PACKAGING BARTLETT PEARS IN POLYETHYLENE FILM BAGS TO REDUCE VIBRATION INJURY IN TRANSIT

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ABSTRACT. *Results from a three-year cross-country transit study showed that transit vibration injury can be significantly reduced by packing Bartlett pears in polyethylene film bags. Pears packed in slitted polyethylene film bags required only 26% more cooling time than conventional tight-fill packages and slitted bags were also effective in reducing vibration injury.* ***Keywords.*** *Vibration, Transportation, Bartlett pears, Packaging, Bags.*

Bartlett pears are subject to damage when excessively vibrated in transit. Vibration damage is of significant concern to California pear growers who market their produce in the Midwest or eastern U.S. due to long transport distances. In a study of produce losses, Pierson et al. (1982) estimated that the losses during transport for the U.S. fresh fruit and vegetable industry in 1977 were between $US268 million and $US380 million (1977 dollars). Ceponis and Butterfield (1974), and Write and Billeter (1975) indicated that specific losses at the retail level were four percent for pears and of that four percent 68.4% was caused by mechanical injury.

Sommer (1957a) found that surface discoloration in Bartlett pears can be caused by vibration damage in transit and, although the internal flesh of the fruit may not be affected, the surface damage may seriously affect marketability. Vibration in transit often causes the fruit to rotate and a discolored region forms a dark band around the fruit resulting in the term “roller bruising”. In addition, Sommer found that vibration damaged fruit looses moisture more rapidly than undamaged fruit, further reducing the quality of the injured fruit. O’Brien et al. (1963) found that the extent of bruising in fruit in transit depended upon the frequency, amplitude and duration of applied vibration as well as the initial condition of the fruit.

California pear packers have attempted to reduce transit damage by wrapping individual fruit in lightly waxed paper or using a “tight-fill” packing system (Mitchell et al., 1968). Industry observations indicate that neither of these methods is entirely effective in reducing vibration damage. Slaughter et al. (1991, 1992) observed that tight-fill may not be working well because: (1) fill weights are not consistent; (2) few packers use the recommended wood fiber pads that expand as they gain moisture; (3) boxes are often not consistently formed so that flaps meet; and (4) boxes lose strength and bulge as they gain moisture in storage. The California Tree Fruit Agreement funded a project which developed another system, which used large elastic bands around a box to maintain a constant pressure and immobilize the fruit (Cayton, 1985). The system was never adopted by the industry (Cayton, 1993). Sommer (1957b) attempted to prevent transit injury to Bartlett pears by packing the pears in protective materials such as shredded paper, shredded polyethylene film, and 1 in. polyethylene film disks. Sommer found that these materials reduced but did not prevent transit injury. Schulte Pason et al. (1990) studied impact bruise damage of apples packed in polyethylene bags, and pulp or foam tray containers for transportation distances up to 584 km (363 mi). Schulte Pason observed upon arrival that the number of unbruised apples packed in bags were greater than those packed in pulp trays and were less than those packed in foam trays. Shulte Pason also found that the number of impacts greater than 20 g were highly correlated to the percent of bruised apples. In contrast, Guillou et al. (1962) and Slaughter et al. (1993b) have observed that the skin of Bartlett pears can be severely discolored when vibrated at acceleration levels slightly above 1 g for periods as short as 30 min.

OBJECTIVES

The objectives of this study were: (1) to determine if polyethylene bags can be used as a packaging material for reducing vibration injury to Bartlett pears when transported in refrigerated highway trailers with steel spring suspensions; and (2) to determine what affects polyethylene bags will have on forced-air cooling rates.

METHODS AND MATERIALS

CROSS-COUNTRY TRANSIT TEST, 1993

In 1993, a preliminary cross-country transit test was conducted in which several experimental packaging treatments were evaluated. The cross-country test was designed as a screening test to show which of the treatments might reduce transit vibration injury to Bartlett pears. The size 120 (120 fruit per standard box) pears used in this test were harvested in the Mendocino pear district at the end of the 1993 California Bartlett pear season. The

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fruit was stored approximately 1 month prior to testing because late season pears shipped out of storage are significantly more susceptible to vibration injury than early season fruit (Slaughter et al., 1993a).

