# Simulated In-Transit Vibration Damage to Packaged Fresh Market Grapes and Strawberries

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## Abstract

Packaged fresh market strawberries and grapes were subjected to vibration conditions which simulate truck transportation. Frequencies ranged from 2 to 30 Hz. Fruit quality was evaluated by several methods before vibration, after vibration, and after a one-week storage period. Effects of vibration frequency and box position in a 9 or a 15 high stack on fruit damage were investigated. The frequency range of 5.0 to 10 Hz caused the maximum damage to both commodities and the top box in this range was the worst for the strawberries. **KEYWORDS.** Transportation, Vibration, Damage, Simulation, Fruit quality, Postharvest, Frequency.

## Introduction

Grapes and strawberries are two commodities that are highly susceptible to in-transit vibration damage. According to a nationwide study conducted by Michigan State University, transportation losses for these two fresh market commodities exceeded $18 million annually in the early 1980s (Pierson et al., 1982). Today the figure is surely higher because greater value and more product are being shipped. According to shippers in the produce industry, the problem is so severe that some highway carriers are refusing to carry these commodities.

Grape berries are often shattered from the clusters during shipment. Although all cultivars of grapes are susceptible to shattering, Thompson seedless are especially fragile. The shattered grape berries are less salable than the full clusters and are usually discarded. Shattering is one of the inspection criteria the USDA uses to determine the grade. More than 12% shattering in a box is grounds for reduction in grade (USDA, 1971). Shattering is also the most common defect found in grapes arriving at the New York terminal markets, occurring in nearly half of the shipments (Cappellini et al., 1986). Berries that are not shattered during transportation may instead be bruised, and this results in discoloration and reduced shelf life.

In-transit vibration may cause skin abrasion and bruising on strawberries. These abrasions and bruises provide a point of entry for micro-organisms, which reduce the berry's already short shelf life. One type of defect cited in the USDA inspection criteria for strawberries is "translucent, dull or watery appearance" (USDA, 1975). This defect is caused by juice oozing from abraded or bruised skin.

### Objectives

This study had the following three objectives:

- To determine the critical vibrational frequencies and resultant damage for Selva strawberries and Thompson seedless grapes as they are now packaged and shipped.
- To determine the effect at position of the box above the truck floor on product damage.
- To identify useful qualitative and quantitative methods of evaluating transportation damage in these two commodities.

## Methods

### Product and Packaging

A major shipper in Bakersfield, California, supplied three lots each of graded and packaged (market ready) Thompson seedless grapes and Selva strawberries. The fruit was shipped by truck to Jessup, Maryland, where the experiments were conducted. The grapes were packed in 11.3 kg (25 lbs) combination wooden/fiberboard lugs. The strawberries were packed in plastic pint baskets with 12 pints to a box. To measure the net change in quality during the experiments, the strawberries were graded to determine the pre-experiment quality and all shattered grapes were removed. After grading, the fruit was repacked in the original containers and tested.

### Equipment

An electro-hydraulic vibration system was used to simulate intransit vibration. The system consisted of a hydraulic pump and a 1220 mm × 1220 mm (4 ft × 4 ft) platform mounted on a hydraulic cylinder. A sine-wave generator connected to an amplifier controlled the pump and the oil fed to the cylinder. The sine-wave generator was set to sweep between the upper and lower limits of each 5 Hz wide range that were the treatments in this experiment. A Fourier transform frequency analyzer precisely monitored the output of the sine-wave generator. Piezoelectric accelerometers rigidly mounted on the boxes at the top and bottom of the stack monitored the accelerations of the fruit containers in those locations. The acceleration imparted to table by the hydraulic cylinder was controlled by adjusting the output of the amplifier.

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Figure 1 shows a schematic view of the experimental equipment.

### EXPERIMENTAL TREATMENTS

In each of the six trials (three with strawberries and three with grapes), boxes of the product were stacked in register on a wooden pallet on the vibration table, as if they were stacked in a truck. The grapes were stacked nine boxes high; whereas the strawberries were stacked 15 boxes high. As figure 1 shows, wooden braces held the boxes in place. One box or tray was set aside in each trial, as a control.

For each vibration treatment, three boxes of fruit were evaluated for pre-experiment quality and placed in the top, middle, and bottom positions in the stack. The boxes in the other positions were reused for the duration of the trial. For the grapes, the pre-vibration grading consisted of unpacking the boxes, removing and weighing all shattered grapes, and repacking. For the strawberries, six pints in each box were graded based on the system in Table 1 and repacked. Any berries that were severely or very severely damaged were removed. After grading, the strawberries were repacked in their pint containers and trays.

