Very soft ^y	Soft ^y	Firm ^y
Early	Shoulder	3.4	19.9	67.2
	Suture	36.3	28.9	26.3
Late	Shoulder	36.9	35.3	14.9
	Suture	62.8	24.1	7.4

^zEffegi penetrometer 7.8-mm-diameter probe.

^yVery soft = 2.2 to 13.3 N; soft = 17.8 to 26.7 N; firm = 35.6 to 53.4 N.

These studies indicate that the shoulder of a soft 'Redhaven' peach consistently bruised at a much lower drop height than a suture of equivalent firmness. Therefore, bruise avoidance must be based on flesh firmness at the shoulder, not the suture or cheek.

The bruise initiation responses and handling impact data collected by the IS can be used to develop conservative cushioning and drop height recommendations to avoid impact bruising on peaches.

Literature Cited

- Brown, G.K., N.L. Schulte Pason, and E.J. Timm. 1990. Impact classification using the instrumented sphere. Paper 90-6001, Amer. Soc. Agr. Eng., St. Joseph, Mich.
- Brusewitz, G.H., T.G. McCollum, and X. Zhang. 1991a. Impact bruise resistance of peaches. Trans. Amer. Soc. Agr. Eng. 34(3):962-965.
- Brusewitz, G.H., X. Zhang, and M.W. Smith. 1991b. Postharvest cooling effects on the bruising of peaches. Paper 91-6036, Amer. Soc. Agr. Eng., St. Joseph, Mich.
- Fridley, R.B. and P.A. Adrian. 1966. Mechanical properties of peaches, pears, apricots, and apples. Trans. Amer. Soc. Agr. Eng. 9(1):135-138, 142.

- Horsfield, B.C., R.B. Fridley, and L.L. Claypool. 1972. Application of theory of elasticity for the design of fruit harvesting and handling equipment for minimum bruising. Trans. Amer. Soc. Agr. Eng. 15(4):746-750, 753.
- Hung, Y.C. and S.E. Prussia. 1989. Effect of maturity and storage time on the bruise susceptibility of peaches (cv. Red Globe). Trans. Amer. Soc. Agr. Eng. 32(4):1337-1382.
- Hyde, G.M. and R. Mathew. 1992. Potato impact damage threshold. Paper 921514, Amer. Soc. Agr. Eng., St. Joseph, Mich.
- Kunze, O.R., W.H. Aldred, and B.D. Reeder. 1975. Bruising characteristics of peaches related to mechanical harvesting. Trans. Amer. Soc. Agr. Eng. 18(5):939-945.
- Maness, N.O., G.H. Brusewitz, and T.G. McCullum. 1992. Impact bruise resistance comparison among peach cultivars. HortScience 27:1008-1011.
- O'Brien, M., B.F. Cargill, and R.B. Fridley. 1983. Principles and practices for harvesting and handling fruits and nuts. AVI/VNR Publishing Co., Florence, Ky.
- Peterson, D.L. and G. Colorio. 1990. Assessing damage susceptibility of peach cultivars for mechanical harvesting. Paper 90-6004, Amer. Soc. Agr. Eng., St. Joseph, Mich.
- Sargent, S.A., J.K. Brecht, J.J. Zoellner, and P. Morgado. 1991. Impact thresholds for mechanical injury to tomatoes and bell peppers. Paper 91-6593, Amer. Soc. Agr. Eng., St. Joseph, Mich.
- Schulte, N.L., G.K. Brown, and E.J. Timm. 1991a. Apple impact damage thresholds. Appl. Eng. Agr. 8(1):55-60.
- Schulte, N.L., E.J. Timm, G.K. Brown, and J. Ladd. 1991b. Peach and pear impact damage thresholds: A progress report. Paper 91-6620, Amer. Soc. Agr. Eng., St. Joseph, Mich.
- Thai, C.N. and R.L. Shewfelt. 1990. Peach quality changes at different constant storage temperatures: Empirical models. Trans. Amer. Soc. Agr. Eng. 33(1):227-233.
- Timm, E.J., G.K. Brown, R.C. Brook, N.L. Schulte, and C.L. Burton. 1991. Impact bruise estimates for onion packing lines. Appl. Eng. Agr. 7(5):571-576.
- Timm, E.J., N.L. Schulte Pason, G.K. Brown, and C.L. Burton. 1989. Apple and impact surface effects on bruise size. Paper 89-6048, Amer. Soc. Agr. Eng., St. Joseph, Mich.
- U.S. Department of Agriculture. 1952. United States standards for grades of peaches. U.S. Dept. of Agriculture, Washington, D.C.
- Vergano, P.J., R.F. Testin, and W.C. Newall, Jr. 1991. Distinguishing among bruises in peaches caused by impact, vibration, and compression. J. Food Quality 14:285-298.
- Zapp, H.R., S.H. Ehlert, G.K. Brown, P.R. Armstrong, and S.S. Sober. 1990. Advanced Instrumentation Sphere (IS) for impact measurements. Trans. Amer. Soc. Agr. Eng. 33(3):955-960.

Fig. 2. Impact surface response lines (1, 2, and 3) for the IS 100 Instrumented Sphere, bruise threshold lines for 'Redhaven' peaches hitting the same three surfaces; impacts (circles) recorded on a commercial peach packing line.