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MECHANICAL DAMAGE OF STRAWBERRY DURING HARVEST AND POSTHARVEST OPERATIONS

Saeed ALIASGARIAN*, Hamid R. GHASSEMZADEH, Mohammad MOGHADDAM, Hossein GHAFFARI

University of Tabriz, Tabriz, Iran

Strawberry is a non-climacteric fruit with a limited harvesting period. Because of high susceptibility to mechanical damage, strawberry has a small postharvest life. In this research, an experiment was designed to study the mechanical damage phenomena in strawberry during the harvest and postharvest operations together with some physical properties of strawberry. Influences of some other factors such as variety, fruit position in the box as well as box position on the truck were also investigated. Results indicated that the variety, operation stage, fruit position in the box, and box position on the truck, had significant effects on the extent of the fruits' mechanical damage. Maximum damage index was related to picking stage. The variety Gaviota showed more susceptibility to mechanical damage than Selva. The maximum damage occurred at the bottom rows in the boxes. Furthermore, it was observed that the higher the position of a box on the truck, the more the susceptibility of fruits would be to mechanical damage.

Keywords: fruit position, physical properties, picking, transporting, variety

Strawberry is one of the non-climacteric fruits and in order to have the highest quality in terms of flavour, taste, and colour, it must be harvested at full maturity. Main changes in fruit composition only happen during maturation process and in contact with the mother plant (Cordenunsi, 2005). Softening of the fruits as they ripen involves thinning of cell walls and liquefaction of cell contents (Szczesniak and Smith, 1969). The large cells and thin cell walls in strawberry fruits contribute to their high level of susceptibility to mechanical damage (abrasions, cuts, bruising, and juice leakage) (Kader, 1991).

Mechanical damage is considered as a type of stress that occurs during the harvest and postharvest manipulation of fruits. This stress is accompanied by physiological and morphological changes that affect the fruit commodity. Apart from the mechanical stress, there are other types of stress due to biological and environmental factors, which also cause quality reduction (Shewfelt, 1993). Mechanical damage of fruits and vegetables, as a consequence of inappropriate harvest, manipulation, and transport techniques, is one of the most common and severe defects; it has great economic repercussions, mainly due to negative changes in organoleptic attributes (skin and flesh browning and off-flavours) and internal breakdown reactions (Castillo, 1992).

Nowadays harvest operation of strawberry used for fresh market is almost done by hand and only fruit used in the producing of processed products may be harvested by mechanical equipment. Also, some of the ordinary postharvest operations such as grading and packing are done manually in the field. Manual processing is advantageous, since it decreases the frequency of product handling. However, this harvesting system places more pressure and responsibility on the pickers (Sherman, 1988) and if proper standard is not used during harvest, marketability of the product will be decreased. Mitchel et al. (1964) reported that after eight days of storage at 5 °C product losses were about 33.7 % for a less careful picker compared to 14.4 % for a more trained picker.

Bruising is one of the most important mechanical damages that might occur mainly due to three types of mechanical abuse: impact, vibration, and compression (Vergano et al.,1992; Brusewitz et al., 1991) and strawberry shows more injury when subjected to compression (Holt and Shoorl, 1976, 1982). For the same energy levels, bruising volume for compression is 40 % higher than impact (Holt and Schoorl, 1982). Bruising may be intensified by some other factors such as texture, variety, maturity stage, water content, fruit shape, temperature, firmness, size, and a series of fruit interior factors such as modulus of elasticity, strength of cell walls, internal structure, and cell shape (Studman et al., 1997; Van Lindeh et al., 2006).

In packaging lines, the probability of exposure of the fruits to impact and vibration forces is more than those of compression test (Garcia et al., 1988). The factors affecting damage severity caused by impact are fruit fall height, contact energy, the number of contact, the kind of contact surface, and the size and ripeness stage of the fruit (Lin and Brusewitz, 1994; Roth et al., 2005). The factors such as size, cultivar, and ripeness stage can influence the response of fruit to compression pressure (Jamieson et al., 2002). Ripe strawberry fruits were reported to be softer than pink

Contact address: *Saeed Aliasgarian, University of Tabriz, Tabriz, PhD Student of Agricultural Mechanization Engineering, Faculty of Agriculture, Iran, e-mail: sa_ir_al@yahoo.com

ones, the difference being reduced during storage (Doving and Mage, 2002) and no difference in firmness was found between ripe and over-ripe fruit (Ourecky and Bourne, 1968).

The objectives of this research were to determine the extent of mechanical damage to fruits during the various stages of harvest and postharvest operations and to study some factors affecting the mechanical damage of strawberry fruits.

Material and methods

Fruits were taken from a greenhouse in Janghour village, the suburb of Tabriz. Two strawberry varieties, Selva and Gaviota, were used in experiments. These varieties are the most dominant in the Iranian market. The initial moisture content of samples was determined using the vacuum oven method at 70 ± 1 °C. Three replications were conducted to obtain a reasonable average (AOAC, 1990). The moisture content of Selva and Gaviota varieties were 91.07 % and 93.16 %, respectively.

