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Simulated In-transit Vibration Damage to Watermelons

F. Shahbazi[1], A. Rajabipour[2], S. Mohtasebi[2], and Sh. Rafie[2]

ABSTRACT

Vibration generated by vehicles during road transport has an important effect on the agricultural products damage process, particularly vegetable and fruit. Modulus of elasticity is one of the most important mechanical properties of fruits and its variation can be described as one of the damage criteria during transportation. This research was conducted to evaluate the effects of vibration parameters (frequency, acceleration and duration) and fruit position in the bin, on watermelon damage. At first, vibration frequency and acceleration were measured on the different points of a truck-bed in order to obtain the range of vibration frequency and acceleration distribution during transportation. Second, a laboratory vibrator was used to obtain some factors influencing damage during watermelons transportation. The damage was described as a difference in the modulus of elasticity of the watermelon (flesh and hull) before and after the test. According to the results measured on the truck-bed, the vibration frequency mean values were 7.50 Hz and 13.0 Hz for 5-10 Hz and 10-15 Hz frequency intervals, respectively. Furthermore, vibration acceleration mean values were 0.30 g and 0.70 g for 0.25-0.50 g and 0.50-0.75 g intervals, respectively. Vibration frequency and acceleration mean values were used for vibration simulation. Vibration durations were 30 and 60 minutes and damage was measured for watermelons at the top, middle and bottom positions in the bin. Laboratory studies indicated that, vibration frequency, vibration acceleration, vibration duration, and fruit position, which were taken into consideration as controlled variable parameters, significantly affected the damage ($P< 0.01$). Damage to the watermelon flesh was higher than watermelon hull. Vibration with a frequency of 7.5 Hz, acceleration of 0.70 g, and duration of 60 minutes caused higher damage levels. Fruits located at the top of the bin showed more damage than those in middle and bottom positions ($P< 0.05$).

Keywords: Acceleration, Frequency, Mechanical damage, Modulus of elasticity, Vibration, Watermelon.

INTRODUCTION

Mechanical injuries are the main reason for considerable decay of fresh fruits and vegetables. Production wasted due to damage in the chain between the grower and the consumer is estimated at around 30–40% (Peleg and Hinga, 1986). The reasons for mechanical injuries are numerous, and are often broadly grouped as impact, abrasion, compression and vibration damage, based on the type of force acting on the fruit (Sitkei, 1986). Vibration damage occurs when fruits are subject to vibratory forces, such as during transport. This type of stimulus can cause impact, abrasion and compression injuries. Vibration injury may cause only one of these types of damage, or all three. For example, in the transport of kiwi fruit Lallu *et al.* (1999) described that vibration generally resulted in abrasion of the skin, with a smaller amount of compression damage and little impact injury. Vibration injury generally occurs during transport,

[1] Department of Agricultural Machinery, College of Agriculture, University of Lurestan, Khoramabad, Islamic Republic of Iran.
[2] Faculty of Biosystem Engineering, College of Agriculture, University of Tehran, Karaj, Islamic Republic of Iran.
* Corresponding author, e-mail: shahbazi.f@lu.ac.ir

with the interaction of the road and vehicle suspension system generating vibration. The vibration caused during transport is semi-random, occurring across a large range of frequencies and with jolts and bumps in the road adding to the background vibration (Hilton, 1994). The irregular nature of vibration input makes it difficult to define a threshold for vibration damage. Fruit will vibrate when the frequency of vibration reaches a certain level. If the resonance frequency of the fruit column is the same as the excitation frequency of the vehicle or road, the acceleration of the fruit can be considerably increased due to the resonance, and thus severe damage can result (Sitkei, 1986). In stacked or palletized produce, the vibration can be directed up through the stack, increasing in magnitude at higher levels (Sitkei, 1986). For this reason, displaced cartons and vibration injuries are most common at the top of stacks. Vibration injury within a box of fruit is also localized to the top layers, as these fruit are most capable of movement. The main types of damage to fruit are bruising and tearing of skin (external) and internal damage (Mohsenin, 1987; Olounda and Tung, 1985; Ogut *et al.,* 1999). The modulus of elasticity is a very important mechanical property of fruits and its variation can be described as internal damage in transportation (Ogut *et al.,* 1999). The damage is always greatest on the top layers of the fruits in the bin and, under severe transport conditions, it my extend down tow or three layers (O'Brien and Guillou, 1969).

