ESTIMATION OF SOME POSTHARVEST LOSSES IN TOMATO DURING SIMULATED TRANSPORT OPERATION

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ABSTRACT

This study was conducted to estimate the extent of the damage occurred in tomato crop during transportation. A simulation prototype for transport process was designed and five levels of vibration frequency (5, 7.5, 10, 12.5 and 15 Hz), three vibration durations (30, 60, 90 min) and three box positions (top, middle and bottom) were used to estimate the mechanical damage occurred in tomato fruits. The damage was evaluated based on three different parameters (damage ratio, the equivalent bruise index "EBI" and bruise area index "BAI"). Also, the effect of the studied variables was investigated on weight loss and firmness. The results revealed that damage ratio, EBI, BAI and weight losses increased and firmness values decreased by increasing vibration duration especially in the upper boxes for all vibration frequency levels. The results showed that the highest values of damage ratio, EBI, BAI and weight losses and the lowest value of firmness were recorded at the upper box when the simulation system was operated at vibration frequency of 7.5 Hz for a duration of 90 min compared to the other frequency levels. The information obtained from this study is very important when designing handling equipment, suspension systems, conveyor belts and packaging methods to reduce mechanical damages of fruits and vegetables.

Keywords: *Postharvest losses, tomato, vibration, firmness, mechanical damage, equivalent bruise index, bruise area index.*

1. INTRODUCTION

The success of a postharvest system encompasses delivering of crops from the place and time of harvest to the place and time of consumption with maximum efficiency, minimum losses and maximum profit.

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Actually, fresh products go through a number of steps in the handing chain such as transportation, cleaning, sorting, classification, packing, weighing, labeling and sealing to enhance their attractiveness before being shipped to the retail stores. Throughout these steps, agricultural products are usually liable to several kinds of losses. This loss may be quantitative losses such as a loss in the product quantity, or qualitative losses such as a loss in nutritional and caloric value, edibility and consumer acceptability to the products. These kinds of losses are much more difficult to assess than quantitative losses **(Kader, 2005)**.

Postharvest loss has been defined as any change in the availability, edibility and wholesomeness or quality of food that prevent it from being eaten by human **(Vursavuş & Özgüven, 2004)**. In some situation, postharvest losses averaged between 24 and 40 % in developing countries and between 2 and 20 % in developed countries **(Rosa, 2006)**. In tomato, the largest percentage of postharvest losses was due to mechanical damage caused by impact, compression, abrasion, puncturing, testing, or several actions combined **(Li & Thomas, 2014)**. Symptoms such as cuts, punctures, abrasions, scuffing, and brown discoloration of bruised tissues predisposed the product to accelerate water loss and to be attacked by various pathogens. These symptoms may not be visible at shipping point, but become noticeable during subsequent handling steps, and have a cumulative effect with each step of the handling process. Therefore, it is important to understand the nature of the shocks and vibrations encountered during truck transport to reduce damage to transported goods **(Lu et al., 2010)**.

One of the mechanical handling processes that can be detrimental to the quality of the fruit is transportation. In general, unreasonable transportation is the one of main factors that causes losses in fruits and vegetables **(Lü et al., 2010)**. Postharvest losses of tomato during transport process were estimated to be about 16 - 22 % **(Bani et al., 2006)**. The results of studies investigated the in-transit damage indicated that vibration damage occurs in the fruits and the extent of such bruising is related directly to the magnitude of vibration accelerations and to the frequency **(Timm et al., 1996; Vursavuş & Özgüven, 2004)**. The

magnitude of vibration acceleration during transport depends on the depth to which the container is filled, the tightness of fill, the type of suspension system used on the truck, the magnitude of forced vibration from the roadbed and the vibrating characteristics of the fruit species. In general, the three types of forces that may cause bruising in fruits are impact, compression load and vibration forces **(Rostampour *et al.*, 2013)**. Vibration forces that usually occur during transportation are difficult to avoid and can be repeated five to fifteen times each second for many hours of the trip **(Vergano *et al.*, 1991)**.

In Egypt, farmers transport their products in medium sized trucks after packaging in palm crates. Rough handling and transportation over Egyptian roads damaged produces by mechanical action resulting in a substantial reduction in quality. A large percentage of fruits are wasted yearly due to damages such as bruising caused mostly by impact during handling, packaging, and transport of fruits **(Amer Eissa & Azam, 2011)**. If damage occurs, economic losses might be minimized by grading damaged fruits based on the severity of damage into different categories. Moreover, damaged fruits could be directed to processing rather than fresh consumption. In either case, an objective and quantitative evaluation of the degree of mechanical damage is required. Ideally, such damages could be minimized through improved understanding of their mechanisms. Therefore, the main goal of this study was to estimate the extent of the damage occurred in tomato crop during transportation process. To fulfill this goal, the following sub-objectives were considered: (1) Designing a transport prototype to control the vibration frequencies and vibration duration, (2) Studying the effect of different vibration frequency levels (5, 7.5, 10, 12.5 and 15 Hz), vibration duration (30, 60 and 90 min) and box position (top, middle and bottom) on the severity of the mechanical damage occurred in the tomato fruits expressed as damage ratio, EBI and BAI and their effect on weight loss and tomato firmness, (3) Determining the critical vibrational frequency level and vibration duration that cause the least possible damage on tomato fruits and the least weight loss and firmness, and (4) Determining the effect of box

position above the truck floor on the severity of the damage, firmness and weight losses of tomato.

2. MATERIALS AND METHODS

2.1. Tomato Samples

Fresh tomato samples (*Solanum lycopersicum* var. El-kudds 448) free from bruises and any visible damages were manually harvested daily from the experimental farm of the Faculty of Agriculture, Suez Canal University (Ismailia, Egypt) at the light red maturity stage during the period from December to March 2015. A random sample of 200 tomatoes was taken and the mass, firmness, total soluble solids and dimensions of each tomato were determined.

Due to the huge amount of tomato fruits required to carry out all experiments of this study, using large boxes (21 x 20 x 17 cm) usually used in transporting tomatoes was not feasible. Therefore, special small boxes made from crates and having the same features but with smaller dimensions were manually fabricated from crates. The box dimensions were chosen based on the average dimensions of the harvested tomato cultivar to accommodate only 27 tomatoes per box arranged in three layers.