The two packaging treatments germane to this study were the conventional "tight-fill" package and an experimental package using polyethylene bags. Both treatments used nominal 16.4 kg (36 lb) tight-fill full telescope containers constructed of 125 kg (275 lb) test curtain coated fiberboard. Each carton had outside dimensions of 45.72 cm long × 30.48 cm wide × 23.50 cm high (18 in. × 12 in. × 9.25 in.) and had ten, 2.54 cm × 8.89 cm (1 in. × 3.5 in.) vent holes, three in each side and two in each end. The conventional cartons were commercially volume filled, vibration settled, and closed with a single strap encircling the middle of the carton. In all tight-fill packages, a single macerated paper pad 35.6 cm × 29.2 cm × 0.85 cm (14 in. × 11.5 in. × 0.33 in.) was placed on the top of the fruit after filling and before vibration settling. No padding was placed between the box bottom and the fruit. For the experimental treatment, pears were packed six to a bag (for a nominal weight of approximately 0.9 kg, 2 lb) in rectangular flat (non-gussetted) "apple" bags constructed from 0.05 mm (2 mil) thick polyethylene material. The bags were sealed tightly around the pears and closed with a plastic clip. No padding was placed in any cartons containing bagged fruit. Due to the irregular shape of the tightly filled bags only 11 bags of pears could be placed in each container. Since the screening test included many package treatments, only one column of six replicate cartons for each treatment could be placed onto a single 1.2 m × 1 m (48 in. × 40 in.) tight-fill pallet for shipment. The pears were pre-cooled and stored in a commercial cold storage facility for 1 month prior to shipment. The pears were shipped at the rear of a 14.6 m (48 ft) long refrigerated highway trailer equipped with a steel spring suspension (Series 7600-7700-7800 Hutchens Industries Inc., Springfield, Mo.) from California to Maryland, a distance of approximately 4480 km (2,800 mi).

Approximately one day after arrival, 20 fruit (18 fruit from three bags for the bagged treatment) were randomly selected from the top, middle, bottom, interior, and periphery of the top carton in the column stack for each treatment. Only fruit from the top carton of each column were evaluated because researchers and California commercial pear packers have observed that vibration acceleration levels and vibration damage are greatest in the top carton (O'Brien et al., 1963). The fruit were then visually inspected and scored for external damage on a six point scale (used by Sommer, 1957a, Gentry et al., 1965, and Slaughter et al., 1993b) where 0 = no damage, 1 = trace, 2 = slight, 3 = moderate, 4 = severe, and 5 = extreme. Damage to the interior of the fruit was not evaluated. Damage levels of 4 and 5 were considered unmarketable fruit.

Laboratory Vibration Tests, 1994

The favorable results with polyethylene bags in 1993 led to four additional tests in 1994 to determine the optimum method of using this technique to reduce in transit vibration injury. The first test of 1994 was set up to evaluate the effects of bag size and closure method in reducing vibration injury to pears. The test used a randomized complete block design with two bag sizes (1.4 kg, called 3 lb bags in this study, and 2.3 kg, called 5 lb bags in this study) and two bag fill methods (tightly filled and loosely filled). The tightly filled bags were sealed with the bag pulled tightly around the fruit (as in the 1993 test) while the loosely filled bags were sealed with enough empty space to allow an additional pear in the bag. All bagged pears were packed by hand into the bags and all bagged treatments were packed into the standard 0.03 m^3 (4/5 bu "tissue wrap") full telescope containers constructed of 125 kg (275 lb) test curtain coated fiberboard. The tissue wrap boxes had outside dimensions of 50.80 cm long × 30.48 cm wide × 26.67 cm high (20 in. × 12 in. × 10.5 in.), and eight 2.54 cm × 8.26 cm (1 in. × 3.25 in.) vent holes, three in each side and one in each end. The 3 lb bags were packed 10 bags to the box and the 5 lb bags were packed 6 bags to the box. The boxes were closed with a strip of cellophane tape encircling the box. Four replicate boxes of size 110 Bartlett pears (110 fruit per standard box) were packed for each treatment.

All the Bartlett pears for the 1994 tests were grown in either the River or Mendocino pear regions of California during the 1994 season. As in 1993, late season fruit were commercially packed and held in commercial cold storage for a period of at least one month prior to testing. The pears were transported from a cold storage facility in the River district to the laboratory, a distance of approximately 112 km (70 miles) or from the Mendocino district to the laboratory a distance of approximately 339 km (130 miles). All treatments were subjected to the same base level of damage incurred in harvest and post-harvest handling and transportation. The average pulp temperature of the fruit at the time of testing was 5°C (41°F).

