

Vibration analysis influence during crisis transport of the quality of fresh fruit on food security

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Abstract: Mechanical damage of agriculture produce is a major problem in the harvest and post-harvest chain. This damage could cause huge economic loss. In addition, it could lead to serious food safety concerns. Several cases of foodborne illness have been traced to poor or unsanitary postharvest practices. *Escherichia coli* (E. coli) O157:H7, *Salmonella*, *Shigella*, *Listeria*, *Cryptosporidium*, *Hepatitis*, and *Cyclospora* are among the diseases and disease-causing organisms that have been associated with fresh fruits and vegetables. Measurements of mechanical characteristics of agricultural products under different static and dynamic loads should help in predicting the type and magnitude of mechanical injuries which will help in minimizing losses and improve the safety the produce. In the current study, we examined the parameters essential for fruit package processes. Fruits were exposed to random excitation(is excited by combination of single- sinusoidal signal and a broad band stochastic single and compared to pure stochastic excitation) by using robust techniques EFDD enhanced frequency domain to harmonic excitation. Six vibration modes were identified in the frequency range of 0-1.6 kHz by two techniques FDD & EFDD. The paper-wrap and foam-net cushioning materials interaction is also studied. Damage identification technique has been applied to determine the integrity of the structure. Nearly all the examined fruit showed deterioration due to vibro-pressure and friction stresses mainly consisting of translucent or darkened bruises and streaks. Results obtained from test without cushioning materials have been correlated with the package of paper-wrap cushioning materials and foam-net cushioning materials.

Keywords: vibration analysis, crisis transport, quality, damage, food safety

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1 Introduction

A large percentage of fruits are wasted yearly because of damage such as bruising. Bruise is mostly caused by impact during handling, packaging, and transport of fruits. During fruit transport and handling, dynamical loads are causing by far the most bruise damage, because these loads are higher in incidence and magnitude than static loads (Mohsenin, 1986; Kupferman, 2006). The fruit journey from orchard to supermarket is extremely

complex and fruits are subjected to a variety of dynamical loads that could result in this damage. It plays a key role for rejecting fruits at quality inspection. In some cultivars, apple bruising can result in product losses up to 50% (Pang, 1992), although typically loss levels are between 10% to 25%, depending on consumer's awareness (Studman, 1997).

Mechanical injuries are responsible for considerable decay of fresh fruits and vegetables. Produce discarded because of damage in the chain between the grower and the consumer is estimated at around 30% to 40% (Peleg and Hinga, 1986). Mechanical stresses occur during picking and packaging. Various studies have been carried out to assess the effects of these stresses on fresh fruits (Bartram et al., 1983; Bollen and De La Rue, 1990;

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Brown et al., 1987; Burton et al., 1989; Peleg, 1985), but a remarkable contribution to the development of damage can be due to transportation from farms to packing houses and from packing houses to retail outlets. With regard to transportation, frequent attention was devoted to delicate fruits such as apples. Singh and Xu (1993) reported that as many as 80% apples can be damaged during simulated transportation by truck depending on the type of truck, package and position of the container along the column. Other results of tests carried out on apples during transportation confirm high susceptibility of these fruits to mechanical vibrations and the great influence of the kind of container on damage (Shulte et al., 1990; Timm et al., 1996). Damage due to transport vibration was investigated on other species of fruits and vegetables, such as cling peaches (O'Brien et al., 1965; Vergano et al., 1991), apricots (O'Brien & Guillou, 1969), potatoes (Grant et al., 1986; Turczyn et al., 1986), tomatoes (Singh and Singh, 1992), grapes and strawberries (Fischer et al., 1992).

The major cause of these losses is mechanical damage (bruising) due to impact. This impact could result from either vibration or sudden drop of the produce from certain heights. Over the years several studies were carried out to assess the mechanical properties and susceptibility to bruising of fruits and vegetables (Holt and Schoorl 1985; Olorunda and Tung 1985; Jones et al. 1991; Roudot et al. 1991; Singh and Singh 1992; Hyde et al. 1993; Ogut et al. 1999; Vursavus and Ozguven 2004; Berardinelli et al. 2005). Impact sensitivity of fruits and vegetables was defined as having components namely bruise threshold and bruise resistance (Bajema and Hyde 1998). Bruising in fruits and vegetables occurs when the produce rubs against each other, packaging containers, parts of processing equipment and the tree (Altsient 1991).

Vibration and shock during transport injures fruit and vegetables, especially fruit with a soft pericarp. Mechanical damage in truck transport, including abrasions and bruises, reduces quality to a level where truck transport may become problematic. Losses in fresh fruit rose by 17% and in vegetables 10% during transport and distribution in 2006 in Japan (Ministry of Agriculture, Forestry and Fisheries, 2008). Fruit must

thus be packaged in cushioning sufficient to protect it from vibration and shock. This is especially true of perishable fruit and vegetables such as pears (Berardinelli et al., 2005, Slaughter et al., 1993, Slaughter et al., 1995, Zhou et al., 2007, Zhou et al. 2008), loquats (Barchi et al., 2002), peaches (Vergano et al., 1991). Domestic fruit is mainly transported by truck using many types of containers, including corrugated fiberboard containers and cushioning materials. Fruit for export may also be packaged using the same material and design as in distribution in Japan, causing problems in mechanical damage and internal quality, necessitating the development of better packaging for exported fruit.