Because tomato fruits were liable to scratching during the manual measurement of dimensions using the digital caliper, and due to human error during recording the data, this manual method may not be an efficient or practical approach to estimate dimensions, particularly in sorting large quantities of fruits (**Sadrnia *et al.*, 2007**). Therefore, image processing method provides an accurate, simple, and rapid method to estimate the dimensions. So, the maximum, intermediate diameter, perimeter and projected area of tomato were measured using an image system (Figure 1). A colour image of each tomato was captured by an imaging system and processed to extract the dimensions directly from the images without holding fruits by hands. All image analysis routines were carried out by a script developed using Matlab7.1 and its image processing toolbox (Mathworks, MA, USA).
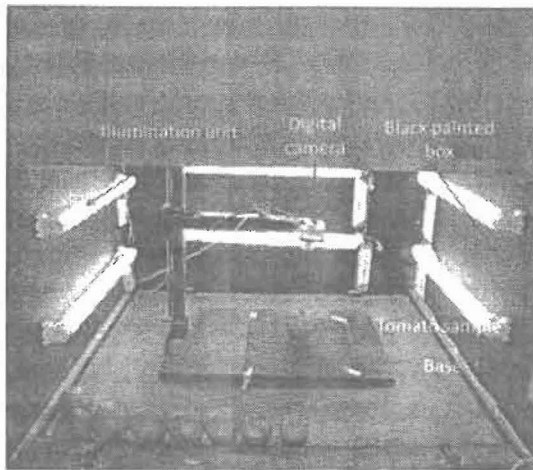
Figure (1): The image acquisition unit.

2.2. Transport Prototype

A prototype was designed and fabricated to simulate the transport process during marketing and moving the products from fields to the big markets or retail stores. The purpose was to identify the critical frequencies during transportation that cause minimum damage to the product. Also, the box position above the truck was evaluated. The simulation prototype (Figure 2) was designed and constructed in the workshop of the Department of Agricultural Engineering, Faculty of Agriculture, Suez Canal University. The prototype composed of a main frame (110 x 70 x 81 cm) which holds the other parts including a power supply, steel spring (with stiffness 20 N/mm), and vibration surface. The power required to move the vibration surface was transmitted by a V-shape belt and two pulleys as shown in Figure (2). The rotation speed of the motor, vibrator and vibration surface was adjusted and controlled by an inverter (model 650G, Parker, U.K).

As shown in Figure (2), the vibration unit consists of a vibrator, comprised of a shaft that contains a longitudinal cam connected with a pulley. When this shaft rotates, a vibration motion is generated to the surface of the vibrator as a result of centrifugal force when the cam rotates. The vibration surface holds on steel springs for damping vibration intensity to some extent as it happens in the transport vehicles.
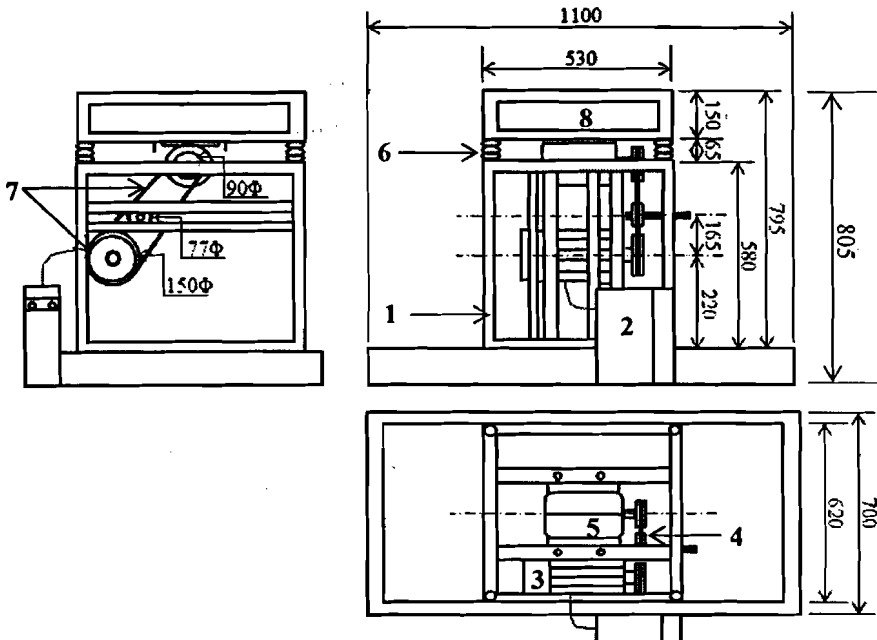
(1) Main frame   (5) Vibrator
(2) Inverter   (6) Steel spring
(3) Electric motor   (7) Belt and pulleys
(4) Tensile pulley   (8) Vibration surface

Figure (2): Elevation, side and plan views of the designed simulation prototype.

2.3. Measurement of Vibration

Because the frequency of the vibration surface is directly related to the rotation number of the vibrator, the frequency of the vibration surface was obtained based on the number of revolutions of the vibrator. Therefore, the speed of the electric motor and the vibrator were measured using a digital Tachometer (Model DT06234N, China, Accuracy ±0.1 %). The number of the revolutions of vibrator measured in revolution per minutes RPM was divided by 60 to get the vibration frequency of vibration surface in Hz and this value was confirmed by measuring the frequency of vibration surface using a digital Tachometer. The acceleration of the vibration surface was directly measured using a vibration meter (VB-8220, Lutron, Taiwan). The vertical displacement (stroke) of vibration

was calculated by the following equation (1) according to **Rostampour** *et al.* (2013):.

$$A = 4 \pi^2 f^2 x \tag{1}$$

where, A is the acceleration *(m/s²)*, f is the frequency *(Hz)* and x is the displacement amplitude *(m)*.

According to **Vursavuş & Özgüven (2004)** and **Shahbazi et al. (2010)** the highest value of distribution percentages of vibration frequencies on the truck-beds were at intervals of 5-10 Hz and 10-15 Hz. Therefore, vibrational frequencies of values from 5 to 15 Hz with an interval of 2.5 Hz were selected for testing vibration effect.