A random vibration test was conducted according to the ASTM Method A of random vibration Test D4728-91 (1991). In this test, a single layer of pear boxes were placed on a foundation mounted servo-hydraulic vibration table (Lansmont Corp., Pacific Grove, Calif.). The pears were then subjected to a continuous range of vibration frequencies between 2 Hz and 30 Hz. The frequency range of 2 Hz and 30 Hz was selected because palletized loads of Bartlett pears have high levels of vibration transmissibility in this region (Slaughter et al., 1993b) and because PSD levels for frequencies above 50 Hz have been found to be insignificant (Caruso and Silver, 1976). The electronic controls of the vibration table were configured to provide closed-loop automatic equalization (ASTM Method A) using an accelerometer mounted to the vibration table for real-time feedback. All fruit was held at room temperature for one day after vibration to allow any injury present to become visible. Twenty fruit, randomly selected from top, middle, bottom, interior and periphery of each box, were visually inspected after the simulated transit test and graded using the same six-point scale used in the 1993 test.

ASTM Standard Practice D4169-94 (1994) recommends three possible intensity levels of power spectral density (PSD) for random vibration testing. Guillou et al. observed that a sinusoidal dwell vibration test at a zero-to-peak acceleration of 1.1 g (0.78 g-rms) for 30 min produced damage levels in Bartlett pears similar to that observed in actual transcontinental rail shipments. The highest level (Assurance Level I) is comparable to that observed by Guillou et al. and was used to set the g-rms acceleration level for this test. Standard Practice D4169-94 also recommends that actual PSD data from the real-world transport vibration environment be used if available.

The PSD data used to quantify the intensity of the random vibration for this test was based upon the PSD data collected from the 1993 cross-country shipment of Bartlett pears from California to Maryland. The vertical acceleration spectrum of this trailer was measured using the same equipment and procedure described by Hinsch et al. (1993) and is shown in figure 1. The PSD data at the rear pallet position is similar to that observed by Hinsch et al.

The spectrum was measured at two locations on the floor of the trailer: the rear most pallet position and one pallet position in from the rear most pallet position. The trailer was fully loaded with Bartlett pears and the vertical acceleration spectrum was measured while traveling between Reedley, California, and Jessup, Maryland, a distance of approximately 4480 km (2,800 mi).

This data was used by Slaughter et al. (1994) to create a composite acceleration spectrum for the ASTM Standard Test Method D4728-91 for random vibration testing of shipping containers. The overall g-rms level of the composite acceleration spectral density curve was scaled to match the value recommended (0.73 g-rms) for an assurance level I test as described in section 11.5.2 of ASTM Standard Practice D4169-94 for performance testing of shipping containers and systems. Slaughter et al. (1994) found that an assurance level I random vibration test based on this vibration spectrum for 30 min duration simulated the levels of transit vibration injury to Bartlett pears observed in actual cross-country shipments. A graph of the PSD data used to control the vibration table is shown in figure 2.

One of the problems encountered with the use of bags in packaging pears was an inability to pack the fruit to a comparable density found in conventional tight-fill or hand wrap packages. When pears are packed as described in the first test, considerable head space is found at the top of the box after the vibration test is complete. The second laboratory test was set up to evaluate the effect of bulk density on vibration injury to pears in bags. The test used a randomized complete block design with package treatments of eight 3 lb bags per box, ten 3 lb bags per box, conventional tight-fill, and an unvibrated control. Four replicate boxes of size 120 Bartlett pears were subjected to random vibration for a period of 30 min for each treatment. All treatments were packed into 16.4 kg (36 lb) tight-fill

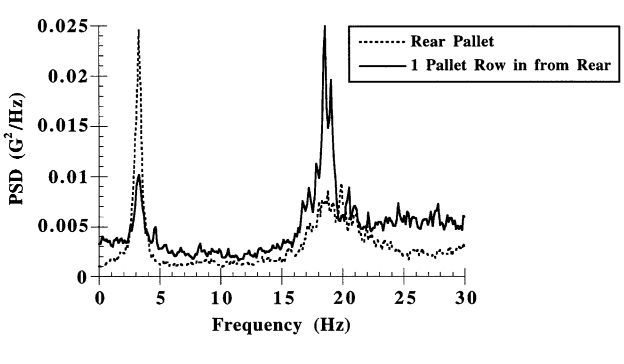

Figure 1–Average power spectral density (PSD) vibration data measured at two locations on the floor of a refrigerated highway trailer with a steel spring suspension in transit from California to Maryland, 1993.