Apple consumers increasingly demand better quality fruits. Mechanical damages such as bruises, abrasions, cuts and punctures are irreversible and are accumulated damages during the handling process. The inevitable consequence of mechanical damage is low grade and low quality fruits, hence less income to both growers and packers (Timm et al., 1996; Abbott and Lu, 1996).

The objective of this study was investigating the dynamic properties of apple during excitation, studying effect of vibration levels on mechanical properties of apple (firmness), and showing the effect of these levels on damage apple properties.

2 Methodology

2.1 Experimental Procedures

The apples used in this study were of the Golden variety, which are 65-83 mm diameter. This variety was selected because it is quite susceptible to bruising, and bruises and abrasion are easy to see. The apples were carefully picked manually in the 2012 season from an orchard and placed in the corrugated fiberboard containers with paper pulp trays in the orchard. This procedure was followed in order to minimize any bruising that may occur from transporting the apples to the laboratory.

In this paper fresh apple was subjected to transport vibrations throw vibration exciter with random force in laboratory of the Agric. Eng. Dept., Faculty of Agriculture Minoufiya University. The dynamic responses were measured using piezoelectric

accelerometers and pulse analyzer with software for measuring OMA using FDD and EFDD. The effect of packaging materials on reduces damage was studied. The experimental procedure of dynamic set of experiments is as follow:

1) Measuring mechanical properties of apple such as (firmness) to show the effect of these levels of vibration on apple properties

2) Subjecting sample of (Apple) to levels of vibration frequency and analyzing dynamic response throw FDD and EFDD using foam and paper as cushioning material for packing (and compare them in case without packing) to show effect of these on bruising of apples and measuring damping capacity of apple to study its effect on bruising damage.

2.2 Vibration measurement procedure

This study was conducted to measure and analyze the dynamic response of fruit apple under random force as natural excitation of road and truck condition to investigate the effect of vibration frequency and warping papers on the mechanical damage during transporting, Figure 2. The fruit was resting on foam bad to simulate free-free condition on the exciter with force transducer in Figure 1 with specification as in Table 1. The excitation frequency was random frequency with selected range of 0-1.6 kHz. The measurements were made using one reference (fixed) accelerometer and roving accelerometer in Figures 2 and 3 for the response at the points determined as in Figure 4. The data acquisition system was portable pulse analyzer; and was composed of five channels and a lap top computer for B&K software. The

pulse modal test consultant was used to set up the hardware. Created the geometry and assigned the measurements to each degree of freedom. The reference accelerometer was maintained at a well-chosen point on the apple fruit such all modes contribute to the reference accelerometer, using a preliminary idea of the mode shape. The raw time histories were captured by a (time capture analyzer) for each measurements set. And damping capacity was measured using EFDD for roving and fixed response as in Figures 5, 6, 7, and Table 2. EFDD for out-put response (roving response and fixed response) measuring transmitted fruit (roving response and fixed response).

Table 1 Physical dimensions and sensitivities of the accelerometers used in the experiment

Model	Dimension /mm	Weight /g	Sensitivity /mV g ⁻¹	Frequency range, Hz/±1 dB
Triaxiel Accelerometer	17×17×21.9	15	97.8	0.3 to 6000
Fixed Accelerometer	10×10×15.3	4.8	99.3	0.3 to 6000
Force transducer type 8200	13×18	21	3.94 Pc N ⁻¹	----
Vibration Exciter Type 4809	149×143	8300	----	10- 20,000
Power Amplifier Type 2706	240×210×133	6000	----	----

Table 2 (EFDD) and damping ratio for apple fruit with different cushioning materials under random excitation

Mode	foam-net		paper-wrap		without	
	Freq /Hz	Dam ratio /%	Freq /Hz	Dam ratio /%	Freq /Hz	Dam ratio /%
Mode 1	25.3	5.011	38.76	0.9925	152.5	6.953
Mode 2	45.26	4.835	315.4	2.438	513.4	1.565
Mode 3	50.17	5.838	510.3	1.623	585.3	1.031
Mode 4	87.09	4.237	587.7	1.521	747.0	0.267
Mode 5	200.5	4.229	657.6	0.6586	775.3	0.3527
Mode 6	371.7	1.489	777.1	0.607	791.7	0.5172