To understand the reasons for in-transit injury of various fruits due to vibration, it is necessary to determine the natural frequency and relate these to the vibration characteristics of the transporting vehicles. Therefore, the natural frequency was calculated by using the following equation (2) according to **Mohsenin (1986)**.

$$f_n = \frac{1}{4\lambda} \sqrt{\frac{Eg}{\rho_b}} \tag{2}$$

where: f_n: natural frequency (Hz), g: *9.81m/s²*, ρ: bulk density *(kg/m³)*, and λ: depth of column of fruit *(m)*. E: elasticity (kg/m²) was calculated according to equation of **Ghazavi et al. (2012)** as:

$$E = \frac{F_{max}}{D_p} \times \frac{1-\mu^2}{2r} \tag{3}$$

where: E: Elasticity modulus *(Mpa)*, F_{max}: Maximum applied force (firmness) *(N)*, D_p: Probe penetration inside the sample *(mm)*, μ: Poisson ratio (0.3), r: Probe radius *(mm)*.

2.4. Experimental Protocol

Tomato samples were collected at a homogeneous harvesting stage and carefully inspected to ensure that they were neither damaged, diseased nor infected. Tomato fruits were then divided into four groups in which one

group was assigned as a control. Three groups of tomato fruits were placed inside boxes (27 fruits per in each box. Then, the boxes (top, middle and bottom) were placed on vibration simulation prototype to conduct a treatment. After operating the prototype at every level of vibration frequency and vibration duration, tomato samples were taken out from the boxes and examined to evaluate the level of damage.

After each vibration treatment (frequency level and duration), a digital caliper was used to measure bruise diameter on the tomato surface and tomatoes were graded according to their bruise diameter as described by **Vursavuş & Özgüven (2004)** as shown in Table (1) and the equivalent bruise index (EBI) for defining the damage occurred in tomato fruits was calculated as:

% EBI = (0.1) Trace bruises + (0.2) Slight bruises + (0.7) Medium bruises
+ (1.0) Severe bruises.   (4)

Table (1): Damage scale by using the bruise diameter.

Bruise diameter (mm)	Type of damage or Equivalent bruise damage (EBI)	
<12	None	0
12-19	Trace	0.1
19-25	Slight	0.2
25-32	medium	0.7
>32	Severe	1

The ratio between the number of tomatoes having bruise damage greater than 12 mm in diameter (N_d) to the total number of tomatoes (N_T) in the treatment (27 fruits) is called the damage ratio and calculated as follow:

$$Damage\ ratio = \frac{N_d}{N_T} * 100 \qquad , (\%) \qquad (5)$$

Also, the bruise area (BA) was determined by measuring the bruise diameter on the tomato surface and assuming that the bruise was elliptical. The BA was calculated by the following equation (**Lu et al., 2010**):

$$BA = \frac{\pi}{4} d_0 * d_1 \qquad (6)$$

where: BA is bruised area (mm²), d_0 and d_1 are the major and minor diameters of a bruise respectively (mm).

The extent of the bruising area in tomato was expressed as bruising area index (BAI), which was determined by using a four stage scale (0, 1, 2 and 3), where 0 = none, 1 = slight (<20% of surface area), 2 = moderate (20 to 50 % of surface area), and 3 = severe (>50% of surface area) as described by **Jing et al. (2009)** and **Cao et al. (2010)**.

Bruising area index (between 0 and 3)
$$= \frac{\sum(\text{scale} \times \text{number of fruit at that scale})}{\text{total number of fruit in the treatment}} \qquad (7)$$

2.5. Fruit Firmness

Firmness of each single tomato fruit was measured to show the effect of different vibration levels, vibration durations and box position on tomato properties. Firmness was determined by resistance to puncture using a fruit firmness tester (Affegi penetrometer, FT- 011Model, Italy, Accuracy ±0.05% kg) at two different places of each tomato fruit after removing the peel **(Batu, 1998)**. About 1 cm² area of the peel was removed very carefully and the maximum force required penetrating the fruit with a 6 - mm diameter round stainless steel probe was recorded.

2.6. Weight Losses

Weight losses were determined by measuring the initial weight of tomatoes before a vibration treatment (W_1) and after 48 hours from the vibration treatment (W_2) using a digital balance then calculate the weight losses from the following equation according to **Van Dijk et al. (2006)** and compared with the weight losses of control samples caused by evaporation from the surface of the fruit:

$$\text{Weight losses} = \frac{W_1 - W_2}{W_1} * 100 \qquad , (\%) \qquad (8)$$

2.7. Statistical Analysis

About 0.61 tons (3645 fruits) of tomatoes were used for carrying out all vibration, duration and position treatment combinations of this experiment. Three replicates at every combination of the experimental factors were used (every replicate consisted of 27 tomatoes). The experimental design for this work was a randomized block design.

The obtained data were subjected to statistical analysis using CoStat 6.4 (CoStat, USA) and the analysis of variance (ANOVA) was conducted in order to ascertain whether there were any significant differences among the vibration frequency levels, box positions and vibration durations on damage parameters, firmness and weight losses of tomato at the significance level of 0.05. Furthermore, the least significant difference (LSD) test was performed to compare the effects of these variables and their interactions on damage parameters (damage ratio, EBI and BAI), weight losses and firmness of tomatoes.

3.   RESULTS AND DISCUSSION

3.1.   Dimensional features

As shown in Table (2), the mean values of the maximum and intermediate diameters as well as projected area of the examined samples were tomato were 68.59, 64.91mm and 35.25 cm^2, respectively. Table (2) shows the imaging technique gave a good estimation of the measured dimensions and could be used directly without touching or holding every sample during measurements.

Table (2): Geometrical features of tomato measured by a digital caliper and the image analysis technique.

Dimensions	Digital caliper			Image analysis		
	Min	Max	Mean± S	Min	Max	Mean± S
Maximum Diameter, mm	53.17	81.56	68.59± 6.84	52.34	84.18	68.8±8.86
Intermediate Diameter, mm	52.65	76.22	64.91± 6.05	50.90	78.50	65.28±8.02
Projected Area, cm^2	21.98	48.05	35.25± 6.56	18.33	53.62	36.92±98.87

3.2.   Influence of Simulated Transport on Mechanical Damage

The next sections demonstrate the influence of the main variables (vibration frequency "VF", vibration duration "VD", and box position "BP") separately, second-order interaction between vibration frequency and both of vibration duration (VF×VD) and box position (VF×VD) as

well as the third-order interaction between vibration frequency, vibration duration and box position (VF×VD×BP) on mechanical damage (damage ratio, EBI and BAI), weight losses and firmness of tomatoes.