Watermelon is one of the main summer fruits. It is a warm-season crop and is most productive in areas that have a long, warm growing season. The three biggest watermelon producing countries are China, Turkey and Iran, respectively, that have 78% share of world watermelon product. Iran produces about 2.2 million tons of watermelons annually. Watermelons require extensive handling during harvest and market distribution and, because of their weight and size, proper care is required during handling. Carelessness during transit results in surface abrasion and damaging (mostly internal) impacts to the melons. Severe impacts will cause obvious external damage but frequently also internal damage, characterized by cracks in the fleshy tissue, that will be undetectable until the melon is cut open. Damage due to dropping, vibration during transport may not be seen on the outside of the melons but will show up internally as water-soaked areas that break down quickly (Armstrong *et al.,* 1977; Martin, 1996). Excessive handling also causes "shaker" melons, where the seeds have been separated from the flesh. Movement of fruits and vegetables, such as watermelon, from farm to market place in many developing countries is generally accomplished by truck. In Iran, for instance, the bulk of watermelons grown under irrigation in the southern parts of the country is shipped to the center and North, a distance of a bout 2,000 km, in bulk bins of trucks with a 10 ton capacity. Pickups loaded with melons are driven to a collection point where melons are off-loaded by hand for sizing/grading and then re-loaded into highway trucks as bulk loads. When transported in the bulk method, melons are handled at least five times from point of harvest to being displayed in retail stores. In order to avoid damage, the magnitude of the handling stress must be kept below the minimum stresses, which causes bruising of different watermelon tissues.

Many research studies have been carried out recently on assessing the effect of transport vibration on farm produce. The frequencies of transport vibration have been monitored for trucks carrying fresh fruit (Hinsch *et al.,* 1993; Jarimopas *et al.,* 2005). Moreover, much attention has been paid to assessing damage due to transport vibration of different species of fruit and vegetables such as potatoes (Turczyn *et al.,* 1986), cling peaches (O'Brien *et al.,* 1965; Vergano *et al.,* 1991), apricots (O'Brien and Guillou, 1969), tomatoes (Singh and Singh, 1992), grapes and strawberries (Fischer *et al.,* 1992), apples (Shulte *et al.,* 1990; Timm *et al.,* 1996; Van Zeebroeck *et al.,* 2006;

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Nicolai and Tijskens, 2007), loquats (Barchi *et al.,* 2002), and pears (Berardinelli *et al.,* 2005; Zhou *et al.,* 2007). Singh and Xu (1993) reported that as many as 80% of apples can be damaged during simulated transportation by truck, depending on the type of truck, package and position of the container along the column. No research finding, exist about vibration damage to watermelons.

The objectives of the present study were: (1) to measure and analyze the distribution of vibration frequency and vibration acceleration generated on the truck-bed under real road conditions during watermelon transportation, (2) to simulate the transport vibration by using a vibration simulator under laboratory conditions to investigate the effects of vibration parameters such as vibration frequency, vibration acceleration, vibration duration, and fruit position in the bin on the damage during watermelon transportation.

MATERIALS AND METHODS

Fruit Selection

The watermelons used in this study were Charleston gray variety, because it is one of the common commercial varieties grown in Iran and all over the world (FAO, 2005). The melons were carefully picked in the 2007 season from an orchard in the Karaj region and placed in the corrugated containers and carefully handled up to the laboratory in order to minimize any bruising before testing. The melons were stored at 5°C and 90% relative humidity until testing. Physical properties such as dimension, mass and volume were measured then the density, spherical coefficient, and geometric mean diameters were calculated. Three mutually perpendicular axes, major (a, longest intercept), intermediate (b, longest intercept normal to a) and minor (c, longest intercept normal to a and b) were measured with an accuracy of 0.05 mm using a long venire caliper. Geometric mean diameters and spherical coefficients were determined from the following equations (Mohsenin, 1986):

$$\text{Geometric mean diameters} = (abc)^{1/3} \quad (1)$$

$$\text{Spherical coefficient} = (abc)^{1/3}/a \quad (2)$$

The mass of each watermelon was measured with five-gram accuracy on a digital balance, and the volume of the melons was obtained from the water displacement method (Mohsenin, 1986). The initial status of melons considered and measured as terms of mechanical properties (modulus of elasticity of hull and modulus of elasticity of flesh).