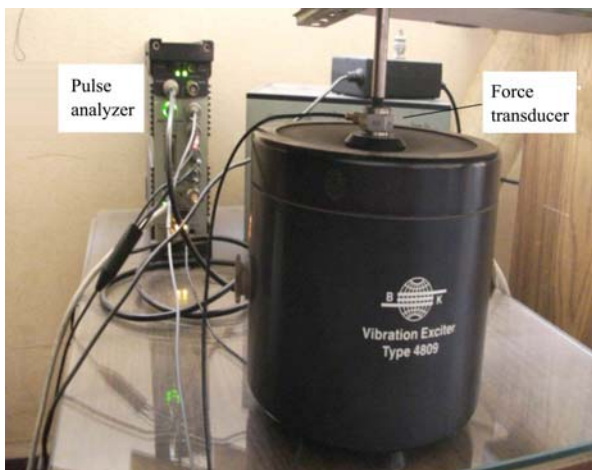


Figure 1 Vibration Exciter- type 4809 with force transducer

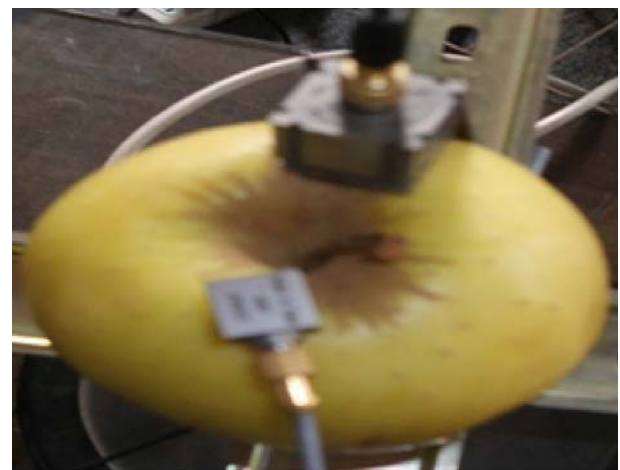


Figure 2 position reference and vertical acceleration

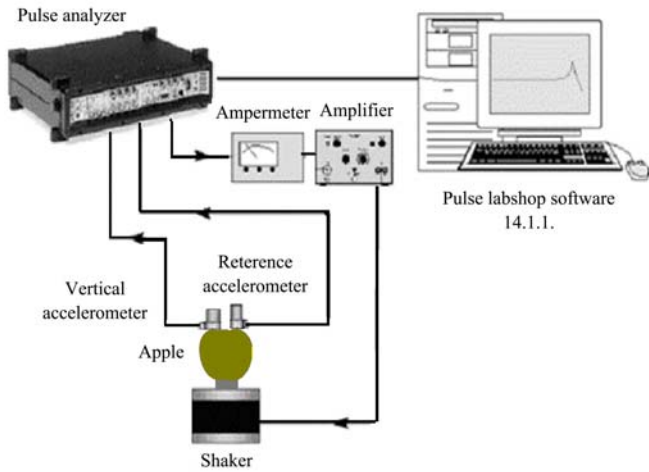


Figure 3 Schematic layout of the system used for preliminary to vibration analysis

