Suspended Tray Package for Protecting Soft Fruit from Mechanical Damage

J. F. Thompson, D. C. Slaughter, M. L. Arpaia

Abstract. *A new suspended fruit packaging system for damage-free transport of soft fruit was developed and laboratory tested. Transit vibration tests simulating a continental U.S. cross-country trip of approximately 4,500 km showed that this suspended fruit system prevents nearly all transport vibration damage to pears when used with a plastic clamshell package and to avocados when used with a plastic clamshell or corrugated fiberboard master container. Comparative damage data are reported for simulated shipment (using American Standards Testing Materials D4169-94 assurance level I) of Hass avocados and Bartlett pears ripened to varying firmness levels.*

Keywords. *Packaging, Vibration damage, Quality, Transportation, Pear, Avocado.*

Many fresh market fruits, especially pears, avocados, peaches, nectarines, tomatoes, are harvested mature but partially ripe, being sufficiently firm to allow them to withstand the physical damage caused by transport and marketing. However consumers prefer these fruit in the ripe condition and will purchase more fruit if they can buy them at optimum eating ripeness (Lee and Coggins, 1982). The fresh fruit industry and the consumer would benefit from a packaging system that would allow ripe fruit to be shipped and marketed without being subject to mechanical damage.

A number of studies have described the mechanisms of soft fruit damage and some have proposed new packing systems to reduce transit injury. Sommer (1957a) reported that dark surface blemishes on Bartlett pears were caused by vibration-induced damage in highway transport. The damage rarely extends into the flesh but does increase moisture loss compared to undamaged fruit. These blemishes are often called 'roller bruising' because loosely packed fruit may rotate during transport causing a band of discoloration around the fruit. Wang and Mellenthin (1973) and Mellenthin and Wang (1974) called the damage friction discoloration and associated it with oxidation of phenol compounds and chlorogenic acid catalyzed by polyphenoloxidase. Fruit may be individually wrapped or packed using the 'tight fill' system (Mitchell et al., 1968) to reduce transit bruising. However neither of these methods proved to be effective. Slaughter et al. (1991, 1992) reported that the 'tight fill' fails in practice because: 1) fruit weights in boxes are not consistent, 2) boxes are not formed consistently so they do not have identical interior volumes, 3) corrugated boxes lose strength and bulge in storage and handling , and 4) few packers use the recommended wood fiber pads that expand to fill void space in boxes. Sommer (1957b) tested the use of shredded paper, shredded polyethylene film, and polyethylene film disks packed with the fruit, but they each proved only partially effective. Cayton (1993) developed a method to secure the fruit in the box by placing large elastic bands around a box to maintain a constant pressure on the fruit. Slaughter et al. (1998) demonstrated that pears packed in polyethylene film bags were much less susceptible to transport vibration damage. Video images of the fruit during simulated transit vibration conditions, acquired by attaching a camera to a vibrating box, showed that fruit in polyethylene bags is prevented from moving with respect to neighboring fruit in the bag (Slaughter et al., 1998). However the fresh pear industry markets only a relatively small amount of fruit in bags. Sales volume of ripe avocado fruit is twice that of hard unripe fruit (Lee and Coggins, 1982). But like pears, avocados are more susceptible to mechanical damage as the fruit soften during ripening (Arpaia et al., 1987).

The concept of a suspended tray (patent pending) was developed to prevent in-transit fruit motion with respect to the interior surfaces of a container or neighboring fruit (fig. 1). The tray is vacuum-formed and contains pockets shaped like pear or avocado fruit with steeply sloping sides so the fruit are wedged into the cup. The deep pockets and sloping sides allow the pockets to accommodate a range of fruit sizes while still immobilizing the fruit above the bottom of the pocket. The pocket is suspended above the bottom of the container so the fruit will not impact the package bottom (or fruit in the package below) during transit vibration. A key aspect of the suspended tray is that the walls of the cup are smooth and flexible (not rough, ribbed, or rigid) allowing the cup to conform to the irregular shape of the fruit, immobilizing the fruit during transit without damaging it.

Submitted for review in July 2007 as manuscript number FPE 7105; approved for publication by the Food & Process Engineering Institute Division of ASABE in October 2007. Presented at the 2006 ASABE Annual Meeting as Paper No. 066188.