Some physical properties of varieties including linear dimensions (length and diameter), mass, volume, geometric mean diameter, sphericity and hardness were determined to establish probable relations between these properties and mechanical damage of the fruit. Two random samples of 100 fruits were taken from each variety. Linear dimensions were measured by a micrometer to an accuracy of 0.01. Strawberries were weighted by an electronic balance to an accuracy of 0.001 g. The volume of fruits was determined by using the liquid displacement method (Mohsenin, 1986). The geometric mean diameter and sphericity were calculated using Eqs (1) and (2), respectively (Mohsenin, 1986)

$$D_g = (LD^2)^{0.333} \quad (1)$$

$$\phi = \frac{(LD^2)^{0.333}}{L} \quad (2)$$

where:
D – diameter of strawberry (mm)
D_g – geometric mean diameter (mm)
L – length of strawberry (mm)
ϕ – sphericity of strawberry

Hardness was measured using Instron Universal Testing Machine Model 1140, and a full scale of 5 N was selected. Loading rate was 50 mm min^{-1} (Bourne, 1982).

In another experiment, fruits were picked in the greenhouse, delivered to packing house, packed, and finally delivered to a market by truck. In order to determine the extent of mechanical damage on strawberry fruits, three main operations were considered, namely, a) picking, b) packing, and, c) delivery to the market. Samples of fruits were collected after completion of each operation and delivered to a laboratory with care to prevent fruits from further damage. Standard 10 × 17 × 10 (width × length × depth) boxes with openings on their bottoms were used for packing. Each box contained three layers of fruits with 20 fruits in each layer. Three layers of boxes with paperboard between the layers were loaded on a truck to transport the product to the market in Tabriz, 55 km away from the greenhouse. The experiment was factorial based on randomized complete block design with two factors and three replications. The factors were varieties (Selva and Gaviota) and operations (picking, packing and delivery to the market). However, the delivery to the market itself consisted of nine treatment combinations of box height on the truck (top, middle and bottom) and fruit layer within the box (top, middle and bottom). The factors and their levels are presented in Table 1. The extent of damage was evaluated based on the strawberry grading system presented by Fischer et al. (1992) having assigned some numerical values to every grade, as seen in Table 2. For each treatment, the number of fruits within each grade was multiplied by related grade value and then averaged to obtain an index for the extent of damage. Statistical analyses were done by using SPSS software (version 16.0). LSD's test was used to determine significant differences among means.

Table 1 Factors used for evaluating the extent of mechanical damage on strawberry fruits

Factor	Level		
Variety	Selva		
	Gaviota		
Operation	picking		
	packing		
	delivery to the market	box height on the truck	top
			middle
			bottom
		fruit layer within the box	top
			middle
			bottom

Table 2 Strawberry grading system with considered value for each damage level

Grade	Value	Description
Undamaged	zero	– berries with no abrasions but may have up to two bruises less than 2 mm in diameter
Slightly damaged	1	– berries with no abrasions but may have up to four bruises less than 2 mm in diameter
Moderately damaged	2	– less than 25 % of the berry bruised or moderate abrasions covering less than 25 %
Severely damaged	3	– any berries with bruises or abrasions which penetrated the surface of the fruit
Very severely damaged	4	– entire fruit bruised, mould formation or pieces of fruit missing

Table 3 Mean values for physical properties of strawberries varieties

Varieties	Gaviota		Selva	
	mean	SD	mean	SD
Length in mm	32.161[a]	0.460	29.697[b]	0.469
Diameter in mm	27.171[a]	0.287	28.260[b]	0.352
Mass in g	12.267	0.603	11.885	0.372
Volume in cm3	12.441	0.390	12.325	0.419
Sphericity in %	0.897[a]	0.800	0.971[b]	0.008
Geometric mean diameter (mm)	28.591	0.289	28.585	0.349
Hardness in N	3.973[a]	0.221	3.632[b]	0.124

In each row, means with different superscript letters show significant difference at 5 % probability level; SD – standard deviation

Table 4 Results of analysis of variance for damage index of fruits in two strawberry varieties

During picking (O1), packing (O2) and delivery to the market (O3) Sources of variation		Degrees of freedom	Mean squares
Block		2	0.132**
Variety (V)		1	0.116**
Operation (O)		10	0.373**
Between O1, O2, O3		2	1.125**
O3	**box height on the truck (H)**	2	0.363**
	fruit layer within the box (L)	2	0.365**
	H × L	4	0.032[ns]
V × O		10	0.020[ns]
Error		42	0.014
Total		65	

[ns], ** – not significant and significant at 1 % probability level, [+] Factors were illustrated in Table 1

Results and discussion

Measured physical properties for each variety are shown in Table 3. The varieties differed significantly for the length, diameter, sphericity and hardness of strawberry fruits. Gaviota had higher mean length than Selva, while the difference in mean diameter was vice versa. This indicates that the sphericity in Selva variety is higher compared to that of Gaviota.