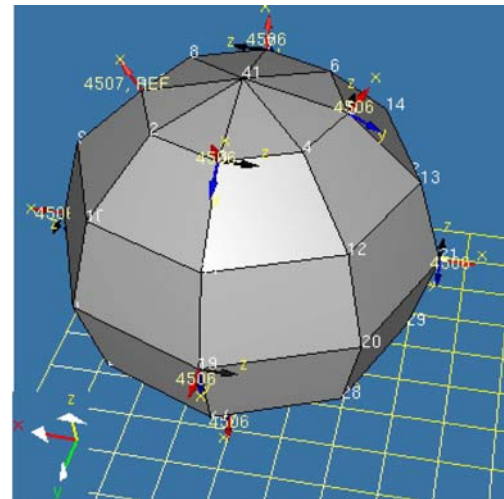


Figure 4 Points of measurements using modal test consultant software

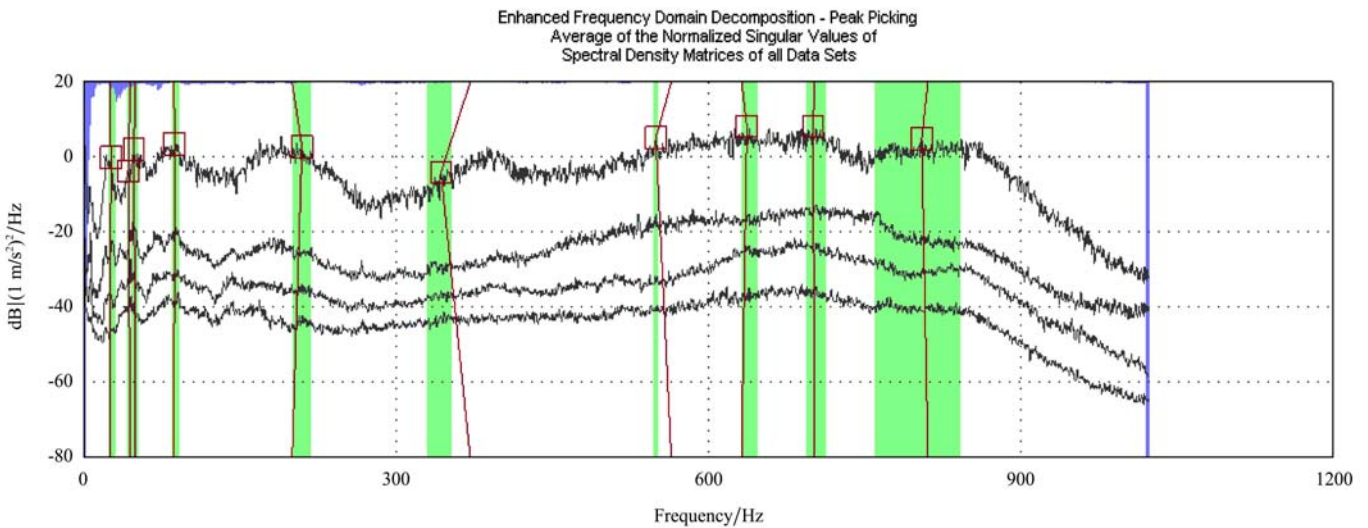


Figure 5 Singular value decomposition of the spectral density matrices for apple fruit with foam-net cushioning materials

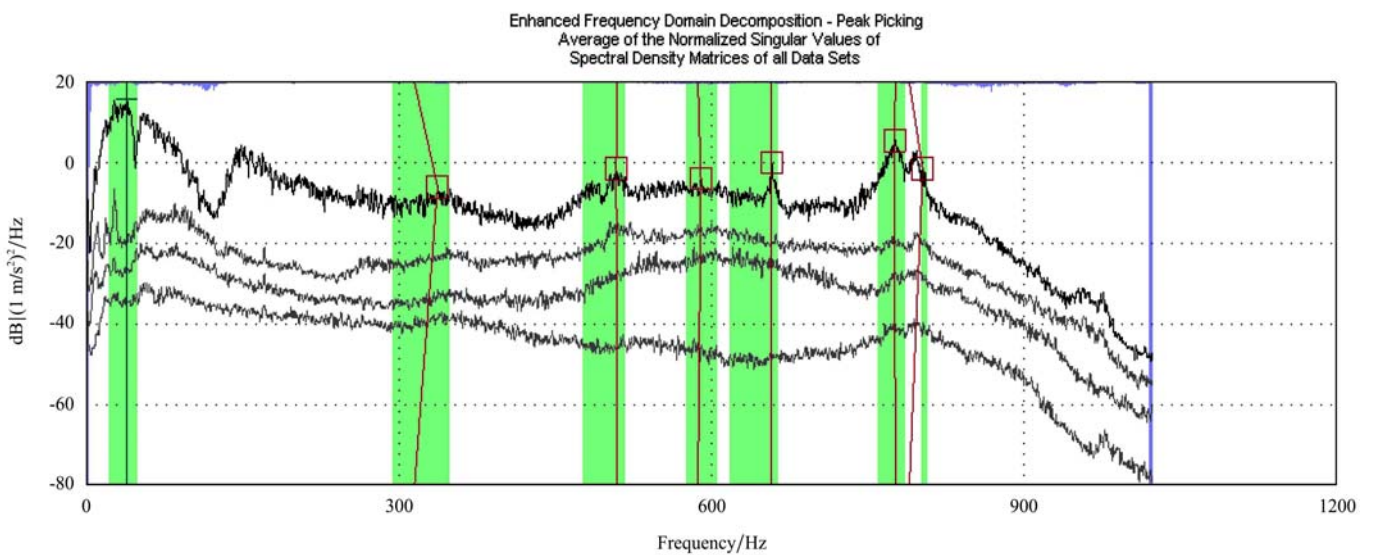


Figure 6 Singular value decomposition of the spectral density matrices for apple fruit with paper-wrap cushioning materials