Vibration Simulator

The vibration simulator used in this study to provide amplitudes and frequencies covering the range measured on trucks, was similar to that described by O'Brien and Guillou (1969), Ogut *et al.* (1999), and Vursavus and Ozguven (2004). Figure 1 shows the laboratory vibration simulator; as shown, it consist of a table on soft springs and attached to it an actuating system that included adjustable weights on two counter-rotating shafts (counterweights) revolving in opposite directions and about the center of gravity of the table and its load, providing vertical vibration only. Counterweights were powered by an electric motor (3.0 kW and 3,000 rpm). The speed of the electric motor was adjusted by means of a speed control unit (inverter), which had a 4.0 kW power. The magnitude and angular velocity of the rotating masses can be changed. Because the frequency of the vibration simulator table is

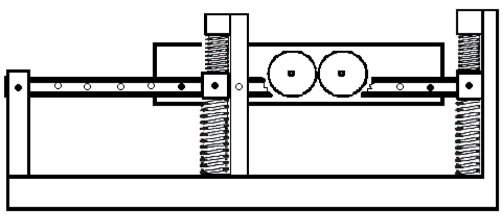

Figure 1. Vibration simulator.

directly related to the rotation number of the counterweights, the frequency of the table was obtained based on the number of revolutions of the electric motor. Therefore, the speed of the electric motor was measured by means of the speed control unit and the number of the revolutions of electric motor measured in rpm was divided by 60 seconds and the frequency of vibration simulator table was obtained in Hz. The acceleration of the vibration simulator table was directly measured using an acceleration measurement device and a piezoelectric accelerometer.

Transit Vibration Measurements

Vibration measurements were carried out on three 10 ton capacity truck-beds, which have two axles and suspension systems with leaf springs in the front and rear axles, under road conditions similar to watermelon transportation from Khuzestan to Tehran, for the laboratory study. In the measurement of road conditions, an acceleration measurement device (X-Viber, X-25, Switzerland) was used. The piezoelectric accelerometer (48 g weight, acceleration range from 0.1 to 20 g, velocity from 0.01 to 19.99 cm s^{-1} and displacement from 0.001 to 1.999 mm) of the device was mounted on the truck-bed floor in different positions, e.g. 20 cm from the right wall of the trucks. The accelerometer was connected to the vibrometer and signals were recorded on a laptop computer. Measurements including acceleration and amplitude were repeated for the front, middle and rear axle positions of the truck-beds. The average data measured from three trucks and at three different positions were considered for vibration analysis. Vibration frequency values of the truck-beds were determined using a computer software program. Vibration frequencies on the truck-bed were calculated by entering vibration acceleration and amplitude values into the software program. The calculated vibration frequency and measured vibration acceleration values were used in order to obtain frequency and acceleration distribution percentages on the truck-beds. Therefore, distribution percentages of vibration frequency and vibration acceleration were obtained with intervals of 5 Hz and 0.25g (-1 g=9.81 m/s^2), respectively. Two of the average values, which give the highest distribution in the distribution percentages depending on intervals of vibration frequency and acceleration, were taken into account to be the controlled variable parameters used in the laboratory tests. The average values selected as controlled variable parameters were 7.50 and 13.00 Hz for vibration frequency and 0.30 and 0.70 g for vibration acceleration (peak acceleration).

Damage tests were carried out by stressing the watermelons by means of the vibration simulator. A wooden bin (60 cm by 60 cm by 120 cm) of watermelons was placed on the vibration table as they would normally be loaded onto truck, for 30 and 60 minutes to simulate an average transport conditions over medium (1,000 km) and long (more than 1,500 km) distances (Semerci and Der, 1985; Acican *et al.,* 2007). The assessment of fruit damage was carried out on the melons in the bin, at the bottom, middle and top positions.

Evaluation of Vibration Damage to Watermelons

After vibration, the control (sample of 20 non vibrated melons from the same bulk as vibrated ones) and vibrated (in each treatment) samples were stored at 25°C for 24 hours (including the time necessary for the test) and then their modulus of elasticity was measured because, according to Horsfield *et al.* (1972 b), the modulus of elasticity of fruits is important in determining the damage from impact and vibration. The percentage of the difference (decay) in modulus of elasticity (between the control and vibrated samples) was assumed to be fruit damage (Zohadie, 1982; Ogut *et al.,* 1999; Erdogan *et al.,* 2003). Watermelon can be simplified as a multilayer spherical elastic body and composed of hull and flesh having different rigidity so, in order to measure the modulus of elasticity of the watermelons, the modulus of elasticity was measured in different locations of watermelon such as red flesh and hull (green and white). The test units were cylindrical samples of red flesh with a diameter of 25 mm and height of 20 mm and hull samples were prepared with a diameter of 14 mm and height of 8 mm (Chen *et al.,* 1996; Mohsenin, 1978; Sitkei, 1986). The cylindrical samples of watermelon flesh and hull were cut with two cylindrical borers and a sharpened blade. The test units were pressed using a material tester. Compression speed was selected at 25 mm min^{-1} (ASAE, 2003). Each sample was compressed until it failed then the force-deformation curve was obtained. Modulus of elasticity of cylindrical samples was determined using Santam computer program software from the force-deformation curve of uniaxial compression at bio yield point. Compressive tests were performed by a Universal Testing machine (Santam, SMT-5).