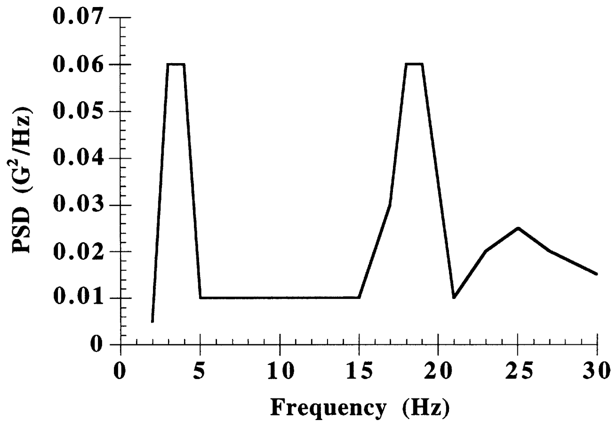

Figure 2–Power spectral density (PSD) vibration data used to simulate a cross-country shipment.

boxes. The boxes with eight 3 lb bags contained approximately 11.8 kg (26 lb) of fruit, those with ten 3 lb bags contained approximately 15 kg (33 lb) of fruit, and the tight-fill boxes contained approximately 16.4 kg (36 lb) of fruit. The boxes with ten 3 lb bags were vibration settled using the conventional vibration settling equipment for tight-fill in order to allow proper box closure. The treatments were tested using the same ASTM random vibration test conducted in the first test. All fruit was held at room temperature for one day after vibration to allow any injury present to become visible. Twenty fruit, randomly selected from top, middle, bottom, interior, and periphery of each box, were visually inspected after the simulated transit test using the same six-point scale used in the 1993 test.

To allow visual observation of pear motion during vibration a videocamera (Sony model XC-711) was mounted on the outside of a clear acrylic box with dimensions similar to a fiberboard pear box. The box was then packed with pears packaged in 3 lb bags (the rectangular flat non-gussetted "apple" bag previously described), individual bags (the rectangular flat non-gussetted "sandwich" bag previously described), and without bags using conventional tight-fill. The acrylic box was then vibrated in the laboratory at an acceleration of 1.1 g and a frequency of 3.5 Hz. The video signal was recorded on videotape to allow subsequent analysis.

Forced Air Cooling Tests, 1994

A laboratory precooling test was conducted in 1994 to determine the effect of different bag types upon cooling rates. Pears packed into tight-fill boxes using each of three bag types (3 lb, slitted, and individual) were compared with conventional tight-fill packaging. The 3 lb bag was the rectangular flat (non-gussetted) "apple" bag previously described. This bag contained thirty-two 0.76 cm (0.3 in.) diameter vent holes. The second type of bag used was a trapezoidally shaped, flat (non-gussetted), slitted "grape" bag. The slitted bag—30.5 cm (12 in.) wide at the top, 14 cm (5.5 in.) wide at the bottom, and 33 cm (13 in.) long—was constructed of 0.05 mm (2 mil) thick polyethylene material. One side of the slitted bag contained 1.9 cm (0.75 in.) long slits spaced 3.8 mm (0.15 in.) apart in a staggered pattern. The other side of the slitted bag contained 12 6.4 mm (0.25 in.) diameter vent holes. The third type of bag used was a rectangular flat (non-gussetted) "sandwich" bag. This bag was used to package each pear in its own individual bag. These individual bags were 16.5 cm (6.5 in.) wide × 14 cm (5.5 in.) long and were constructed of 0.0175 mm (0.7 mil) thick polyethylene material.

Each package type was placed three boxes deep in the laboratory precooler and cold air (1.6°C, 34.9°F) was drawn through the boxes. The three boxes were placed in the precooler so that the air was drawn through the shorter dimension of each box in succession, forcing the air to travel roughly the equivalent of the width of a pallet of fruit. Any vent openings or seams on the top and ends of the box were sealed off with masking tape which assured the air traveling through the boxes traveled the full three widths. Fruit pulp temperatures were monitored every 15 min using type T thermocouples and a data logger (Campbell Scientific, model 21X). For each package type the temperature was recorded in a fruit near the edge of the first box where cold air entered the boxes, in a fruit near the edge where the air exited the last box, and in several pears randomly selected in all three boxes. Each thermocouple was placed in the center of a pear.

The slitted and individual bag types used in the precooling test were also evaluated for vibration characteristics. This test was designed to determine if: (1) slitted bags prevent transit vibration injury in a manner comparable to non-slitted bags; and (2) individual bags prevent transit vibration injury by placing a polyethylene film barrier between each fruit even though fruit motion is not constrained. The test used a randomized complete block design with package treatments of nine slitted bags per box with six pears per bag, pears packed in individual "sandwich" bags, conventional tight-fill, and an unvibrated control. All treatments were packed into 16.4 kg (36 lb) tight-fill boxes. Four replicate boxes of size 120 Bartlett pears per treatment were subjected to the same random vibration test described previously. All fruit were held at room temperature for one day after vibration to allow any injury present to become visible. Twenty fruit, randomly selected from top, middle, bottom, interior, and periphery of each box, were visually inspected after the simulated transit test using the same six point scale used in the 1993 test.

