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Effect of mechanical damage on mass loss and water content in tomato fruits**

Zhiguo Li, Pingping Li, and Jizhan Liu*

Institute of Agricultural Engineering, Jiangsu University, 212013 Zhenjiang, China

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A b s t r a c t. This study was carried out to determine the effect of mechanical damage on mass loss and water content in three-locular and four-locular tomato fruits by loading, storage and drying tests. Four compressibility levels, namely, 4, 8, 12 and 16%, and three loading positions were used. The results showed the compressibility and loading position had no significant effect on the water content. The mass loss was increasing with storage period at all the combinations of compressibility and loading position. The loading position had no significant effect on mass loss during storage at 4 and 8% compressibility, the mass loss at 4% was 0.63% per day and for 8% it was 8.4%. But loading position had a gradual significant effect on mass loss during storage at 12 and 16%.

K e y w o r d s: tomato, mechanical damage, mass loss, water content

INTRODUCTION

Mechanical damage of tomato fruits, as a consequence of inappropriate harvest, manipulation, and transport techniques, is one of the most common and severe defects; it has great economical repercussions, mainly due to negative changes in sensory attributes (skin and flesh browning and off-flavours) and internal breakdown reactions (Martinez *et al*., 2004). Therefore, damage prevention is necessary to control the quality of fresh market tomatoes. Effective prevention is only possible when the factors responsible for physiological change are known. Some research has focused on factors that affect the bruise susceptibility of fruit, such as variety, texture, maturity, temperature, shape, impact energy, harvested date and impact surface. Other research focused on the physiological change of intact fruits during storage. Under the viewpoint of applied nutritional science, the fruit skin often shrivels up and the fruit becomes unmarketable as the mass loss of putrescible fruit is more than 5%. Martinez *et al*. (2004) showed the mass loss in fruits was an indirect indicator of mechanical damage. Shatat (1999) reported the bruise was proportional to the mass loss for 'Starkrimson' and 'Mar spur' postharvest apple during storage in two orchards. Chen and Peng (2008) reported the degree of mechanical damage had no significant effect on mass loss in olive fruit. Martinez *et al*. (2004), Elshiekh and Abugoukh (2008), and Assi *et al*. (2009) reported lower mass loss in plum, grape and tomato fruits by advanced handling methods comparable to traditional handling methods. Akar and Aydin (2005), Aviara *et al*. (2007), and Sessiz *et al*. (2007) studied the relationship between water content and physical properties of intact fruits. Arazuri *et al*. (2007), Singh and Reddy (2006), and Mahajan *et al*. (2008) studied the change of firmness, water content and mass loss in fruits and mushrooms during storage.

To sum up, the studies on the effect of mechanical damage on water content and mass loss in tomato fruit have not been fully explored. Limited information exists on the detailed relationship between the degree of mechanical damage, water content, and mass loss in tomato fruits. An objective classification of the degree of bruising has still been beyond the possibilities so far. The above literature shows that the degree of mechanical damage is only classified as non-damaged tomato and damaged tomato based on visual assessment. Limited classification is difficult to exactly prevent the change trend in mass loss and water loss of tomato fruit with degree of mechanical damage. There is a knowledge gap on the effect of structure characteristics on mass loss and water content in tomato fruit during loading. The apple, pear and plum tissue properties are homogeneous, and each fruit has no difference in structure characteristics (Bajema *et al*., 2000). However, the tomato fruit is unique. The single fruit

*Corresponding author's e-mail: lizhiguo0821@126.com

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tissue properties are inhomogeneous and depend mainly on the number of locules in tomato fruits. Different degrees of mechanical damage would be caused at various loading positions (Li *et al*., 2010), thereby leading to various physiological changes of the tomato fruit during storage. Predicting the effect of mechanical damage on mass loss and water content in tomato fruit during storage, therefore, is helpful for estimating the quality of fresh tomato fruits and designing its handling, packaging and storage conditions.

The aim of this study was to measure the mass loss and water content of damaged tomatoes at various loading positions during storage.

MATERIALS AND METHODS

Fresh tomato fruits of two structure types were used in this study: three-locule (*T*) and four-locule (*F*). Tomatoes were uniformly grown at the Yangzhou Vegetable Research Institute in the eastern region of China. 140 tomatoes were hand harvested in December 2009 at the light red ripening stage according to USDA Standards. After being carefully transported to the laboratory, the tomatoes were inspected again to ensure that they were non-damaged and not infected by worms. In addition, the loading-unloading test was conducted within 24 h.