Statistical Analysis

The data recorded under laboratory test conditions were statistically analyzed using randomized complete block design basis on a factorial experiment with four factors to study the effects of vibration frequency (7.50 and 13.00 Hz), vibration acceleration (0.30 and 0.80 g), vibration duration (30, and 60 minutes), and bin position (top, middle and bottom) on the percentage of the decay on the modulus of elasticity (PDME) of the melons. The Duncan's multiple range test was used to compare the means. From the results of the analysis, the effects of the main factors and their interactions with the PDME were determined. 20 melons were taken from each treatment and three replications were conducted for each combination of variables. Statistical analysis was carried out using SPSS 9.0.

RESULTS AND DISCUSSION

Some of physical and mechanical properties of tested watermelons are shown in Table 1.

Vibration Levels in Transit

According to the results from the vibration measurement on the truck-beds during watermelon transportation, the highest value of distribution percentages of vibration frequencies was 33.20%, on an interval of 5-10 Hz. After that, the second value was 30.17% on an interval of 10-15 Hz (Table 2). The average values at intervals of 5-10 Hz and 10-15 Hz were 7.49 Hz and 13.03 Hz, respectively (7.50 and 13.0 Hz were selected for test). Table 3, shows the distribution percentages of vibration accelerations on the truck-beds during watermelon transportation. As shown in the table, the intervals of 0.25-0.50 g and 0.50-

Table 1. Some physical and mechanical properties of tested watermelons.

Variable	Physical properties					Mechanical properties	
	Mass(g)	Volume (cm^3)	Density (g cm^{-3})	Spherical coefficient (mm^{-1})	Geometric mean diameters (mm)	Modulus of elasticity of hull (MPa)	Modulus of elasticity of flesh (MPa)
Mean	6273	6839	0.917	0.612	301.81	2.7235	0.3515
SD	1213	1512	0.010	0.052	16.92	0.1240	0.0361
CV%	26.12	23.71	1.092	5.91	6.99	1.1302	0.8401

Table 2. Distribution percentages of vibration frequencies on the truck-bed.

Position in the truck bin	0-5 Hz	5-10 Hz	10-15 Hz	15-20 Hz	20-25 Hz	25-30 Hz	30-40 Hz	> 40 Hz
	Frequency interval (Hz) Frequencies distribution (%)							
Front	6.226% (3.30 Hz)[a]	34.19% (7.40 Hz)	26.46% (13.02 Hz)	15.36% (18.30 Hz)	8.30% (22.49 Hz)	4.18% (26.16 Hz)	3.07% (34.72 Hz)	2.19% -
Middle	4.19% (13.02 Hz)	23.12% (7.99 Hz)	34.02% (14.01 Hz)	11.23% (17.42 Hz)	7.12% (23.18 Hz)	4.13% (2712 Hz)	3.18% (37.92 Hz)	3.02% -
Rear	8.47% (4.01 Hz)	32.29% (7.10Hz)	13.10% (12.15 Hz)	12.11% (21.17 Hz)	6.79% (24.04 Hz)	5.09% (28.07 Hz)	2.22% (35.18 Hz)	4.12% -
Mean	6.29% (3.18 Hz)	33.20% (7.49 Hz)	30.17% (13.03 Hz)	12.9% (17.55 Hz)	7.40% (23.23 Hz)	4.46% (27.11 Hz)	2.82% (35.94 Hz)	3.11% -

[a] Means of measured frequencies in the interval.

0.75 g had the highest distribution percentages of vibration accelerations, that the values in these intervals were 35.06 and 23.59% respectively. The average values at intervals of 0.25-0.50 g and 0.50-0.75 g were 0.31 g and 0.71 g, respectively (0.30 and 0.70 g were selected for test). Maximum and mean vibration frequency values obtained under road conditions on the truck-beds were 55.36 Hz and 12.47 Hz, respectively, and values for vibration acceleration were 3.12 g and 1.5 g, respectively. The accelerations of over 97% of vibrations recorded on the transported bins had values below 2 g. The results of the vibration frequency and acceleration values measured in this research are close to those reported by O'Brien *et al.* (1969), O'Brien and Fridley (1970), Peleg (1985), Brown *et al.* (1993), Hinsch *et al.* (1993), Slaughter et al. (1993), and Vursavus and Ozguven (2004) for truck beds with different axles and suspension systems. O'Brien *et al.* (1969) reported that frequencies under 40 Hz commonly occurs during truck transportation. Hinsch *et al.* (1993) and Slaughter *et al.* (1993) reported that, frequencies of 3.5, 9, 18.5 and 25 Hz, are of frequent occurrence during transportation; however, the levels of 3.5 and 18.5 Hz were observed to be the most significative ones. O'Brien and Fridley (1970) compared the values of acceleration of vibrations occurring in transport means with different suspension systems. Peleg (1985) reported that frequency values on the truck-bed ranged between 3 and 200 Hz and frequency levels above 50 Hz are insignificant. Brown *et al.* (1993) found that the values of the most common vibrations of the chassis of

Table 3. Distribution percentages of vibration accelerations on the truck-bed.