Each stack of product was vibrated at the frequencies and conditions shown in Table 2. Vibrational frequencies and acceleration levels were chosen to fall within the range of 1 to 200 hz measured in trailers during over-the-road travel (Peleg and Hinga, 1986). The peak acceleration levels were increased over average over-the-road values which were to allow a reduced vibration time (Kawano et al., 1984), (Peleg and Hinga, 1986). The acceleration levels and vibration durations actually used were chosen based on preliminary trials.

After the first trial for each commodity was completed, it was clear that the frequency range of 5 to 10 Hz range caused the most damage to both fruits. To further pinpoint the critical frequency within the 5-10 Hz range, two additional treatments using 5 to 7.5 Hz, and 7.5 to 10 Hz were added.

### DAMAGE EVALUATION

After vibration, the quality of the fruit in each frequency range and stack position was evaluated in several ways. The primary measure of quality was the weight of shattered grapes and the percentage of unsalable strawberries (severely and very severely damaged). With the grapes, the shattered berries were removed and weighed. The strawberries were graded into the five categories mentioned above, just as they were in the pre-experiment evaluation.

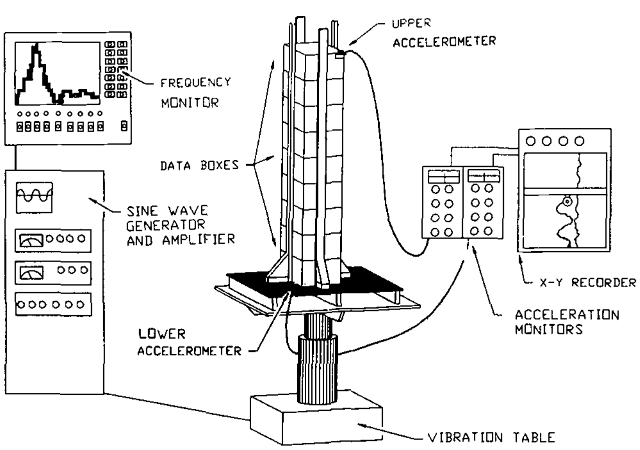


**Figure 1–Schematic view of experimental vibrational equipment.**

**TABLE 1. Strawberry grading system**

**Undamaged**
Berries with no abrasions but may have up to two bruises less than 2 mm in diamater.

**Slightly damaged**
Berries with no abrasions but may have up to four bruises less than 2 mm in diameter.

**Moderately damaged**
Less than 25% of the berry bruised or moderate abrasions covering less than 25%.

**Severely damaged**
Any berries with bruises or abrasions which penetrated the surface of the fruit.

**Very severely damaged**
Entire fruit bruised, mold formation or pieces of fruit missing.

The color of both the strawberries and the grapes was evaluated using a Gardner XL-800 tristimulus colorimeter. Tristimulus "L", "a" and "b" values were determined for 20 randomly selected individual fruit, which represented 15% of the layer from each frequency and stack. The tristimulus "L" value is a measure of lightness or darkness, the "a" value represents redness or greenness, and the "b" value is a measure of yellowness or blueness.

The firmness of the grapes was measured using an Instron Universal Testing Machine. With the grapes, firmness was determined by recording the force required to compress individual grapes 1 mm (0.039 in.) between two flat plates. Twenty randomly selected grapes from each treatment were measured. Strawberry firmness was measured as the maximum force needed to completely shear a 100 g (3.53 oz) sample in a Kramer shear cell. Three samples from each treatment frequency and stack position were sheared.

The respiration rate and ethylene production of fruits from each treatment level were measured at 20° C (68° F). To determine the respiration rate (mg $CO_2$/kg/h), about a 100-g (3.53 oz) sample was placed in a 0.5 or 1 L (1 qt) sealed container with humidified air metered through it. Outlet from the container was connected to a gas chromatograph for $CO_2$ measurements over an 18 h period. Ethylene production (ppm) was determined by placing about a 100-g (3.53 oz) sample in a 0.5 L (0.5 qt) sealed

**TABLE 2. Experimental parameters**

| | |
|---|---|
| **Grapes** | |
| Frequency (Hz) | 2-5, 5-20, 10-15, 15-20, 20-25, and 25-30 range |
| Acceleration level | 0.75 G for all frequency ranges |
| Time period | 60 min for each frequency range |
| **Strawberries** | |
| Frequency (Hz) | 2-5, 5-20, 10-15, 15-20, 20-25, and 25-30 range |
| Acceleration level | 0.6 G for all frequency ranges |
| Time period | 30 min for each frequency range |

container and aliqouts were analyzed periodically over a 4 h period for ethylene content with a gas chromatograph.