Cross-country Transit Test, 1994

Based upon the results from the laboratory tests a cross-country transit test was designed to verify the reduction in vibration injury to pears packed in bags. Four package treatments were included in the transit test: (1) 3 lb bags of pears loosely filled; (2) 5 lb bags of pears loosely filled; (3) conventional tight-fill; and (4) standard tissue wrap. The bag and tissue wrap treatments were packed into the standard 0.03 m^3 (4/5 bu) box and the tight-fill was packed into the conventional 16.4 kg (36 lb) tight-fill box. All tight-fill and tissue wrap packages contained a standard macerated paper pad between the fruit and the box top. No padding was placed in any of the boxes with bagged pears. The 3 lb bags were packed 10 bags to the box and the 5 lb bags were packed 6 bags to the box. Bartlett pears of size 110 were used in all treatments. Three columns of tissue wrap boxes, seven high and four columns of tight-fill boxes, six high were palletized into a single pallet. Three columns of 3 lb bag boxes, seven high and four columns of 5 lb bag boxes, seven high were palletized into a second pallet. The pears had been stored in commercial cold storage for one month prior to shipment. The two test pallets were placed side by side at the rear of a refrigerated trailer with a steel spring suspension (Series 7600-7700-7800 Hutchens Industries Inc., Springfield, Mo.) and were shipped approximately 4320 km (2,700 mi). All boxes from the top layer of each of the two pallets were evaluated for vibration injury after shipment. An unvibrated control treatment was included in the test, unfortunately these boxes were lost during storage and could not be evaluated. Approximately one day after arrival, 20 fruit were randomly selected from the top, middle, bottom, interior, and periphery of the top carton in the column stack for each treatment. The fruit were then visually inspected using the same six-point scale used in the 1993 test.

Cross-country Transit Test, 1995

Based upon the 1993 and 1994 findings, a full-scale commercial cross-country shipping test was conducted in 1995. Four test pallets of pears, one for each package treatment, were packed with fruit grown in the Mendocino pear region. As in 1993, late season fruit were commercially packed and held in commercial cold storage for a period of at least one month prior to testing. The four package treatments were: (1) conventional tight-fill; (2) conventional tissue wrap; (3) nine 3 lb bags of pears loosely filled and loosely packed into tight-fill containers; and (4) twelve 3 lb bags of pears loosely filled and loosely packed into tissue wrap containers. Bartlett pears of size 120 were used in all treatments. The fruit was shipped from California to Maryland in the two rear most pallet positions of a refrigerated highway trailer fully loaded with Bartlett pears and equipped with a steel spring suspension (Series 7600-7700-7800 Hutchens Industries Inc., Springfield, Mo.). The pallet of tight-fill packages and the pallet of bagged fruit in tight-fill cartons were shipped side-by-side in the rear most position, and the tissue-wrap packages and the bagged fruit in tissue wrap cartons were shipped side-by-side one pallet position in from the rear most position. All boxes from the top layer of each of the four pallets were evaluated for vibration injury after shipment. Approximately one day after arrival, 20 fruit were randomly selected from the top, middle, bottom, interior, and periphery of every carton in the top layer of each pallet. The fruit were then visually inspected using the same six-point scale used in the 1993 test. An unvibrated control for each treatment was also evaluated in California upon return. The vertical acceleration spectrum of this trailer was measured at the rear most pallet position and one pallet position in from the rear most pallet position using the same equipment and procedure described by Hinsch et al. (1993).

A Fisher's protected least significant difference (LSD) test was conducted on the average bruising scores for each treatment for all vibration tests using the GLM statistical procedure (SAS, 1990) to determine if any of the packaging treatments were significantly better than others. This statistical procedure automatically used the harmonic mean number of observations in computing the LSD values for the data in table 5 when the number of observations per treatment were not equal.

Results and Discussion

The results of the bag size and closure method test show (table 1) that there was no significant difference between the level of vibration injury observed in either the tightly packed 3 lb or 5 lb bag or the loosely packed 3 lb bag treatments. The 5 lb loosely packed pears had significantly less vibration injury than the other treatments, however the difference between the average injury score of this treatment and the 5 lb tightly packed treatment only exceeded the lease significant difference (LSD) value by 0.01 bruising score units. These results indicate that there is no advantage to tightly sealing Bartlett pears in bags and that differences between 3 lb and 5 lb bags are small.