Position in the truck bin	0-0.25 g	0.25-0.50 g	0.50-0.75 g	0.75-1.0 g	1.0-1.25 g	1.25 -1.5 g	1.5-1.75 g	> 2 g
	Acceleration interval (g) Accelerations distribution (%)							
Front	21.82% (0.15 g)[a]	32.43% (0.25 g)	20.16% (0.68g)	10.24% (0.0.83 g)	5.19% (1.08 g)	2.76% (1.29 g)	4.23% (1.72 g)	2.12% -
Middle	13.66% (0.17 g)	35.58% (0.27 g)	23.13% (0.72 g)	11.51% (0.84 g)	4.47% (1.12 g)	5.03% (1.34 g)	4.07% (1.71 g)	2.55% -
Rear	8.47% (0.18g)	37.18% (0.42 g)	27.49% (0.73 g)	9.75% (0.88 g)	5.79% (1.18 g)	4.30% (1.37 g)	3.25% (1.86 g)	3.17% -
Mean	15.19% (0.16 g)	35..06% (0.31 g)	23.59% (0.71 g)	10.55% (0.85 g)	5.15% (1.12 g)	4.13% (1.30 g)	3.85% (1.77 g)	2.61% -

[a] Means of measured accelerations in the interval.

transport means in motion fell within the range of 0.25-0.50 g.

Evaluation of Vibration Damage to the Watermelons

The analysis of the vibration damage data indicated that the average PDME values of watermelon flesh was 50.71% (compared with control samples) and maximum and minimum values were 89.70% and 14.07% respectively. The average PDME values of the hull was 34.18% and the maximum and minimum values were 74.29% and 10.78%, respectively.

Variance analysis of the vibration damage data results indicated that all independent variables, namely, vibration frequency (F), vibration acceleration (A), vibration duration (D) and fruit position in bin (P), had significant effects on the PDME of the watermelon flesh and hull ($P< 0.01$). The effects of the main factors were the most significant. The effects of the main factors are the most significant meanwhile; the interaction effects of the F×A, F×D, A×P and F×A×D, for flesh, and F×A, F×D, A×D and A×P, for hull, all being significant ($P< 0.01$). Among the second-order interactions, F×A×P, F×D×P, F×A×D, for flesh, and F×D×P and F×A×T, for hull, were significant ($P< 0.05$).

Table 4 shows the Duncan's multiple range tests ($P< 0.05$) performed to determine the differences among the mean values of the PDME of the watermelon flesh and hull at different positions in the bin. As shown in Table 1, fruit being in the top position caused damage levels higher than in other positions. In other words, damage increased from bottom to top layers in the bin. According to Slaughter *et al.* (1993) this is due to the higher acceleration levels in the upper position. It was observed in the test that when the vibration acceleration of the table (bottom of the bin) was adjusted to 0.3 g, the acceleration measured at the top position increased to 1.2 g and the top melons moved freely. Damage to flesh is higher than to hull. Duncan's multiple range tests showed (Table 4) that the difference between damage to flesh in the middle and bottom positions is not significant. Further, the differences in damage to hull at the three positions were significant ($P< 0.05$). The test results in this study were similar to those obtained by O'Brien *et al.* (1964), O'Brien *et al.* (1965), O'Brien and Guillon. (1969), Ogut *et al.* (1999) and Zhou *et al.* (2007). O'Brien *et al.* (1965), also referred to by Mohsenin (1986), stated that fruit damage gradually increases from bottom to top, due to the increasing peak acceleration from bottom to top. It has been observed (O'Brien and Guillon, 1969; Chesson and O'Brien, 1971; O'Brien *et al.,* 1983) that when the combination of amplitude and frequency in the surface layers of fruits is sufficient to generate vibrations close to 1 g, the fruits in those layers can move freely as they receive sufficient energy from the lower layers. Cyclic states of zero gravity permit fruits to rotate and impact against one another which, according to those authors, explains the occurrence of the highest rates of damage in the top (upper 2/3 of the container depth) layers of fruit in the containers. The rate of damage decreased with increasing depth in the container, and the least damage was observed in the bottom fruit layers, where the values of acceleration did not exceed 0.36 g (O'Brien *et al.*, 1983). Ogut *et al.* (1999) observed that in the top positions, the maximum variation of modulus of elasticity of peach was seen for the wooden containers. Zhou *et al.* (2007) results showed that, during transportation, pears in the top of containers were more damaged

Table 4. Duncan's multiple range tests of PDME values for different positions in bin.