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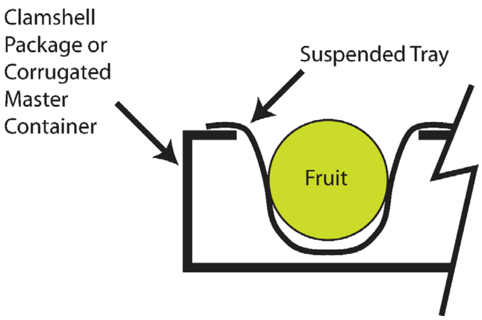
(a)



(b)

Figure 1. Clamshell package with suspended tray (a). Insert shows a bottom section of package cut away to show the tray. Schematic of the system used with the retail clamshell pack and the 12 fruit count master container described in figure 3).

The suspended tray system has been incorporated into a ‘clamshell’ package and a version for more fruit with the tray supported by a corrugated fiberboard structure. The goal of this research was to quantify the ability of the suspended tray system to protect ripe fruit from transport vibration damage.

Materials and Methods

Size 80 Californian Bartlett pears were obtained from a local packinghouse. The fruit had been sorted, sized, and packed after harvest then held in commercial refrigerated storage for several weeks.

Approximately 80 pieces of fruit were placed in a 0°C room to slow continued ripening. An additional 160 pieces of fruit were placed in a 20°C room to allow them to ripen. Fruit firmness was measured regularly on an independent subsample with an automated Magness-Taylor (1925) style penetrometer (FTA, model GS-14, Guss Manufacturing Ltd., Strand, South Africa, www.gusstoday.com) using a standard 7.9-mm diameter tip. The initial penetrometer flesh firmness was 67 N (equal to 15 lb, the industry standard unit of measurement). As the fruit progressively softened two 80 fruit batches were sequentially placed in the 0°C room so that the complete set of 240 test fruit ranged in firmness from the initial level to about 18-N (4-lb) penetrometer firmness.

All fruit samples were then transported a distance of 160 km to a commercial transit vibration test facility in San Jose, California, for simulated transit testing. The fruit were allowed to warm to room temperature and immediately prior to transit vibration testing the firmness of each fruit was measured with a nondestructive impact-type firmness tester (Interim Bench Top model SIQFT-B, Sinclair Systems International, LLC, Fresno, Calif., www.sinclair-intl.com). The firmness tester describes firmness using a relative scale, termed SIQ units. The following package types were included in the test:

- Suspended tray clamshell – six pieces of fruit per clamshell package (fig. 1) four clamshell packages per layer and two stacked layers per corrugated fiberboard master container. The clamshell package was vacuum-formed from 0.483-mm (equal to 19 mil, the industry standard unit of measurement) polyvinyl chloride (PVC) sheet. The bottom section of the clamshell was shaped to provide support around each cup. The tray was formed from 0.127-mm (5-mil) PVC sheet and the cups were shaped to allow the pears to rest horizontally when packed.
- Conventional clamshell – eight pieces of fruit per clamshell, three clamshells per layer and two layers in a corrugated master container (fig. 2). This clamshell pack was vacuum-formed from 0.432-mm (17-mil) polyethylene terephthalate sheet and shaped so pears lay horizontally with half of the fruit contained within the bottom half of the clamshell and a lid with the same shaped depressions covering the top half of the fruit. A key difference between the conventional clamshell and the suspended tray clamshell was that the walls of the conventional clamshell were fairly rigid while the suspended tray walls were more flexible. Also in the conventional clamshell, the weight of the upper layer of clamshells in the master container was partially supported by the fruit below, while in the suspended tray clamshell, the weight of the upper layer was supported by the package walls, not by the fruit.
- Conventional tray pack – 24 fruit per tray, vacuum-formed from 0.102-mm (4-mil) PVC sheet, two stacked trays per corrugated fiberboard master container. Fruit were oriented horizontally in the trays.

A separate portion of fruit was used as a non-vibrated, non-ripened control. These fruit were packed in the same conventional tray packs described as package system number 3 in the above list and were transported to and from the vibration test facility in San Jose, California, with the other fruit, however they were not exposed to the simulated transit test conditions.