The results of the packing density test show (table 2) that packing bags of pears in boxes at bulk densities approaching that of conventional tight-fill does not significantly affect the bags ability to reduce vibration injury. In this test, the unvibrated control fruit had a slightly higher damage level than the vibrated fruit packed in bags. While the fruit for this test was collected at nearly the same time in the packing shed it did not necessarily come from the same tree and was not necessarily picked by the same person. It is believed that the differences shown in table 2 between the unvibrated control and the vibrated fruit in bags were due to handling conditions at harvest or in the packing shed. This test also showed a significant reduction in the amount of vibration injury to bagged pears as compared to the conventional tight-fill package. The results from this test are particularly important for pears stored in fiberboard cartons. Fruit looses weight (and volume) in storage and containers deform in high humidity conditions. These changes cause tight fill packaging to be less effective as the fruit is no longer immobilized. This study shows that the effectiveness of bagging does not depend upon a precise packing density to provide immobilization and will work for stored pears. Observation of fruit packers packing bagged pears into boxes indicates that a well-designed bag packing system should be able to pack bagged pears in cartons with about 10% less weight per box as compared to tight-fill or tissue wrap packing methods.

Shown in table 3 are the laboratory vibration results for the slitted bag and individually bagged fruit tests. These results show that slitted bags reduce vibration injury to Bartlett pears at a level comparable to the 3 lb bag test results shown in table 2 and that vibrating pears packed in slitted bags does not result in a significant increase in bruising over the unvibrated fruit (control). Some slitted bags were ripped upon inspection at the end of the test. The polyethylene bags used were designed for grapes and may need to be stronger for use with pears. Packing pears in individual polyethylene film bags does not prevent vibration injury as well as packing pears in slitted bags. These results also show that preventing transit vibration injury by packing pears in bags is not solely due to placing a layer of polyethylene film between each fruit. Visual observation of pears packed in a clear acrylic box showed that, for tight-fill, fruit at the bottom of the box remained motionless with respect to the box while the fruit at the top of the box was in continuous motion, rotating and sometimes migrating across the top of the fruit mass. Fruit packed in 3 lb bags settled within the first few strokes and then remained motionless with respect to the box. Fruit packed in individual polyethylene bags behaved similarly to the fruit packed without bags using tight-fill methods. These results and earlier findings by Guillou et al., Gentry et al., and Sommer indicate that the advantage of bagging pears may be related to their ability to immobilize the fruit.

The results of the laboratory forced air cooling tests are shown in table 4 and figures 3 and 4. In general, the results show that any material which tends to blocks air flow increases the time required to cool the fruit. Figure 3 shows the airflow rates for each of the four package types at different air pressures. Figure 4 shows a set of simulated

Table 1. Evaluation* of laboratory simulated transit vibration injury to Bartlett pears for different fill weights and bag fill methods, 1994

Packaging Features	Fill Method	Average Injury Score†	Score of 3 or Higher (%)
3-lb bags	Tight	2.29a	40
3-lb bags	Loose	2.08a	35
5-lb bags	Tight	2.04a	30
5-lb bags	Loose	1.75b	19

* Evaluation based on average of 80 fruit.
† Means with the same letter are not significantly different; $\alpha = 0.05$; df = 316; MSE = 0.81; Least Significant Difference = 0.28.

Table 2. Evaluation* of laboratory simulated transit vibration injury to Bartlett pears for different packing densities, 1994

Packaging Features	Nominal Mass per Box (kg)	Average Injury Score†	Score of 3 or Higher (%)
Tight-fill	16.4	2.61a	53
Control	16.4	1.93b	21
3-lb bags	15.0	1.85c	15
3-lb bags	11.8	1.79c	13

* Evaluation based on average of 80 fruit.
† Means with the same letter are not significantly different; $\alpha = 0.05$; df = 316; MSE = 0.61; Least Significant Difference = 0.24.

Table 3. Comparison* of laboratory simulated transit vibration injury to Bartlett pears for bagged and non-bagged packaging methods, 1994

Packaging Features	Pears per Bag	Average Injury Score†	Score of 3 or Higher (%)
Tight-fill	-	2.79a	63
Individual “sandwich” bag	1	2.21b	34
Slitted “grape” bag	6	1.95c	21
Control	-	1.71c	10

* Evaluation based on average of 80 fruit.
† Means with the same letter are not significantly different; $\alpha = 0.05$; df = 316; MSE = 0.61; Least Significant Difference = 0.24.