The analysis of variance results given in Table (3) showed that vibration frequency (VF), vibration duration (VD) and box position (BP) significantly affected the damage ratio, EBI and BAI values of tomatoes. The effects of the main factors are highly significant on damage ratio, EBI and BAI, and the interaction effects of the (VF×VD), (VF×BP), (VD×BP) and (VF×VD×BP) were significant on EBI and weight losses values (P ≤ 0.05). However, the interaction effects of the (VF × BP), (VD×BP) and (VF×VD× BP) were not significant on damage ratio values, and the interaction effects of the (VF×VD×BP) were not significant on BAI values (P ≤ 0.05). Also, the interaction effects of the (VD×BP) were not significant on firmness values (P ≤ 0.05).

Table (3): Statistical analysis results for damage ratio, EBI, BAI, weight losses in tomato fruits. Values reported in this table are the F table of the analysis of variance (ANOVA) for each variable.

Source of variance	df.	Damage ratio (%)	EBI (%)	BAI	Weight losses (%)	Firmness (N)
Vibration frequency (VF)	4	103.3095***	99.6984***	82.8706***	96.1737***	422.0104***
Vibration Duration (VD)	2	40.1649***	56.9935***	55.9067***	62.5227***	140.4635***
Box Position (BP)	2	34.7195***	61.4860***	43.5065***	39.1460***	167.2930***
VF×VD	8	3.1683**	11.1929***	8.4012***	18.4363***	12.4473***
VF×BP	8	2.0415 NS	6.6275***	4.4639***	9.5453***	8.0417***
VD×BP	4	0.5391 NS	5.3779***	3.0140*	3.4877*	1.7190 NS
VF×VD×BP	16	1.1218 NS	2.3741*	1.9188 NS	2.5127**	1.9034*
Error	88	-	-	-	-	-

NS: not significant at 0.05 level of probability.
*, **, ***: significant differences at 0.05 level of probability.

Generally, vibration can continuously cause damages to the fruits that may be duplicated with time. Thus, using the laboratory vibration

prototype under controlled conditions is very important to expect the effect of transportation during handling processes. Effects of vibration frequency levels, vibration durations and box position on mechanical damage of tomato during transport process will be discussed in the subsequent sections.

3.2.1. Effect of Vibration Frequency

The results shown in Table (4) present the damage ratio, EBI and BAI values observed in tomato during simulated transport of different vibration frequency. The damage ratio was 8.60, 20.80, 16.27, 9.14 and 18.11 % at vibration frequency of 5, 7.5, 10, 12.5 and 15 Hz, respectively. The results indicated that the EBI and BAI values in tomato were 2.24, 9.74, 5.81, 2.36 and 6.50 % and 0.41, 1.01, 0.73, 0.40 and 0.83 at vibration frequency of 5, 7.5, 10, 12.5 and 15 Hz, respectively. This means that the highest values of damage ratio, EBI and BAI in tomato (20.80 %, 9.74% and 1.01) were observed at the vibration frequency of 7.5 Hz. The result for damage ratio and EBI are in agreement with those reported by **Shahbazi et al. (2010)** and **Vursavuş & Özgüven (2004)**, respectively. This is may be due to the high acceleration and maximum displacement at this level. The results obtained from the measurement of acceleration and displacement at every level of vibration frequency showed that the acceleration was 2.00, 11.50, 7.30, 6.00 and 8.40 m/s2 and the displacement was 4.05, 10.35, 3.7, 1.94 and 1.89 mm at vibration frequency of 5, 7.5, 10, 12.5 and 15 Hz, respectively as shown in Figure (3).
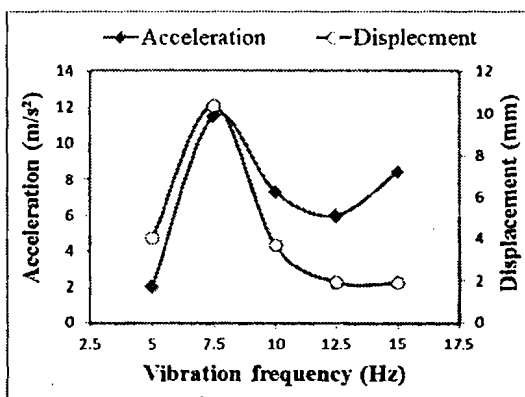

Figure (3): The relationship between the vibration frequency and vibration displacement or vibration acceleration during the simulation test.

These results revealed that the highest acceleration occurred at the vibration frequency of 7.5 Hz because this level made the surface of the vibration to reach the maximum displacement in terms of force and speed (vibration frequency). Increasing the speed of vibration (vibration frequency) led to a decrease in the displacement significantly and an increase in the vibration acceleration. On the other hand, the force of vibration at the vibration frequency of 5 Hz was not enough to reach the maximum displacement. Therefore, when combining the vibration frequency value and displacement value according to equation (1), the highest acceleration occurred at vibration frequency of 7.5 Hz and the lowest acceleration occurred at vibration frequency of 5 Hz. According to **O'Brien & Bridley (1970)**, this high acceleration makes some fruits momentarily weightless and free to strike other fruits, causing high damage.

If forced frequency is equal to the natural frequency called resonance frequency and according to **Shahbazi** *et al.* **(2010)**, 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 a severe damage may occur. The result shows that the natural frequency of tomato was 22.16 Hz according to equation (2). This result is closed to those reported by **O'Brien** *et al.* **(1965)**. This result explain the reason of increasing the severe damage and convert the fruit to juice at a vibration frequency of 25 Hz in the preliminary experiments as a result of its proximity to natural frequency.