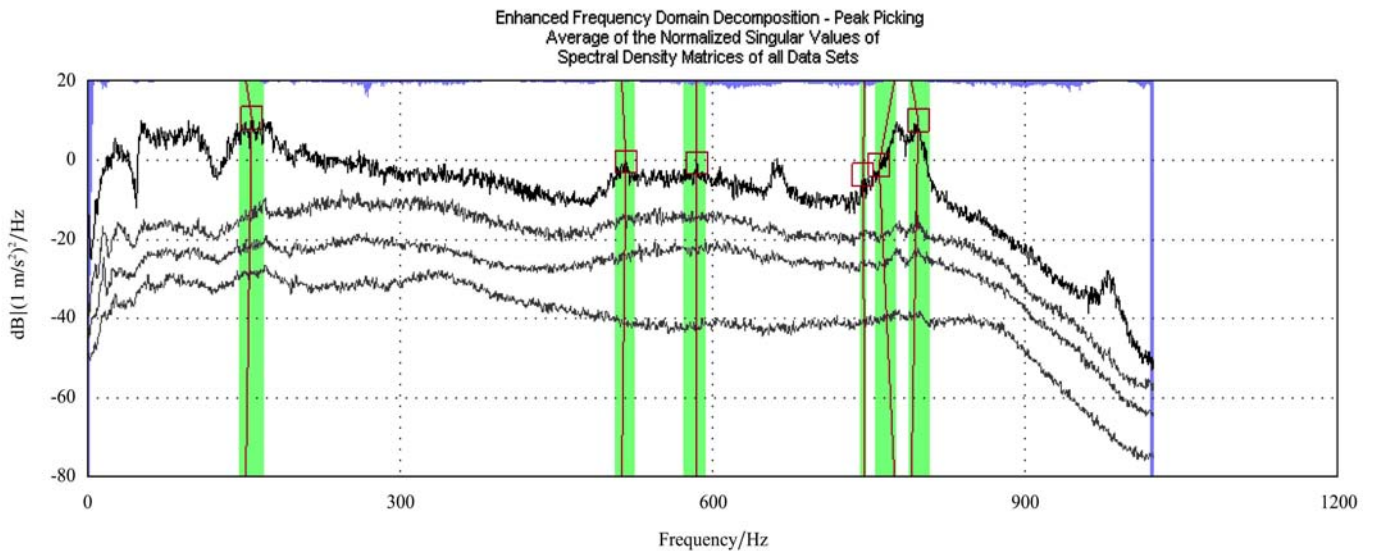


Figure 7 Singular value decomposition of the spectral density matrices for apple fruit without cushioning materials

To indicate firmness f or spherical fruit, stiffness factor (S_f) or firmness index (FI) (first introduced by (Nourain Jamal, et al., 2005) can be calculated by Equation (1) as:

$$S_f = f^2 m^{2/3} \quad (1)$$

where, S is the stiffness coefficient, $\text{kg}^{2/3} \text{s}^{-2}$; f the dominant frequency where response magnitude is the greatest, Hz; and m the fruit mass, g.

Gómez et al (2005), proposed a mathematical model for the interpretation of the vibrational behavior of intact fruit. They showed that the Elastic Modulus could be estimated satisfactorily as follows Equation (2):

$$E = f^2 m^{2/3} \rho^{1/3} \quad (2)$$

where, E is the elasticity coefficient, Pa; and ρ the density, kg m^{-3} .

2.3 Apple damage

The width and depth of each bruise were measured. Since the bruises were approximate ellipsoids, a measure of bruise volume was obtained from the Equation (3). The fruit cut in the middle of the two bruised spots perpendicularly to the fruit surface and the diameters (D) and depths (t) (in mm) of the spots were measured as is shown in Figure 8. The bruise volume in Figure 8 was calculated using the following formula (Zarifneshat, 2010):

$$V_B = \frac{\pi}{6} D^2 t \quad (3)$$

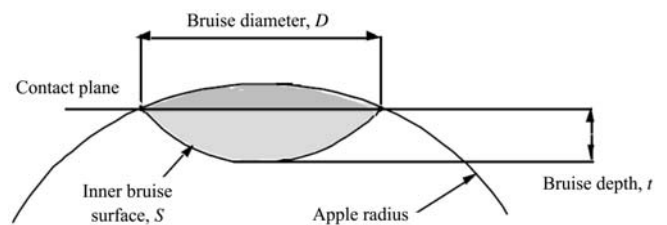


Figure 8 Bruise volume calculation

The damage was considered as the visible damage to the human eyes after 24 hours for each test in Figure 9 and Figure 10. Scuffed samples (with surface abrasion damage to skin) and those with flesh damage were separated from each test and their percentages based on the weights of the corresponding dropping were taken as apple mechanical damage.