Table 4. Evaluation of forced air cooling times for different types of pear packaging

Package Type	Pears per Bag	Cooling Coef.	7/8ths Cooling Time* (h)
Tight-fill	-	0.62	3.4
Slitted bags	6	0.48	4.3
3 lb bags	7	0.31	6.7
Individual bags	1	0.14	15.3

* Cooling time based on an assumed 22°C (72°F) initial fruit temperature, a 0°C (32°F) cooling air temperature, and cooling coefficients determined in cooling tests.

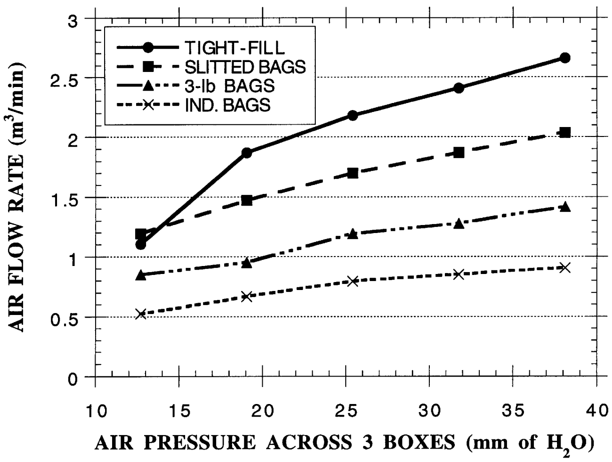

Figure 3–Graph of airflow rate vs air pressure for four types of pear packages.

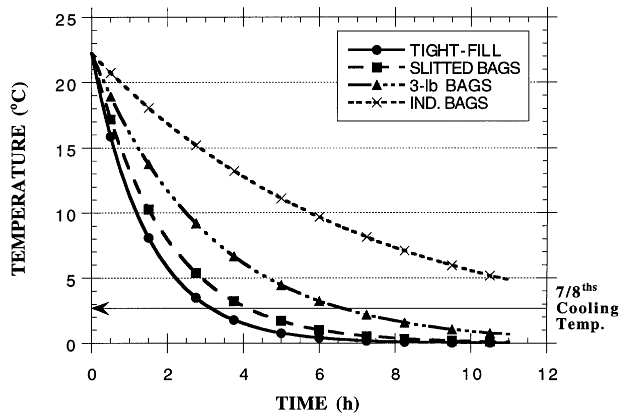

Figure 4–Graph of fruit temperature vs time for four types of pear packages.

cooling curves for the four types of packages where all fruit began cooling at a hypothetical temperature of 22.2°C (72°F). The data shown in figure 3 is based upon the cooling coefficient of each package type shown in table 4. These results show that tight fill, without any material between the fruit, had the highest air flow rate and the fastest cooling rate. Slitted bags cooled faster that the non-slitted 3 lb bags, and significantly faster than the individually bagged fruit. Since the pears packed in individual polyethylene film bags cool very slowly and do not prevent vibration injury as well as larger bags their use is not recommended.

The cross-country transit test results are shown in table 5. In all three years, the pears packed in bags arrived with significantly less vibration injury than those packed using conventional tight-fill methods. In 1993, 60% of the fruit in tight-fill boxes had bruising scores greater than 2 while only 11% of the bagged fruit had bruising scores greater than 2 when they were shipped on the same pallet. Again in 1994, 60% of the pears in tight-fill boxes had bruising scores greater than 2 while the 5 lb bags and 3 lb bags had only 19% and 12% of their fruit with scores above 2, respectively. In 1994, the tissue wrapped pears

Table 5. Evaluation of different packaging methods for their ability to reduce vibration injury to Bartlett pears during cross-country transit tests