Fruit firmness is one of the most important mechanical properties to determine the tomato quality and can be used as an index to estimate and manage the damages because it expresses the fruit resistance to penetration or the force needed to penetrate the fruit during handling operations. The original firmness of tomatoes varied from 18.39 to 39.84 N with an arithmetic mean value of 27.28 N with a coefficient of variation value of 17.94%.

Table (4): Overall mean values of damage ratio, EBI and BAI recorded in the fresh tomatoes at different vibration frequency levels, different vibration durations and box positions.

Parameters		Damage ratio (%)	EBI (%)	BAI	Weight losses (%)	Firmness (N)
Vibration frequency (Hz)	5	8.69d*	2.24c	0.41d	2.77d	11.30a
	7.5	20.67a	9.74a	1.01a	5.06a	8.25e
	10	16.27c	5.81b	0.73c	3.61c	9.81c
	12.5	9.15d	2.36c	0.40d	2.99d	10.45b
	15	17.97b	6.50b	0.83b	4.01b	9.43d
Vibration duration (min)	30	12.04c*	3.72c	0.52c	3.22c	10.25a
	60	14.38b	4.99b	0.65b	3.51b	10.02b
	90	17.23a	7.29a	0.86a	4.32a	9.28c
Box position	Top	16.98a*	7.40a	0.84a	4.19a	9.25c
	Middle	14.51b	4.86b	0.64b	3.54b	9.96b
	Bottom	12.15c	4.62c	0.55c	3.33c	10.34a

Same letters in the same column indicate no significant difference among corresponding treatments at a significant level of $P \leq 0.05$.

The results shown in Table (4) demonstrate that the weight losses and firmness values observed in tomato during simulated transport of different vibration frequency. The weight losses were 2.77, 5.06, 3.61, 2.99 and 4.01 and the firmness was 11.30, 8.25, 9.81, 10.45 and 9.43 N at the vibration frequency of 5, 7.5, 10, 12.5 and 15 Hz, respectively. These results revealed that the highest value of weight losses in tomato (5.06 %) and the lowest value of tomato firmness (8.25 N) were recorded at the

vibration frequency of 7.5 Hz. This is may be ascribed to the high acceleration and maximum displacement at this level. According to **Jung & Park (2012)**, the vibration stress clearly accelerated the degradation of fruit quality, resulting in increased weight loss and decreased firmness.

Generally, weight losses during storage were expected owing to tomato transpiration. The results showed that weight losses increased after the vibration treatment compared to the control group that did not received any vibration stress. Tomato fruits treated by vibration (different frequencies or different duration) may have a higher respiration and mechanical damage therefore may experience more weight loss. Also, according to **Idah et al. (2012)**, the opening of the bruised areas led to a release of moisture from the damaged fruits. This also exposed the fruits to infestation by other spoilage organisms accelerating the rate of decay. Those rotten fruits showed signs of shrinkage and this led to a decrease in the weight of tomato fruits.

Table (4) shows the least significant difference (LSD) tests performed to determine the differences among the mean values of the damage ratio, EBI, BAI, firmness and weight losses in the tomato at different vibration frequency levels. In general, there was a significant difference ($P \leq 0.05$) among vibration frequency levels on the values of damage ratio, EBI, BAI, firmness and weight losses. The LSD test showed that there was a significant difference between the effect of vibration frequency of 7.5, 10 and 15 Hz on damage ratio, BAI and weight losses value ($P \leq 0.05$). However, there is no significant difference between vibration frequency of 10 and 15 Hz in EBI value ($P \leq 0.05$). Furthermore, there is no significant difference between vibration frequency of 5 and 12.5 Hz in damage ratio, EBI, BAI and weight losses value ($P \leq 0.05$). However, there was a significant difference between the effect of vibration frequency of 5, 7.5, 10, 12.5 and 15 Hz on tomato firmness.

3.2.2. Effect of Vibration Duration

The results shown in Table (4) indicated that increasing the vibration duration led to increasing the damage ratio and the weight losses and this trend of result agrees with the findings reported by **Fischer et al. (1992)** and **Shahbazi et al. (2010)**. Also, increasing the EBI and BAI values with

vibration duration is in agreement with **Vursavuş & Özgüven (2004)** and decreasing of the tomato firmness value with vibration duration is in agreement with **Demir et al. (2010)**. The damage ratio was 12.24, 14.49 and 17.01 % when the vibration duration was 30, 60 and 90 min, respectively. On the other hand, the EBI and BAI values were 3.72, 4.99 and 7.29 % and 0.52, 0.65 and 0.86 when the vibration duration was 30, 60 and 90 min, respectively. Also, the weight losses were 3.22, 3.51 and 4.32 and fruit firmness were 10.25, 10.02 and 9.28 N when the vibration durations were 30, 60 and 90 min, respectively. These results may be attributed to the fact that continuing vibration forces the fruits received and to strike each other and impacted during the entire vibration duration leading to increasing the damage ratio, EBI, BAI and weight losses and decreasing the firmness of the tomato fruits.

As indicated in the significant letters shown in Table (4), the LSD test revealed that the effects of the three vibration durations (30, 60 and 90 min) were significant on damage ratio, EBI, BAI, weight losses and firmness values (P ≤ 0.05).

3.2.3. Effect of Box Position

The results shown in Table (4) indicated that the damage ratio in tomato was 16.92, 14.57 and 12.23 %, the EBI values were 7.40, 4.86 and 4.62 %, the BAI values were 0.84, 0.64 and 0.55, the weight losses were 4.19, 3.54 and 3.33 and the firmness values were 9.25, 9.96 and 10.34 N at the upper, middle and bottom boxes, respectively. This means that damage ratio, EBI, BAI and weight losses values increased and the firmness values decreased from bottom to upper boxes. According to **O'Brien & Guillou (1969), Singh & Xu (1993)** and **Demir et al. (2010)** this is because the bottom box usually receives the lowest acceleration level, and the upper box receives the highest acceleration level. Also, the fruits in the upper box can move freely as they receive sufficient energy from the bottom boxes. This result indicated that the input accelerations at the truck during transporting tomatoes were magnified in fruits in the upper boxes. During vibration, when the acceleration in the upper boxes exceed certain values, the fruits approach an unstable condition and begin to move freely as a result of energy received from fruits at lower levels. This causes the fruit at the top to be intermittently weightless and strike each

other. However, the magnitude of vibration acceleration in the upper boxes during transit depends on the depth of fruits in the box, tightness of fill, type of suspension system used on the transport vehicle, magnitude of forced vibration transmitted from the real road and vibration characteristics of the fruit.