Figure 9 Shape of damage to the flesh of apple

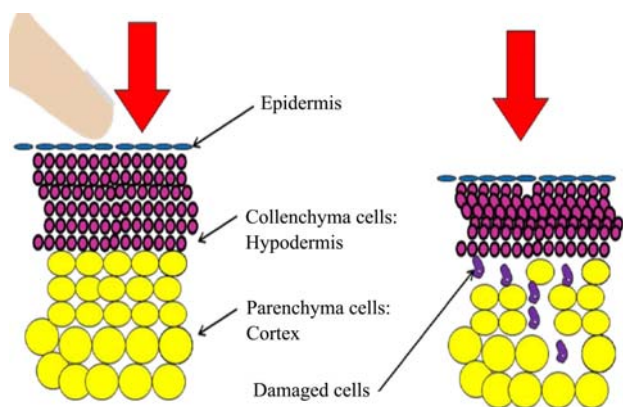


Figure 10 Proposed bruising mechanism for 'Golden Delicious' apples

3 Experimental Results and discussion

3.1 Effect different levels of vibration frequency on dynamic properties of apple during excitation

The variation of vibration characteristics of this type of apple with the correlation of its behavior and material characteristics was investigated using (OMA) for three types of cushioning materials. The dynamic behavior of exciting apples are governed by vertical bending and torsion modes, in the frequency range of 0–1.6 kHz, six modes have been identified in this frequency range. Tables 3, Table 4 and Table 5 show the obtained natural frequencies, damping loss factor, elasticity and stiffness factor for technique of estimation of the model under the excitation conditions for both three types of cushioning materials. To comprehend the factors involved with in-transit damage of apple, it is necessary to understand that in vibrating systems, when the natural frequency is reached, much higher acceleration occurs. It is desirable, therefore, to transport apple on vehicles that have natural frequency in a range which differs from that of the apple (Gomaa et al., 2011). The first test was carried out for foam-net cushioning material while the second test for paper-wrap cushioning material and the third was using without-paper cushioning material for each apple. Very little change appears in the natural frequencies obtained from the three experimental tests, as can be seen from the values shown in Table 3, Table 4 and Table 5.

Our data suggested that foam-net materials were the most efficient in alleviating vibration intensity during transport. This phenomenon could be due to the texture

of foam-net materials, which had more elasticity and springiness than paper-wrap materials. So the foam-net materials were able to improve the quality and safety of apple after harvest and postharvest process.

Table 3 Determining natural frequency, damping ratio, elasticity and stiffness factor for apple fruit with foam-net cushioning materials

Mode	Frequency /Hz	Damping ratio/%	Elasticity, E/MPa	Stiffness, $S/10^4 \text{ Hz}^2 \text{ kg}^{2/3}$
Mode, 1	25.3	5.838	0.0013	0.0173
Mode, 2	45.26	5.011	0.0043	0.0552
Mode, 3	50.17	4.835	0.0052	0.0679
Mode, 4	87.09	4.237	0.0158	0.2045
Mode, 5	200.5	4.229	0.0835	1.0839
Mode, 6	371.7	1.489	0.2871	3.7251

Table 4 Determining natural frequency, damping ratio, elasticity and stiffness factor for apple fruit with paper-wrap cushioning materials

Mode	Frequency /Hz	Damping ratio/%	Elasticity, E/MPa	Stiffness, $S/10^4 \text{ Hz}^2 \text{ kg}^{2/3}$
Mode, 1	38.76	2.438	0.0031	0.0405
Mode, 2	315.4	1.623	0.2067	2.6821
Mode, 3	510.3	1.521	0.5411	7.0211
Mode, 4	587.7	0.9925	0.7176	9.3124
Mode, 5	657.6	0.6586	0.8985	11.6594
Mode, 6	777.1	0.607	1.2547	16.2819

Table 5 Determining natural frequency, damping ratio, elasticity and stiffness factor for apple fruit without cushioning materials

Mode	Frequency /Hz	Damping ratio/%	Elasticity, E/MPa	Stiffness, $S/10^4 \text{ Hz}^2 \text{ kg}^{2/3}$
Mode, 1	152.5	6.953	0.0483	0.6270
Mode, 2	513.4	1.565	0.5477	7.1066
Mode, 3	585.3	1.031	0.7118	9.2365
Mode, 4	747.0	0.5172	1.1594	15.0450
Mode, 5	775.3	0.3527	1.2489	16.2066
Mode, 6	791.7	0.267	1.3023	16.8995

From Table 3, Table 4, and Table 5 it was noticed that increasing damping in case of foam-net compared to paper-wrap, its refer to this materials add mass which may move the natural frequency of fruit out of range of that the transporting vehicle (exciting force) and reduced resonant vibration and vibration bruising.

3.2 Dynamic properties of apple fruit:

Figures 11 and Figure 12 show the relation between

natural frequency and damping ratio with stiffness factor and modulus of elasticity for apple fruit, which show that decreasing damping ratio by increasing natural frequency, stiffness factor and modulus of elasticity for all three types of cushioning materials. The decreasing rate of damping ratio for apple was 74%, 75% and 96% at three types of cushioning materials (foam-net, paper-wrap, without), respectively. It refers to the texture of foam-net materials, which has more elasticity and springiness than paper-wrap materials.