Position in the bin	PDME (%)	
	Flesh	Hull
Top	54.55 a [a]	36.70 a
Middle	49.80 b	33.99 b
Bottom	47.78 b	30.86 c

[a] Values within a line followed by the same letter are not significantly different ($P< 0.05$).

than those in the bottom of containers within the same column.

Figure 2 shows the effect of vibration frequency by vibration acceleration interaction on the PDME values. The relationship among the combinations was determined according to Duncan's multiple range tests (P< 0.05) and is shown in Figure 2. Increasing vibration acceleration for each vibration frequency increased the PDME for both flesh and hull. A comparison between 7.5 and 13 Hz vibration frequencies showed that the PDME for watermelon flesh was higher at 7.5 Hz than at a 13 Hz vibration frequency. The average values of the PDME for flesh at 7.5 Hz and 13 Hz were 58.40% and 43.02%, respectively. Consequently, 13 Hz vibration frequency compared with 7.5 Hz and PDME values were as much as 1.3 times greater at 7.5 Hz as seen in Figure 2. The lowest and highest PDME values among the combinations were 26.79 and 74.56 for 13 Hz by 0.3 g and 7.5 Hz by 0.7 g interactions, respectively. This result shows that flesh of watermelon is sensitive to a vibration frequency close to 7.5 Hz. The results are similar to those obtained by Fischer *et al.* (1990) for grapes and strawberry where critical frequency was found to lie between 7.5-10 Hz. The PDME values for watermelon hull was higher at 13 Hz than 7.5 Hz vibration frequency, the average values of the PDME values for hull at 7.5 Hz and 13 Hz were 22.91% and 45.56%, respectively, which shows that by increasing vibration frequency and vibration acceleration, damage to hull increased.

The effect of vibration frequency by vibration duration interaction on the PDME is shown in Figure 3. As shown in the graphic when vibration duration increased from 30 to 60 minutes the PDME values and all frequencies increased for both flesh and watermelon hull. Mohsenin (1978) and Schulte *et al.* (1990) reported similar results to the test results obtained in this study whereby an increase in the distance traveled raised the percentage of fruit bruised during transportation. The relationship among the combinations was determined according to Duncan's multiple range tests (P< 0.05) and is shown in Figure 3. The highest and lowest PDME values for flesh among the combinations were 68.49% and 33.38% for 7.5 Hz by 60 minute interactions and 13 Hz by 30 minute interactions, respectively. These results show that if the vibration frequency of the truck during watermelon transportation is close to 7.5 Hz, in a short distance (duration) the flesh of the watermelon may be damaged. The damage to watermelon hull increased by increasing vibration frequency and duration. The average values of the PDME values for hull at 7.5 Hz was 22.91% and the maximum and minimum values were 29.30% and 16.51% respectively, which occurred at 30 and 60 minutes respectively. The average of the PDME values for hull at 13 Hz was 45.46% and the maximum and minimum values were 61.82% and 29.10% and occurred at 30 and 60 minutes, respectively. Consequently, a 60 minute vibration duration was compared with a 30 minute and one PDME values were as much as 1.52 times greater at 60 minutes. The test results were similar to those obtained by Laurenti *et al.* (2002) who vibrated potato specimens at 20, 40 and 60 minutes and concluded that the 40 and 60 minute vibration durations caused a higher percentage of decay on the modulus of elasticity values.

Figure 4 exhibits the effect of vibration acceleration by vibration duration interaction on the PDME. As shown for both cases of flesh and hull, the PDME values increased with increasing vibration acceleration from 0.3 g to 0.7 g but the effects on flesh are higher than on hull. The PDME values in the vibration acceleration of 0.7 g increased from 57.04 to 76.78% for flesh and from 35.92 to 55.15% for hull, with an increase in the vibration duration compared to 24.66 to 44.37% for flesh and from 18.18 to 27.43% for hull in the vibration acceleration of 0.3 g. The lowest and highest average PDME values among the combinations were 21.42 (the average of the PDME values for flesh and hull) and