The effect of variety was significant at 1 % probability level on mean damage index (Table 4). Based on Table 5, Gaviota was more susceptible to damage than Selva. Although the two varieties were significantly different in length and diameter, their differences in masses and volumes were insignificant. It seems that shape is an effective factor causing fruit susceptibility to damage because fruits with small sphericity values were more susceptible to mechanical damage. According to the dimension properties of varieties, we can say that strawberries shapes of Selva and Gaviota were globose conic and long conic, respectively. Ourecky and Bourne (1968) reported that the small strawberry fruits subjected to compression pressure were firmer and tougher than the medium and large fruits. The results of analysis of variance for damage index are shown in Table 4.

The effect of operation factor on damage index was significant at 1 % probability level. The minimum and maximum values of mean damage index were related to packing and picking stages, respectively (Table 5). The percentage of damage for each stage is shown in Figure 1 as a percent of overall damage. Ferreira et al. (2008) mentioned the picking operation as the main source of mechanical damage. Also, based on observed results for

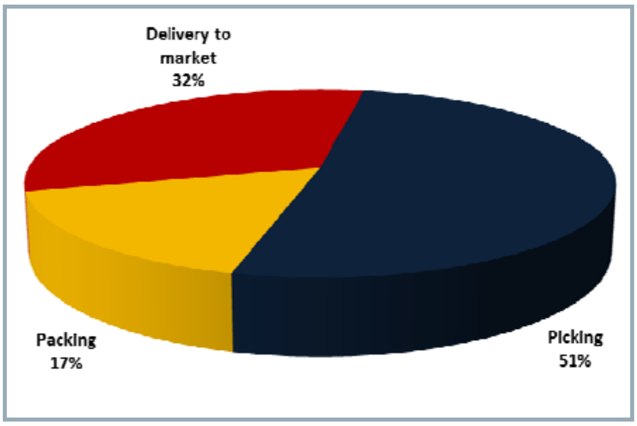

Figure 1 Percent of damage to strawberry fruits during different stages of handling

Table 5 Mean damage index on strawberry fruits for factors used in studying of harvest and postharvest operations

Factor	Level	Mean damage index
Variety	Selva	0.451[a+]
	Gaviota	0.528[b]
Operation	picking[++]	0.733[c]
	packing[++]	0.242[a]
	delivery to the market[+++]	0.490[b]
Box height on the truck	top	0.742[c]
	middle	0.485[b]
	bottom	0.242[a]
Fruit layer within the box	top	0.371[a]
	middle	0.405[a]
	bottom	0.693[b]

[+] for each factor, means with different letters are significantly different at 1 % probability level; [++] based on 6 observations (variety × replication); [+++] based on 54 observations (variety × replication × height × layer)

berries utilization, the mechanical or manual harvesting system will have different repercussions (Brown, 1996). Martinez-Romero et al. (2004) mentioned the number of days elapsed between harvest and initiation of the mechanical damage as an effective factor in susceptibility of fruits to the damage. They reported that increasing in the number of elapsed days led to decreasing the turgidity of young tissues and finally raised their resistance to damage. Therefore, one of the causes of high susceptibility of fruits to damage in the pickup stage could be high turgidity of young tissues.

The effect of height on damage index was significant. The damage index value varied from low values at the bottom to high values at the top (Table 5). This can be attributed to high vibrations in top boxes. Since the paperboards used between the layers of the boxes save them against compression, the compression damage of the product due to higher box weight could be negligible during transportation. Fischer et al. (1992) simulated the strawberry transportation process by the electro-hydraulic vibration system and obtained the same results.

The fruit layer within the box also had significant effect on damage index. Based on results obtained, there was not a significant difference between damages occurred in the top and middle layers of fruits within the boxes, but the extent of damage in the bottom layer was significantly different from the two other layers (Table 5), implying that the creep due to compression might have occurred. Kitinoja and Kader (1995) represented that one of the damaging causes during the transporting was compression caused by excessively stacking the product within packaging boxes.

Conclusion

Due to the high susceptibility of strawberry to damage during the picking stage, using of trained workers and proper equipment is essential. Also, daily supervision of the harvested product quality and improving the situation can decrease losses due to harvest.

It seems that safe delivery of product to a market depends mainly on proper packaging and standard handling practices. To reduce the losses during handling the packages, overfilled boxes must be avoided and the number of layers within boxes must be kept as low as possible. Employing the paperboards or plastic boards between the fruit layers can be beneficial due to preventing fruits from in place motion hence decreasing the fruit damage. Using the vehicles with suitable suspension system and well trained driver along with smooth roads are all key factors in safe handling of strawberry.

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