Year	Trailer Location	Ave. Floor Acceleration (g-rms)*	Package Features	Fill Method	Average Injury Score†	Fruit with a Score of 3 or Higher (%)	Number of Fruit Evaluated
1993							
	Rear pallet	0.29	Tight fill	Tightly packed	3.05a	75	20
	Unshipped control	0.00	Tight fill	Tightly packed	1.20b	5	20
	1 pallet in from rear	0.37	Tight fill	Tightly packed	2.60a	60	20
	1 pallet in from rear	0.37	2-lb bags	Tightly sealed	1.44b	11	18
	Unshipped control	0.00	Tight fill	Tightly packed	1.20b	5	20
1994							
	Rear pallet	-	Tight fill	Tightly packed	2.58a	60	80
	Rear pallet	-	Hand wrap	Tightly packed	2.02b	25	60
	Rear pallet	-	5-lb bags	Loosely sealed	1.75bc	19	80
	Rear pallet	-	3-lb bags	Loosely sealed	1.62c	12	60
1995							
	Rear pallet	0.34	Tight fill	Tightly packed	1.59a	6	180
	Rear pallet	0.34	3-lb bags	Loosely sealed	1.04b	2	180
	Unshipped control	0.00	Tight fill	Tightly packed	0.75c	1	180
	Unshipped control	0.00	3-lb bags	Loosely sealed	0.72c	0	180
	1 pallet in from rear	0.38	Hand wrap	Tightly packed	2.36a	44	140
	1 pallet in from rear	0.38	3-lb bags	Loosely sealed	0.93b	1	140
	Unshipped control	0.00	3-lb bags	Loosely sealed	0.59c	0	140
	Unshipped control	0.00	Hand wrap	Tightly packed	0.58c	0	140

† Means with the same letter for each pallet location/year treatment are not significantly different, $\alpha = 0.05$.

* The average floor acceleration levels were measured for the 0 to 30 Hz frequency region (see Hinsch et al. for details). Average floor acceleration levels were not available for 1994 due to equipment failure.

All transit tests were a minimum of 4480 km in commercial refrigerated highway trailers with steel spring suspensions.

had an average level of vibration injury in between the tight-fill and bagging treatments and were not significantly different that the pears in 5 lb bags, while the pears packed in 3 lb bags had a significantly lower average bruising score than the tissue wrapped fruit. In 1995 the pears in tight-fill packages had lower bruising scores than in 1994 or 1993 with only 6% of the fruit having bruising scores above 2. In 1995 the tissue wrapped pears had a greater level of bruising injury than those in tight-fill containers with 44% of the fruit having bruising scores above 2. The pallets of bagged pears in 1995 had 2% or less of the fruit with bruising scores above 2 upon arrival and their average injury scores were significantly less than the tight-fill and tissue wrapped pears.

Differences between the level of vibration injury observed from year to year with the same type of packaging may be due to several factors including physiological differences in the fruit, mechanical differences between trailers such as the location of the rear wheels which are adjusted by the driver to balance the weight load between the front and rear axles, and differences in travel speed and roadway condition. The fact that the average acceleration level on the trailer floor was not correlated with average injury score may due to the observation by Slaughter et al. (1992) that Bartlett pears are less susceptible to vibration injury at 0-to-peak acceleration levels below 1 g and since the vibration data logger used in this study was set up to record equally spaced acceleration events and not the most severe acceleration events.

The results of this test show that packaging Bartlett pears in polyethylene bags can reduce the level of in transit vibration injury as compared to pears shipped in conventional tight-fill packages and will have a similar or better arrival condition than tissue wrapped pears. In the three cross-country tests, bagging reduced the number of pears with vibration injury scores over 2 by 67% to 82% when compared to tight-fill packages and by 24% to 98% when compared to tissue wrapped pears. The level of improvement expected in any given shipment will be a function of many factors including type of trailer suspension, pallet location in the trailer and bruising susceptibility of the fruit.

Fruit in the 1995 tests were followed through to retail marketing. On display, bagged fruit had fewer punctures and scratches, less surface discoloration, and less shriveled fruit than either hand wrapped or tight fill packed fruit. Bags can be quickly and gently emptied for bulk display if desired.

CONCLUSIONS

Packaging Bartlett pears in polyethylene film bags was shown to be effective in reducing transit induced vibration injury as compared to conventional tight-fill or tissue wrap methods. The mechanism by which bags prevent vibration injury is not solely due to the placement of a layer of polyethylene film between each fruit, but may also be related to their ability to partially immobilize the fruit. Pears packed with six pears per bag had less transit induced vibration injury than pears packed individually in polyethylene film bags and pears packed in slitted polyethylene film bags were very effective in reducing vibration injury. Packing pears loosely in polyethylene film bags was as effective in reducing vibration injury as tightly sealed bags and there was no observed difference in the level of vibration-induced bruising injury between boxes tightly or loosely packed with bags of pears.

Bagging reduces that amount of fruit that can be packed in a box compared with either tight-fill or tissue wrapped methods, with a well designed bag packaging system expected to result in about 10% less fruit weight per box as compared with tight-fill or tissue wrap packages. The use of slitted polyethylene film bags will allow bagged pears to be force-air-cooled with only 26% more cooling time than tight-fill packages.

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