The three test packages were subjected to a 30-min random vibration test to simulate a U.S. West to East coast

Figure 2. Conventional clamshell package tested with Bartlett pears.

cross-country trip (approximately 4,500 km) on a refrigerated highway truck with a steel spring suspension system [ASTM Method D4728-91 (1991) and Standard Practice D4169-94 (1994), assurance level I as described in Slaughter et al., 1998]. The fruit, still in the test packages, were then transported by car back to UC Davis and held in a 20°C laboratory for 24 h to allow surface bruising to become fully developed at which time vibration induced bruises appeared as dark brown to black patches on the surface of the fruit. All fruit were rated for vibration bruising damage using a six-point, visual rating method (Slaughter et al., 1993). A rating of 0 = no damage, 1 = trace, 2 = slight, 3 = moderate, 4 = severe, and 5 = extreme damage, where damage levels above 3 are considered unmarketable fruit. After evaluation, selected fruits were retested with the nondestructive impact-type firmness tester and the penetrometer in order to develop a correlation between the industry standard penetrometer and the nondestructive firmness device.

The same ripening procedure was used to determine the ability of the suspended tray to protect Californian Hass avocados from transit vibration damage. The complete set of 480 test fruit ranged in penetrometer flesh firmness from about 50 N (11 lb) to about 2 N (0.5 lb). The following packages were tested:

- Suspended tray clamshell – six pieces of fruit per clamshell, four clamshells per layer, and two stacked layers per returnable plastic master container. This was the same clamshell design used for Bartlett pears.
- Suspended tray – 12 fruit per tray, one tray per corrugated master container (fig. 3). Tray was vacuum formed from 0.254-mm (10-mil) PVC sheet and supported by grid of interlocking corrugated fiberboard strips oriented vertically. Avocados were oriented vertically in the circular cups formed in the trays.
- Conventional rigid paper pulp tray, two stacked trays per corrugated fiberboard master container.
- Conventional loose-filled fruit in a corrugated fiberboard box. No interior packaging.

A separate portion of fruit was used as a non-vibrated, non-ripened control. These fruit were packed in the same single-layer pulp tray described as package system number 3 in the above list and were transported to and from the vibration test facility in San Jose, California, with the other fruit, however they were not exposed to the simulated transit test conditions.

Figure 3. Suspended tray in a corrugated fiberboard container.

All fruit were transported to the same vibration test facility in San Jose, California, and the four test packages were subjected to the same 30-min random vibration test described previously. The fruit were allowed to warm to room temperature before testing and immediately prior to transit vibration testing the firmness of each fruit was measured with the nondestructive impact-type firmness tester described previously.

After vibration testing the fruit were transported by car back to UC Davis. Firm fruit were held at 20°C until they reached the eating ripe stage (4 to 14 N or 1– to 3-lb firmness) prior to evaluation. Each piece was peeled and evaluated for damage using the six-point scale described for the pear tests. Damage was evaluated as flesh discoloration of two longitudinal cross-sections of the fruit, amount of adhered flesh on the inside surface of the peel, and flesh softening on the exterior surface of the peeled fruit. A separate batch of fruit was used to determine the relationship between the nondestructive impact-type firmness tester and the standard penetrometer firmness measurements.

The level of damage observed in each package type was evaluated across a range of fruit firmness categories. For pears, data were grouped in sets of four SIQ units, centered at 38, 42, 46, and 50 units. For avocados, data were grouped in sets of 10 SIQ units, centered at 25, 35,45, 55, and 65 units. These groupings resulted in package type/firmness level categories with about 15 and 19 fruit each for pear and avocados respectively. For both pears and avocados, fruit with transit vibration damage scores of 3 would generally require price discounting to be marketable and fruit with damage exceeding a score of 3 would be considered unmarketable. Thus pears were considered "damaged" by transit vibration if the bruising score was 3 or greater (moderate to extreme damage). Avocados were considered damaged if there were large indentations on the fruit surface or adhering flesh or flesh-browning scores were 3 or greater (moderate to extreme damage).

A Fisher's protected least significant difference (LSD) test was conducted on the average proportion of damaged fruit within each package type/firmness level category. The statistical analysis was conducted using Proc GLM (SAS, 1990) in order to determine if any of the package types were significantly ($\alpha = 0.05$) better at preventing transit vibration damage across different firmness levels. This statistical procedure was selected because it automatically used the harmonic mean number of observations in computing the LSD values for each package type/firmness level category, which varied across package types due to the natural variation in the ripening rates of the fruit.