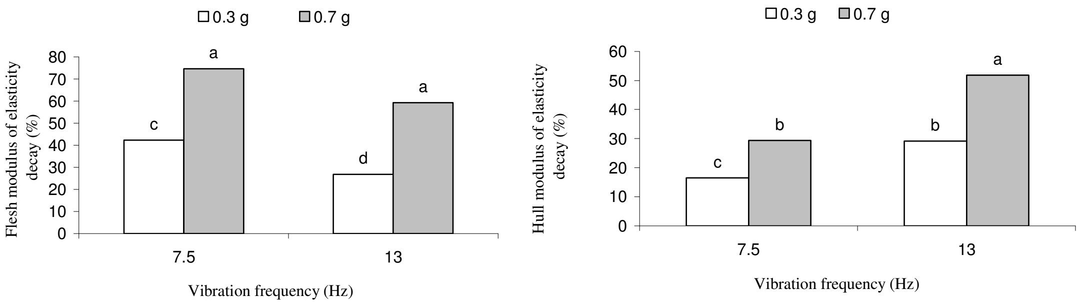

Figure 2. Effect of vibration frequency by vibration acceleration interaction on the PDME.

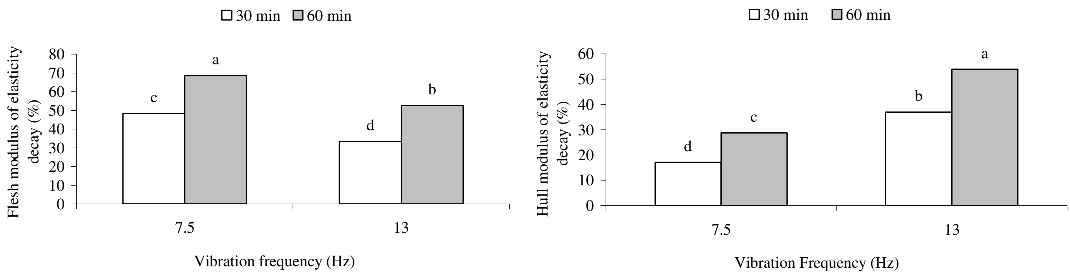

Figure 3. Effect of vibration frequency by vibration duration interaction on the PDME.

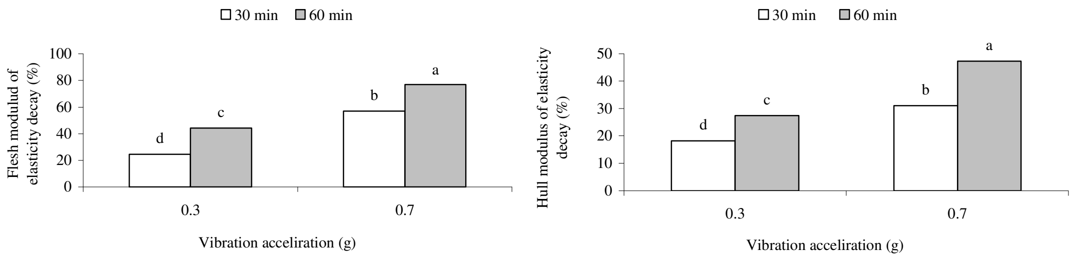

Figure 4. Effect of vibration acceleration by vibration duration interaction on the PDME.

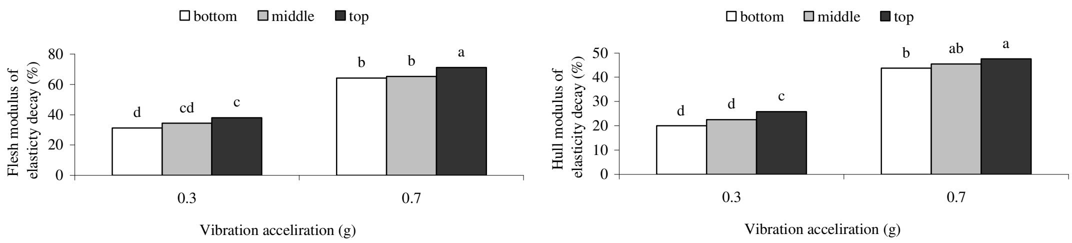

Figure 5. Effect of vibration acceleration by fruit position in bin interaction on the PDME.

65.96% for 0.3 g by 30 minute and 0.7 g by 60 minute interactions, respectively. Consequently, 0.3 g vibration acceleration was compared with 0.7 g and the PDME values were as much as 1.96 times greater at 0.7 g (the average PDME values for flesh and hull at 0.7 g was 56.23% and for 0.3 g was 28.660%) as seen in Figure 4. O'Brien and Guillon (1969), Chesson and O'Brien (1971) and O'Brien *et al.* (1983) reported that more extensive damage is caused by vibrations with higher acceleration values, even if their duration is relatively short. The test results obtained in this study were similar to results obtained by those authors.