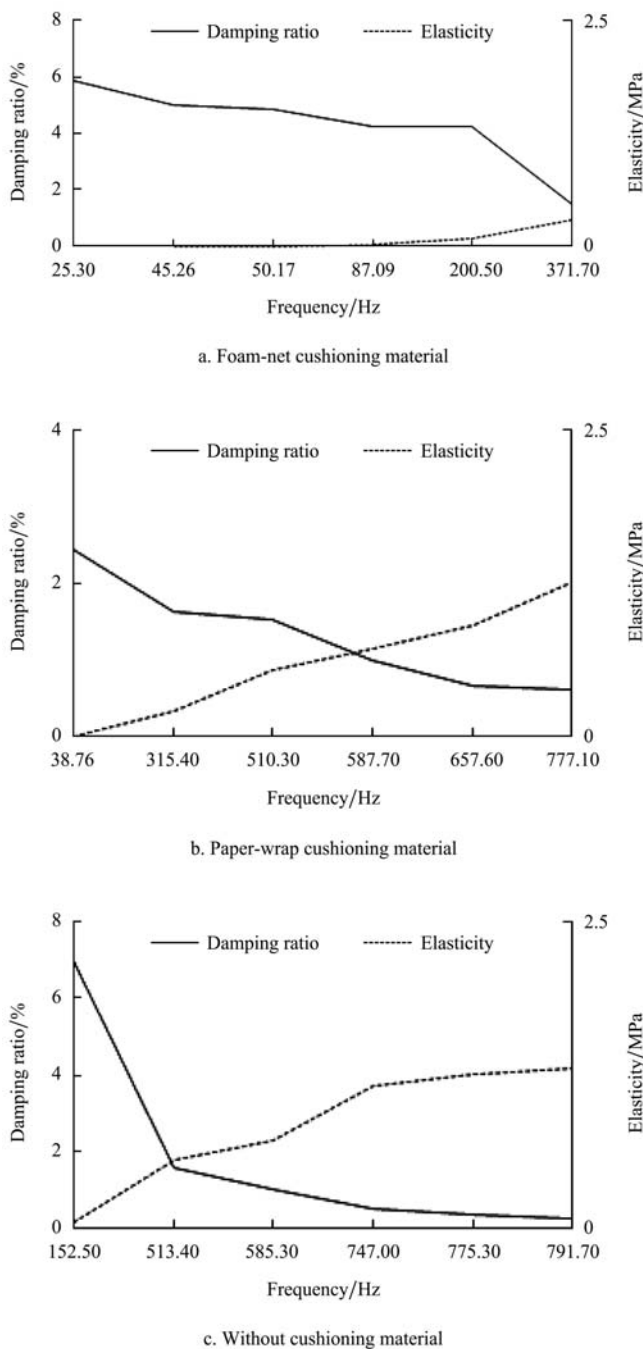


Figure 11 Response apple fruit for the frequency (F) as a function of young's modulus and damping ratio with

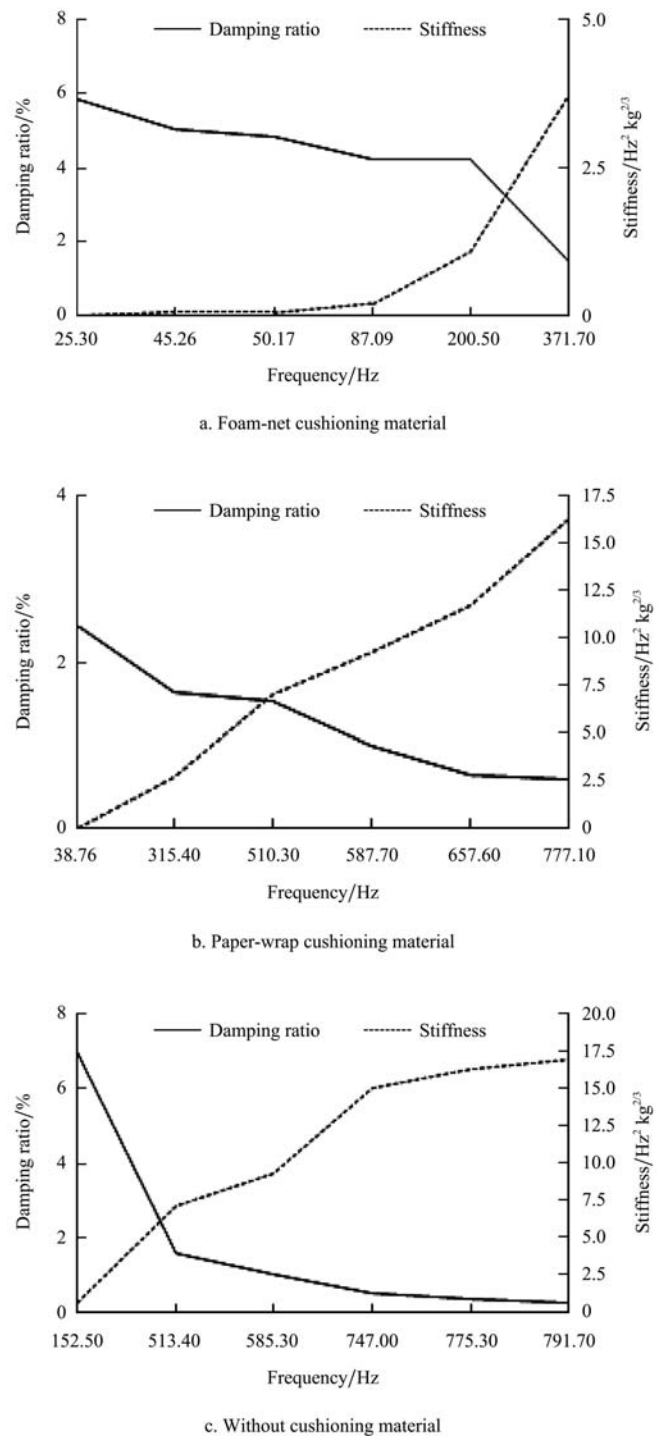


Figure 12 Response apple fruit for the frequency (F) as a function of stiffness factor and damping ratio with