Results and Discussion

Correlation between Impact and Penetrometer Firmness Measurements

For both fruits the nondestructive impact firmness correlated reasonably well, $r^2 \geq 0.80$, with the commercially used destructive penetrometer method (figs. 4 and 5). It should be noted that the impact firmness measurements were conducted with the skin intact, while the skin was removed for the penetrometer measurements. The differences between the mechanical properties of Bartlett pear skin and Hass avocado skin may partially explain the large differences in

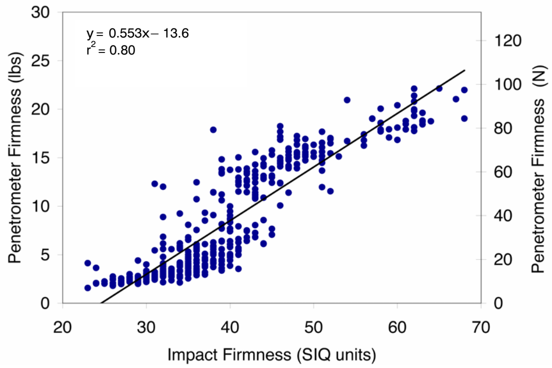


Figure 4. Relationship between nondestructive impact firmness and penetrometer firmness in Bartlett pears.

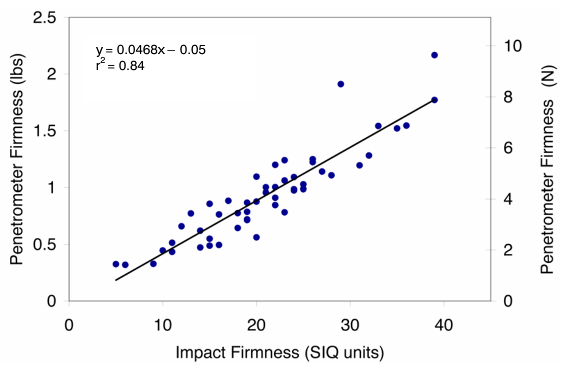


Figure 5. Relationship between nondestructive impact firmness and penetrometer firmness in Hass avocado.

the regression model coefficients observed between these two fruits. There is a great deal of additional work that could be done looking at the relationships between devices that measure the failure strength of fruit tissue versus those that measure elastic properties, however this research was not intended to address that issue. The correlations appear to be accurate enough for using the nondestructive test method to approximate the firmness of the fruit just before vibration testing, when a nondestructive method is essential.

Package Testing

At pear firmness levels above 50 SIQ units (14-lb penetrometer firmness), the maximum damage level was less than 12% for all packaging treatments (table 1). Bartlett pears are usually shipped at a firmness above 50 SIQ units to avoid damage in transport and handling (California Pear Advisory Board, undated). Softer fruit was progressively more susceptible to damage particularly if packed in the two commercial methods. Pears at 38 to 42 SIQ units (7- to 9-lb penetrometer firmness) are considered ready to display and the tray pack and the commercial clamshell treatments had high percentages of damaged fruit. At 38 SIQ units firmness two-thirds of fruit were damaged in the conventional tray and more than 90% of the fruit were damaged in the commercial clamshell. We noticed that fruit in the commercial clamshell package were damaged where they touched the bottom or the lid of the package and the skin of the fruit was often cut in areas of the fruit located between a 1-cm gap between the lid and bottom. The commercial clamshell has a small radius of curvature in these areas. The conventional tray pack had

Table 1. Percent of Bartlett pears damaged by transit vibration.

Firmness (SIQ Units and [penetrometer, lb])	Damaged Fruit[a] (% of total)				
	All	38[7]	42[9]	46[11]	50[13]
Package Type					
Conventional clamshell (%)	60.3a	92.3a	71.4a	57.9a	11.8a
Conventional tray (%)	34.6b	66.7b	46.4b	11.8b	7.7a
Suspended tray clamshell (%)	6.4c	13.3c	8.0c	0b	0a
Unvibrated control (%)	0c	0c	0c	0b	0a
Harmonic mean number of observations per package/ firmness category.	78	13	23.1	18.4	15.9
Least Significant Difference (%)	11.5	23.5	22.3	19.9	14.9

[a] Fruit was considered damaged if surface bruising scores were 3 or greater. Damage percentages with the same letter within each firmness category were not significantly different, $\alpha = 0.05$.

consistently less damage than the commercial clamshell, probably because it did not have a lid that the fruit could touch. Relative motion between a fruit and neighboring fruit or hard surfaces causes vibration bruising. The suspended tray clamshell package was far superior to the other two packaging treatments in protecting soft fruit from damage. In this package, only 8% of the fruit were damaged at 42 SIQ units (9-lb firmness) and only 13% at 38 SIQ units (7-lb penerometer firmness), neither of which were significantly different ($\alpha = 0.05$) from that of the unvibrated control fruit. The design of the suspended tray prevents relative motion between the fruit and any hard surfaces, preventing fruit motion from inducing damage.