Figure 5 shows the effect of vibration acceleration by fruit position in bin and its interaction on the PDME. The fruits at top of the bin for each acceleration experienced more damage than other positions. Similar trends to vibration frequency and vibration duration by fruit position interactions were obtained in this interaction. The relationship among the combinations was determined according to Duncan's multiple range tests and is shown in Figure 5 ($P< 0.05$). The lowest PDME value for flesh among the combinations was 31.27% for a vibration acceleration of 0.3 g by the bottom position interaction. This case changed for 0.7 g vibration acceleration and the highest PDME value obtained was 71.11% for 0.7 g for the top position interaction. The maximum and minimum PDME values for hull were 20.03 and 47.55% for vibration acceleration of 0.3 g in the bottom position and 0.7 g by top position relatively.

CONCLUSIONS

The current research showed that the vibration levels of the truck-bed under road conditions during watermelon transport were different, and levels of the frequency of the 5-10 and 10-15 intervals had the highest percentage distribution and the average values of those intervals were 7.49 and 13.03 Hz, respectively. The greatest acceleration distribution occurred at vibration acceleration intervals of 0.25-0.50 and 0.50-0.75 g, and the average values of those intervals were 0.31 and 0.71 g, respectively. Laboratory studies indicated that the damage to watermelon flesh was higher than to watermelon hull; watermelon flesh is sensitive to vibration of a 7.5 Hz frequency, 0.70 g acceleration and 60 minute duration. At the top position in the bin, maximum decay of modulus of elasticity watermelon of flesh and hull was seen for all treatments. Therefore, the results suggest that the packaging of watermelons (such as carton packages) to medium-long transportation and for export to foreign countries should be designed and improved.

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شبیه سازی اثر ارتعاشات حمل و نقل بر روی صدمات هندوانه

ف. شهبازی، ع. رجبی پور، س، محتسبی و ش. رفیعی

چکیده

ارتعاشات ناشی از حمل و نقل اثر زیادی بر روی میزان صدمات محصولات کشاورزی خصوصاً میوه ها و سبزی جات دارد. مدول الاستیسیته یکی از مهمترین خواص مکانیکی میوه هاست که تغییرات آن می تواند مشخص کننده میزان صدمه وارده به محصول در طی حمل و نقل باشد. در این مطالعه اثرات فرکانس ارتعاش، شتاب ارتعاش، مدت زمان ارتعاش و موقعیت قرارگیری محصول داخل مخزن، بر روی میزان صدمات وارده بر هندوانه مورد مطالعه قرار گرفت. ابتدا میزان فراوانی فرکانس و شتاب ارتعاش در طی حمل و نقل با کامیون در جاده اندازه گیری شد. سپس با استفاده از یک دستگاه شبیه ساز ارتعاشات در آزمایشگاه، ارتعاشات حمل و نقل شبیه سازی و اثر پارامترهای مختلف بر روی میزان صدمات بررسی شد . میزان صدمه برمبنای اختلاف بین مدول الاستیسیته هندوانه قبل و بعد از ارتعاش، برحسب درصد درنظر گرفته شد. با توجه به نتایج به دست آمده از اندازه گیری و آنالیز ارتعاشات حمل و نقل، فرکانس های بین ۵ تا۱۰ هرتز و ۱۰ تا ۱۵ هرتز دارای بیشترین فراوانی بودند و میانگین فرکانس های این دامنه ها به ترتیب برابر با ۵/۷ و ۱۳ هرتز بود. همچنین شتاب های بینg ۵/۰ تا ۲۵/۰ وg ۵/۰ تا ۷۵/۰، بیشترین فراوانی را داشتند و میانگین شتاب های این دامنه ها به ترتیبg ۳/۰ وg ۷/. بود که همین میانگین های فرکانس و شتاب برای شبیه سازی ارتعاش در نظر گرفته شدند. مدت زمان ارتعاش برابر ۳۰ و ۶۰ دقیقه در نظر گرفته شد و میزان صدمات در لایه های بالایی، میانی و پایینی هندوانه در داخل مخزن اندازه گیری شد. نتایج آنالیز داده ها نشان داد که اثرات فرکانس ارتعاش، شتاب ارتعاش، زمان ارتعاش و موقعیت قرارگیری محصول داخل مخزن، که به عنوان منابع تغییرات در نظر گرفته شدند، در سطح یک درصد بر روی میزان صدمات معنی دار است. ارتعاشات با فرکانس ۵/۷ هرتز، شتابg ۷/۰ و مدت زمان ۶۰ دقیقه بیشترین صدمات را وارد کرده اند .میزان صدمات وارده هندوانه های واقع در لایه های بالایی مخزن بیشتر از لایه های زیرین و وسطی است.