3.3. Second-Order interactions between Vibration Frequency and Vibration Duration (VF×VD)

The effect of vibration frequency levels on damage ratio, EBI, BAI, weight losses and firmness values in fresh tomato fruits at different vibration durations is shown in Figure (4) and (5). Vibration frequency of 7.5 Hz caused the highest damage ratio, EBI and BAI compared to the other vibration frequency levels. Also, it is noticed from Figure (4) and (5) that increasing vibration duration led to increasing all damage parameters (damage ratio, EBI and BAI) and weight losses and decreasing the firmness in tomatoes for all vibration frequency levels. This trend of result agrees with those reported by **Fischer** *et al.* **(1992)**, **Shahbazi** *et al.* **(2010)** and **Vursavuş & Özgüven (2004)**. For example, the results revealed that increasing the vibration duration from 30 to 90 minutes increased the damage ratio from 7.13 to 10.56, from 16.18 to 26.61, from 13.85 to 18.24, from 7.00 to 11.25 and from 16.05 to 19.48 % at vibration frequency levels of 5, 7.5, 10, 12.5 and 15 Hz, respectively. Furthermore, the results shown in Figure (5) indicated that increasing the vibration duration from 30 to 90 minutes led to increasing the weight losses from 2.56 to 3.09, from 3.73 to 7.11, from 3.35 to 3.88, from 2.77 to 3.22 and from 3.71 to 4.32 % for the vibration frequency levels of 5, 7.5, 10, 12.5 and 15 Hz, respectively. On the other hand, increasing the vibration duration from 30 to 90 minutes led to decreasing the tomato firmness from 11.48 to 11.04, from 8.90 to 7.08, from 10.24 to 9.26, from 10.73 to 10.19 and from 9.97 to 8.86 N for the vibration frequency levels of 5, 7.5, 10, 12.5 and 15 Hz, respectively.

Figures (4) and (5) show also the least significant difference (LSD) tests performed to determine the differences among the mean values of the damage ratio, EBI, BAI, weight losses and firmness for the interaction between vibration frequency and vibration duration (VF×VD). The LSD

tests showed that there was a significant difference among the three vibration durations in damage ratio, EBI and weight losses values at vibration frequency of 7.5 Hz (P ≤ 0.05). However, there was no significant difference between vibration duration 30 and 60 min in BAI and firmness values at the vibration frequency of 7.5 Hz (P ≤ 0.05).
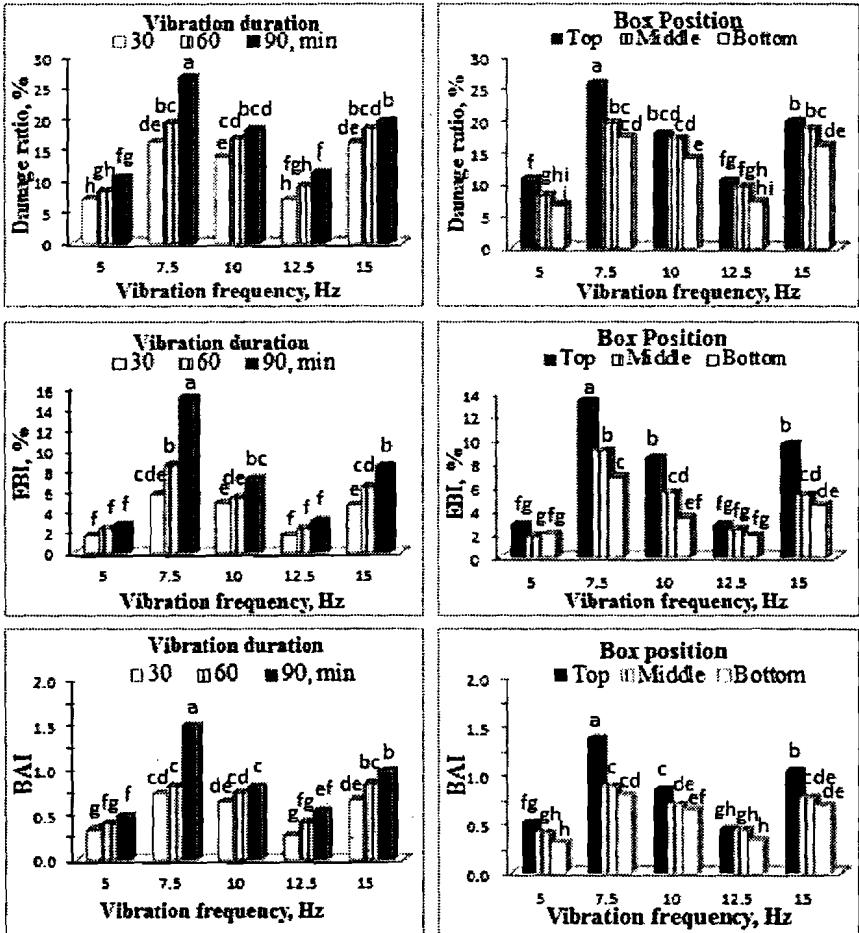

Figure (4): Effect of different vibration frequency levels on the average value damage ratio, EBI and BAI in fresh tomato fruits at different vibration durations and box positions.

The same letters above the bars means there is no significant difference (p ≤ 0.05).

The results also showed that the lowest value of damage ratio and BAI values among the combinations of vibration frequency and vibration duration was 6.99 % and 0.27 respectively, recorded at a vibration frequency of 12.5 Hz operated for 30 min. However, the lowest value of EBI and weight losses values among the combinations was 1.69 % and 2.56 % at a vibration frequency of 5 Hz operated for 30 min. On the contrary, the highest value of damage ratio, EBI, BAI and weight losses values among the combinations was 26.61 %, 15.03 %, 1.49 and 7.11 % respectively, recorded at 7.5 Hz for 90 min. Also, the lowest value of tomato firmness among these combinations was 7.06 N at 7.5 Hz for 90 min. On the other hand, the highest value of tomato firmness among the combinations of vibration frequency and vibration duration was 11.48 N obtained at 5 Hz for 30 min as seen in Figure (4) and (5).