After evaluation, the fruit was placed in cold storage at 0° C (32° F) for one week and then re-evaluated for quality, color, and firmness. This was done to determine whether the vibration treatment had any latent effect on the fruit that would affect shelf life.

To determine whether the various treatments had a statistically significant effect on fruit quality, the analysis of variance technique (ANOVA) was used. If the ANOVA showed significance greater than 95% ($p \leq 0.05$), the least significant difference method (LSD) was used to rank the treatment means. The data on percent shattered grapes and percent injured strawberries were transformed to square root before analysis by a Sidak T test.

## RESULTS

### GRAPES

Before treatment, the grapes had an average of 8% shattered berries, by weight, due to previous handling and the trip from California to Maryland. After the vibrational treatments, an average of 16% of the grapes were shattered at the 5 to 10 Hz frequency range, which was significantly more than that noted below 5 or above 10 Hz frequency range (fig. 2). A 16% shatter is sufficient to lower the USDA grade of the grapes.

The average of the three trials indicated that the top box had twice as much shatter as the middle box and four times more than the bottom box (fig 2), but these differences were not significant based on the Sidak T test. In each of the three trials, the top box did have twice as much shatter as the middle box and at least four times more than the bottom box, but the differences between trials for a given location was almost as great as that between locations for a given trial, which nullified the location differences.

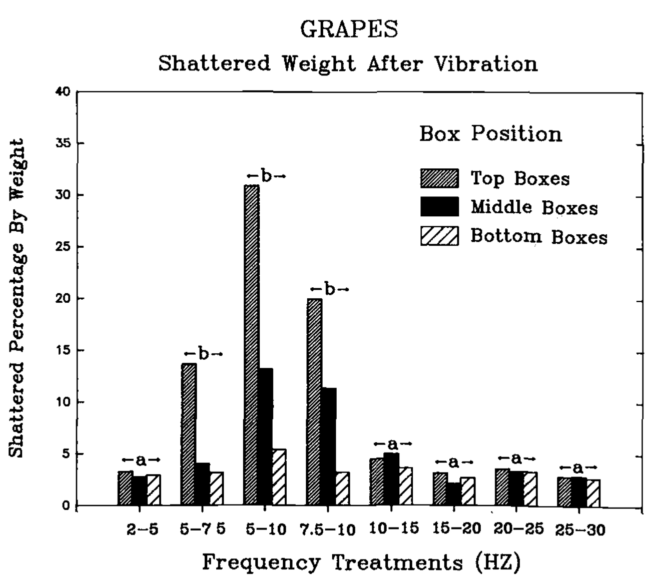


**Figure 2–Percent shattered grapes after vibration at different frequencies. Differences between locations were not significant. Frequency treatments with the same letter above the bars are not significantly different.**

Within the 5 to 10 Hz range, more shatter was noted at the 7.5 to 10 Hz range than at the 5 to 7.5 Hz range (fig. 2), but the differences were not significant.

Color analysis showed that the grapes vibrated at the 5 to 10 Hz range became significantly darker ($p \leq 0.05$), with an decreased L value, after treatment. After one week of storage, the fruit in the 5 to 10 and 10 to 15 Hz treatments were significantly darker ($p \leq 0.05$) than those in other treatments. Thus, as damage increased, the fruit became darker. The browning was probably due to oxidation of phenols which were released as the cells were ruptured by the vibration.

Firmness of the fruit was not affected by the vibration treatments ($p \leq 0.05$), either before or after the storage period. As might be expected, firmness did decrease across all the treatments, as a result of the storage period.

Respiration rate, as determined by the carbon dioxide production, of fruits in top boxes were determined. The carbon dioxide production by grapes vibrated in the 5 to 10 Hz range was greater than those vibrated at other frequencies (fig. 3). Physical damages cause respiration rate to increase and high rates contributes to decreased shelf life in other commodities (Hardenburg et al., 1986). It appears as though the five increased metabolic activity or caused some damages, and certainly the high rate will hasten deterioration of quality. The elevated respiration rate with the 5 to 10 Hz treatment was much greater in the first trial than that noted in the last trials, which all were significant. The differences between the first and the last trials may be due to differences in the physiological age or condition, in that the respiration rate of grapes in the first trial was higher than those in the last two trials. Grapes produced a very small amount of ethylene, 0.06 $\mu l/kg/h$, and the rates did not differ with the vibration treatments.