Similar results were obtained with Hass avocados. Virtually no transit vibration damage was observed in any of the packaging treatments when the fruit was very firm, 65 SIQ units (3.0-lb penetrometer firmness) (table 2). As the avocados became softer there was a clear separation between the two conventional packing methods, loose-fill and the conventional pulp tray, and the suspended tray systems. At 45 SIQ units (2.1-lb penetrometer firmness) the conventional tray pack had 16% damaged fruit and the loose-fill had 60% damaged fruit, while the suspended tray systems had no damaged fruit. At 25 SIQ units (1.1-lb penetrometer firmness), eating ripe fruit, the conventional packing treatments allowed more than three quarters of the fruit to

Table 2. Proportion of Haas avocados damaged by transit vibration.

Firmness (SIQ Units and [penetrometer, lb])	Damaged Fruit[a] (% of total)					
	All	25 [1.1]	35 [1.6]	45 [2.1]	55 [2.5]	65 [3.0]
Package Type						
Conventional loose-fill (%)	55.2a	86.2a	62.5a	60.0a	38.9a	6.7a
Conventional tray (%)	36.5b	77.8a	42.9a	15.8b	10.0b	0a
Suspended tray clamshell (%)	12.5c	23.5b	0b	0b	0b	0a
Suspended tray (%)	10.4c	17.7b	5.9b	0b	0b	0a
Unvibrated control (%)	9.4c	13.3b	0b	0b	0b	0a
Harmonic mean number of observations per package/ firmness category.	96	18.2	13.6	16.7	16.5	16.8
Least Significant Difference (%)	15.6	25.6	22.8	19.0	19.1	7.4

[a] Fruit was considered damaged if there were large indentations on the surface or adhering flesh or flesh-browning scores were 3 or greater. Damage percentages with the same letter within each firmness category were not significantly different, $\alpha = 0.05$.

be damaged; the suspended tray in the clamshell container had 24% damaged fruit and the suspended tray in the corrugated box had 18% damaged fruit. The damage observed in the suspended tray systems for eating ripe fruit was not significantly greater ($\alpha = 0.05$) than the damage observed in the unvibrated control treatment (13%).

In commercial practice fruit can change firmness quite rapidly once they have begun to soften. In order to provide consumers with ready to eat fruit, it will need to be shipped at an intermediate firmness to allow them to just reach eating firmness upon arrival at the consumers' home. For example, Bartlett pears will soften from 38 to 42 SIQ units (7- to 9-lb penetrometer firmness) to 31 SIQ units (3-lb penetrometer firmnes) in about one day if held at 20°C and in about 2.5 days at 15°C. If transported in one of the suspended tray systems, the fruit can begin transport slightly above 38 to 42 SIQ units (7- to 9-lb penetrometer firmness) if kept near 0°C, where softening proceeds very slowly, and be subject to very little damage. At retail display the fruit will progress rapidly to eating firmness especially if displayed in an unrefrigerated area. The clamshell design will also help to prevent bruising susceptible fruit from being touched while on retail display, potentially reducing damage caused by consumer handling.

Conclusions

Bartlett pears and Hass avocados are subject to transport vibration damage and their susceptibility to damage increases as the fruit soften during ripening. Firm fruit, greater than 50 SIQ units (13-lb penetrometer firmness) for pears and greater than 65 SIQ units (3.0-lb penetrometer firmness) for avocados, could be shipped in a wide variety of conventional packages with little transit vibration damage. However softer fruit sustains significant transit vibration damage when packed in conventional packaging systems and subjected to severe in-transit vibration conditions common to cross-country transit in the United States. This study demonstrated that softer fruit was protected from transit vibration damage when packed in a suspended tray packaging system. The study showed that even eating-ripe fruit could be shipped in the suspended tray system with transit vibration damage not significantly greater than nonvibrated control fruit.

Acknowledgements

The authors would like to thank the California Pear Advisory Board and the California Avocado Commission for their support of this research, the F-D-S Manufacturing Co., Inc., Pomona, California for providing the commercial prototypes of the suspended tray packaging systems, and Victor Tokar for his support and assistance with the research.

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