3.4. Second-Order Interaction between Vibration Frequency and Box Position (VF×BP)

Similar to the results observed in the interactions between vibration frequency and vibration duration, the data shown in Figure (4) and (5) indicated that fruits located at the upper box exhibited the highest value of damage ratio, EBI, BAI and weight losses and the lowest value of firmness compared with those located in the middle and bottom positions. In other words, the values of damage ratio, EBI, BAI and weight losses increased and the firmness decreased from bottom to upper boxes for all vibration frequency levels. This trend of result agreed with those obtained by **Demir** *et al.* **(2010)** and **Aliasgarian** *et al.* **(2013)**. The results in Figure (4) showed that changing the box position from bottom to upper boxes increased the damage ratio from 6.72 to 10.84, from17.01 to 25.65, from 13.98 to 17.83, from 7.27 to 10.56 and from 15.78 to 19.75 % at vibration frequency levels of 5, 7.5, 10, 12.5 and 15 Hz respectively. Similar to the results found in the case of damage ratio, the results showed that changing the box position from bottom to upper boxes led to an increase in EBI values from 2.02 to 2.83, from 6.87 to 13.25, from 3.40 to 8.47, from 1.90 to 2.81 and from 4.52 to 9.63 % at the vibration frequency levels of 5, 7.5, 10, 12.5 and 15 Hz, respectively. Also, the results showed that changing the box position from bottom to upper boxes led to an increase in BAI values from 0.31 to 0.51, from 0.79 to 1.37,

from 0.65 to 0.85, from 0.33 to 0.44 and from 0.69 to 1.04 at the vibration frequency levels of 5, 7.5, 10, 12.5 and 15 Hz, respectively.

Moreover, the results in Figure (5) showed that changing the box position from bottom to upper boxes led to an increase in weight losses from 2.66 to 2.90, from 4.20 to 6.56, from 3.25 to 3.99, from 2.89 to 3.13 and from 3.66 to 4.39 % at vibration frequency levels of 5, 7.5, 10, 12.5 and 15 Hz, respectively. Also, the results showed that changing the box position from bottom to upper boxes led to a decrease in tomato firmness from 11.68 to 10.87, from 9.02 to 7.21, from 10.43 to 9.05, from 10.67 to 10.20 and from 9.90 to 8.90 N at vibration frequency levels of 5, 7.5, 10, 12.5 and 15 Hz, respectively.

Figures (4) and (5) showed the least significant difference (LSD) tests performed to determine the differences among the mean values of the damage ratio, EBI, BAI, weight losses and firmness for the interaction between vibration frequency and box position (VF×BP). The LSD tests revealed that changing the box position had no significant effect on damage ratio and firmness (P ≤ 0.05). However, changing the box position was significantly effective on the EBI, BAI and weight losses values (P ≤ 0.05). Therefore, there was a significant difference among the three box positions in EBI and values at vibration frequency of 7.5 Hz or 10 Hz (P ≤ 0.05). However, there was no significant difference between the middle and bottom box in BAI and weight losses values at vibration frequency of 7.5 Hz or 10 Hz (P ≤ 0.05).

Generally, the results showed that the lowest value of damage ratio, BAI and weight losses values among the combinations of vibration frequency and box position was 6.72 %, 0.31 and 2.66 %, respectively at 5 Hz for bottom box. The lowest value of EBI values among the combinations was 1.86 % at 5 Hz for the middle box. On the other hand, the highest value of damage ratio, EBI, BAI and weight losses values among the combinations was 25.65 %, 13.25 %, 1.37 and 6.56 %, respectively at 7.5 Hz for the upper box as seen in Figure (4) and (5). Also, the lowest value of tomato firmness among the combinations was 7.21 N at 7.5 Hz at the upper box. However, the highest value of tomato firmness among the combinations of vibration frequency and box position was 11.68 N at 5 Hz at the bottom box as seen in Figure (5).
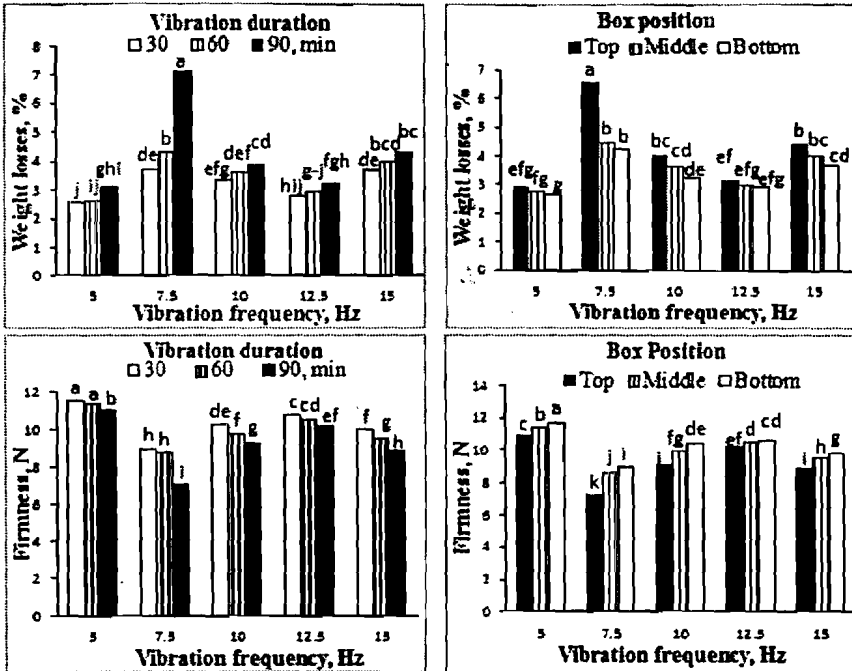
Figure (5): Effect of different vibration frequency levels on the average value of weight losses and firmness in fresh tomato fruits at different vibration durations and box positions.

The same letters above the bars means there is no significant difference (p ≤ 0.05).