3.3 Firmness of apple fruit after excitation:

The firmness of apple decreased significantly during the storage after excitation in Figure 13. The highest and lowest levels of firmness were noted at fruit with foam-net cushioning materials and fruit without cushioning materials, respectively. The use of foam-net cushioning materials was more effective in maintaining the firmness of apple than paper-wrap cushioning

materials. The fruits without cushioning materials had the fastest softening rate, losing about 54% of their firmness during storage period, while the softening rate of fruits with paper-wrap and foam-net cushioning materials was 41% and 38%, respectively. These data demonstrated that mechanically injured fruits had a higher rate of softening than intact fruits during storage in ambient temperature.

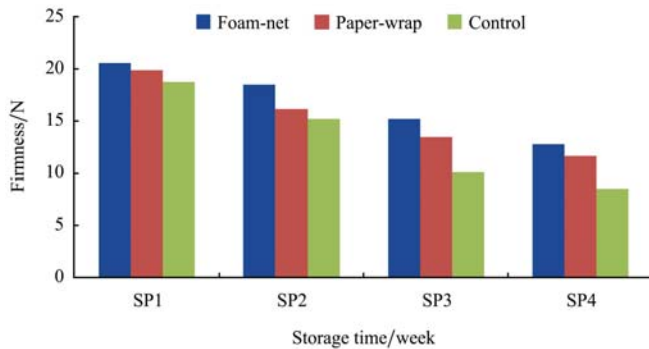


Figure 13 Changes in firmness after transport apple fruit with different cushioning materials during storage time

3.4 Evaluation vibration damage

In this study, the apple fruit were exposed to severe vibration and extended transit time. Injuries to apples included darkened burnings of the skin and bruises with little or no penetration into the flesh. Figure 14 gives the results of damage evaluation of apple fruit with different cushioning materials. The greatest damage was noted in apple fruit without cushioning materials compared to others. Similar to what was seen with vibration levels, the use of foam-net materials was more efficient at reducing damage to individual apples than paper-wrap materials. Both of the cushioning materials efficaciously reduced bruise volume per fruit in Figure 14. This phenomenon was not solely due to the placement of a layer of cushioning materials between each fruit, but may also be related to their ability to decrease vibration levels during transport. Clearly, foam-net packages had more protective effect than paper-wrap packages.

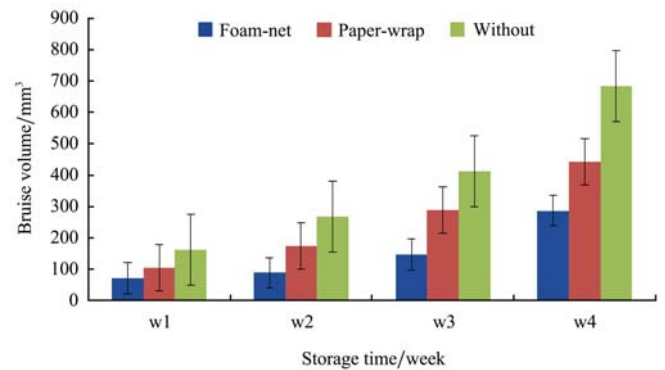


Figure 14 The bruise volume of apple fruit with different types of cushioning materials during excitation test

4 Conclusion

The results indicated that apple damage can be reduced and quality can be improved during harvest and postharvest process if apples packaging with foam-net cushioning material.

The range of resonance frequency of apple fruit is important when transporting without cushioning material, a higher starting resonance is an indication of a stiffer apple bottom, the cushioning material moves resonance frequency compared without cushioning material.

Another interesting observation in this work is that if the internal damping capacity of fruit is high, even if its natural frequency may fall within the range of excitation, it may not receive as much exciting vibration injury as fruit with low damping capacity.

Packaging fruit by cushioning material may move the natural frequencies of the fruit out range of that the transport vehicle resulting in reduced resonant vibration and vibration bruising for fruit.

Study of the dynamic response of agriculture product makes it possible to get very quick knowledge of actual condition and help in design handling equipment, suspension and conveyor.

Not exposed apple fruit for high frequencies of vibrations so as to increase that frequency less than the damping ratio of the cushioning material while increasing the number of fruits damaged.

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