### STRAWBERRIES

More than 55% of the strawberries in the top box were unsalable after the vibration at the 5 to 10 Hz range (fig. 4). As noted with the grapes, the larger amount of damage noted at the 7.5 to 10 Hz range was not significantly greater than that noted at the 5 to 7.5 Hz range.

Color and firmness measurements were not affected by the vibration treatments ($p \leq 0.05$).

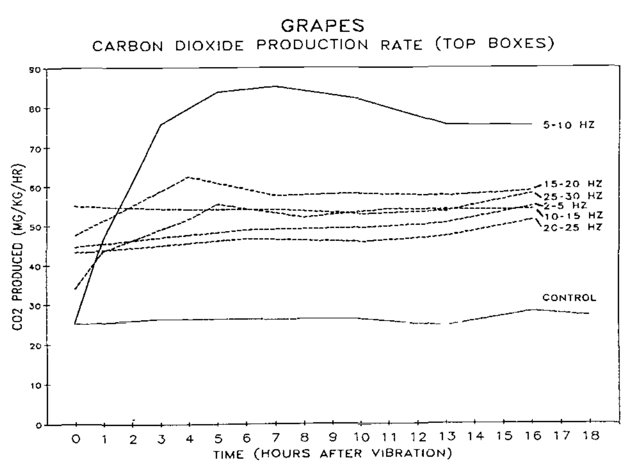


**Figure 3–Respiration rate of grapes after vibration at different frequencies.**

Respiration and ethylene gas measurements did not show any clear pattern in relation to the vibration treatments. The overall average carbon dioxide respiration rate was found to be 90 mg/kg/h, compared to average rate of 39 mg/kg/h by the grapes. The average ethylene production was 0.43 μL/kg/h.

## CONCLUSIONS

In examining a wide range of vibrational frequencies, the 5 to 10 Hz range caused the most damages to both fruits. By damping the force of the vibrations between 5 and 10 Hz, the amount of damage could be greatly reduced. It may also be possible to reduce damage by shifting the forcing frequency from the suspension further above the critical frequency.

Location of the box in the stack was shown to have a significant effect on strawberry damage, with the top box faring the worst damage. These results support anecdotal statements from shippers that the upper boxes in a load usually sustain the most damage. Although, statistically, location did not have a significant effect on grape damages, the effects were apparent visually. Maturity of grapes may have had an effect on the susceptibility to amount of damages, which needs further evaluation. Color was shown to be good measure of quality in grapes, since the results for this parameter mirrored the weight of shattered berries. Respiration also showed potential as an indicator of damage in grapes. For strawberries, neither color, firmness, respiration, nor ethylene production was shown to be an accurate measure of damage. The next phase of this project will involve testing new types of packaging, both in the laboratory and over the-road, that can be used to reduce damage.

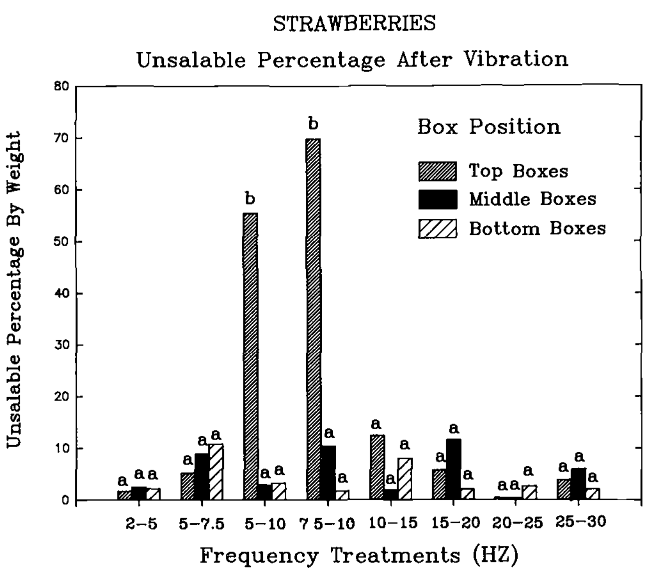


**Figure 4–Percent unsalable strawberries after vibration at different frequencies. Location or frequency treatments with the same letter above the bar are not significantly different.**

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