3.5. Third-Order Interaction between Vibration Frequency, Vibration Duration and Box Position (VF×VD×BP)

The results in Table (3) indicated that there was no significant difference for the interaction between these three variables on damage ratio and BAI values in the tomato fruits. However, there was significant difference for the interaction between the three factors on EBI, weight losses and firmness. Moreover, the results in Table (5) show that the lowest value of damage ratio and EBI of 5.35 % and 1.05 % was obtained at the vibration frequency of 12.5 Hz and vibration duration of 30 min at the bottom box. Furthermore, the lowest value of BAI and weight losses was 0.22 and 2.44 % when the vibration frequency of 5 Hz was operated for a vibration duration of 30 min at the bottom box. Also, the lowest value of tomato firmness was 5.83 N was obtained at the vibration frequency of 7.5 Hz for

a vibration duration of 90 min at the upper box. On the other hand, the highest value of damage ratio, EBI, BAI and weight losses was 29.63 %, 20.75 %, 2.15 and 9.94 %, respectively when the vibration frequency was 7.5 Hz and the vibration duration was 90 min at the upper box. Also, the highest value of tomato firmness of 11.95 N was obtained at the vibration frequency of 5 Hz and the vibration duration of 30 min at the bottom box.

Table (5): The lowest and the highest value of the damage ratio, EBI, BAI, weight losses and firmness for the interaction among the combinations of the studied variables (VF×VD×BP).

Variables	Lowest value (obtained at)	Highest value (obtained at)
Damage ratio	5.35 % (12.5 Hz, 30 min and bottom)	29.63 % (7.5, 90 min and upper box)
EBI	1.05 % (12.5 Hz, 30 min and bottom)	20.75 % (7.5, 90 min and upper box)
BAI	0.22 (12.5 or 5 Hz, 30 min and bottom)	2.15 (7.5, 90 min and upper box)
Weight losses	2.44 % (5 Hz, 30 min and bottom)	9.94 % (7.5, 90 min and upper box)
Firmness	5.83 N (7.5, 90 min and upper box)	11.95 N (5 Hz, 30 min and bottom)

4. SUMMARY AND CONCLUSIONS

The main aim of this study was to determine the postharvest losses in tomato and identify the critical frequencies that cause minimum and maximum damage during transporting the product. Moreover, determining the effect of box position above the truck floor on the severity of the damage, firmness and weight losses of tomato. The summary of the results that have been obtained as follows:

- The values of damage ratio, EBI, BAI and weight losses increased and the firmness values decreased from the bottom to the upper boxes for all vibration frequency levels.
- Increasing the vibration duration led to increasing in damage ratio, EBI, BAI and weight losses in tomatoes and decreasing the tomato firmness value for all vibration frequency levels.

- The analysis of variance results showed that the interaction effects of the (VF × VD× BP) were significant on EBI, weight loss and firmness values (P ≤ 0.05). However, the interaction effects of the (VF × VD× BP) were not significant on damage ratio and BAI values (P ≤ 0.05).
- The results revealed that the vibration frequency of 7.5 Hz, vibration duration of 90 min and upper box caused the highest value of damage ratio, EBI, BAI and weight losses and the lowest value of firmness compared to the other vibration frequency levels.

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الملخص العربى

تقدير بعض فواقد ما بعد الحصاد فى الطماطم خلال محاكاة عملية النقل

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أجريت هذه الدراسة بهدف تقدير الضرر الميكانيكى الذى يحدث لمحصول الطماطم أثناء عملية النقل. ولذلك فقد تم تصميم نموذج محاكاه معملى لعملية النقل واستخدمت خمسة ترددات إهتزاز هى ٥، ٧.٥، ١٠، ١٢.٥، ١٥ هرتز وثلاث فترات إهتزاز هى ٣٠، ٦٠، ٩٠ دقيقة وثلاثة مواضع مختلفة لصندوق النقل وهى العلوى والأوسط والسفلى لتقدير الضرر الميكانيكى من خلال ثلاثة معايير مختلفة وهى نسبة الضرر ومؤشر شدة الكدمة ومؤشر مساحة الكدمة، وكذلك تم دراسة تأثير هذه العوامل الثلاثة كل على حدة وكذلك التفاعل فيما بينها على مقدار الضرر الميكانيكى والفقد فى الوزن وصلابة الطماطم بعد الإهتزاز.

وقد أظهرت نتائج تحليل التباين أن المتغيرات الرئيسية (تردد الإهتزاز 'VF'، ومدة الإهتزاز 'VD' وموضع الصندوق 'BP') كانت ذو تأثيراً معنوياً جداً على قيم نسبة الضرر ومؤشر شدة الكدمة ومؤشر مساحة الكدمة والفقد فى الوزن وصلابة الطماطم. فزيادة مدة الإهتزاز أدت إلى زيادة نسبة الضرر ومؤشر شدة الكدمة ومؤشر مساحة الكدمة والفقد فى الوزن وانخفاض صلابة الثمار لجميع مستويات تردد الإهتزاز. كما زادت قيم نسبة الضرر ومؤشر شدة الكدمة ومؤشر مساحة الكدمة والفقد فى الوزن وانخفضت قيم الصلابة من الصناديق السفلى إلى العليا لجميع مستويات تردد الإهتزاز.

ولقد أوضحت نتائج الدراسة أن تردد إهتزاز ٧.٥ هرتز مع مدة إهتزاز ٩٠ دقيقة عند الصندوق العلوى قد تسبب فى إحداث أعلى قيمة لنسبة الضرر ومؤشر شدة الكدمة ومؤشر مساحة الكدمة والفقد فى الوزن وأقل قيمة لصلابة الطماطم مقارنة بمستويات تردد الإهتزاز الأخرى لأنه عند الدمج بين الإزاحة والتردد فى الطبقات العليا عند تردد إهتزاز ٧.٥ هرتز حدث أعلى تسارع هذا التسارع يؤدى إلى إنعدام الوزن بشكل متقطع لبعض الثمار خلال فترة الإهتزاز بأكملها.

والمعلومات التى تم الحصول عليها من هذه الدراسة مهمة جداً عند تصميم معدات التداول وأنظمة التعليق والسيور الناقلة واختيار وسائل التعبئة والتغليف المناسبة التى تقلل من الأضرار الميكانيكية فى محاصيل الخضر والفاكهة.

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