Most cultivated varieties of tomato fruits have 3~8 locules. Three-locular tomato and four-locular tomato were chosen in order to reduce the number of test cases. The three-locular (*T*) tomato indicates the fruit has asymmetric internal structure, which represents tomatoes with 3, 5 or 7 locules; while the four-locular (*F*) tomato indicates the tomato has symmetric internal structure, which represents tomatoes with 4, 6 or 8 locules (Fig. 1). The seeds and gelatinous membranes are located inside of each locular cavity in the tomato fruits. A radial wall separates the locules. Different degrees of mechanical damage were caused as each four-locular tomato was loaded at the locular tissue and radial wall tissue (Linden *et al*., 2005). Thus two positions at the fruit surface (locular: *L* and radial-wall: *RW* tissue) were loaded. The two positions on the cross section of tomato: position 1 at the radial wall tissue and position 2 at the locular tissue, are shown in Fig. 1. Locular tissue is the pericarp over the locules, whereas radial wall tissue is the pericarp located over the septum. Position 1 corresponded to the valley between two adjacent fruit shoulders, and position 2 corresponded to the middle of one fruit shoulder. Additionally, the degree of mechanical damage had little difference at the two positions for three-locular tomatoes because the angle nears 120° between radial wall tissues (Li *et al*., 2010). Therefore, three loading positions were compared in order to study the effect of structure on the water content and mass loss of tomato fruits, which can be described as radial wall tissue of three-locular tomato *T*RW*, radial wall tissue of four-locular tomato *F*RW* and locular tissue of four-locular tomato *F*L*. Compressibility is the most important explanatory variable in the model of the degree of mechanical damage of tomato fruit. It shows a significant positive effect on

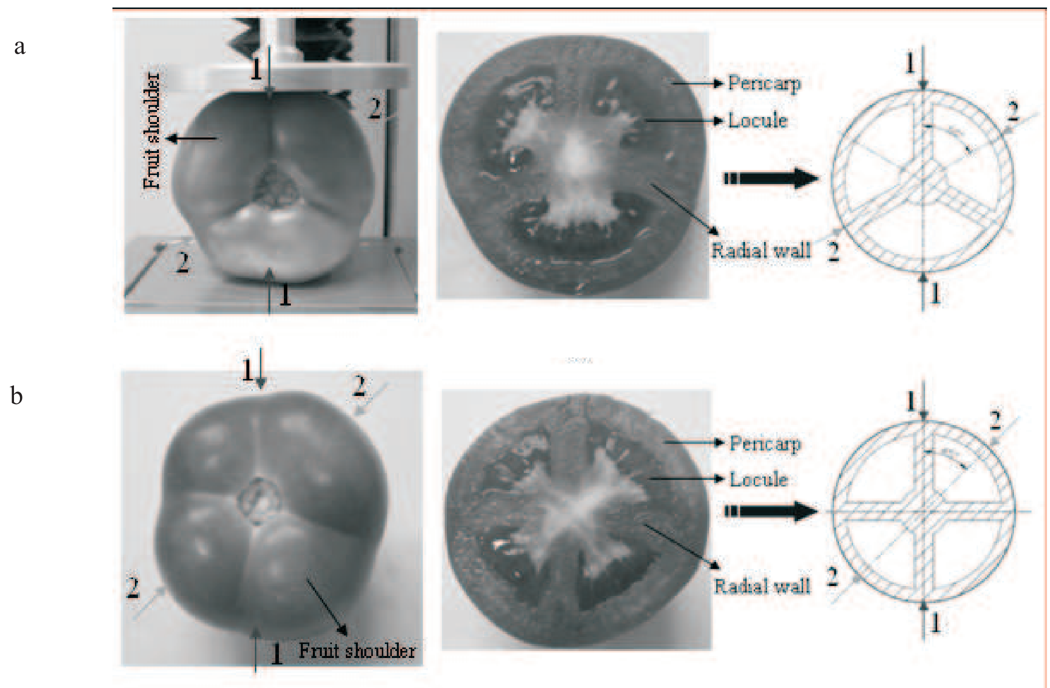

Fig. 1. Three-locular and four-locular tomatoes, their cross sections and simplified structures: a – three-locular tomato, b – four-locular tomato; 1– locular tissue, *L*; 2 – radical wall tissue, *RW*.

the degree of mechanical damage for the same loading position and structure type (Li *et al*., 2010). Four compressibility levels: 4, 8, 12, and 16% were used in this test, which indicated four increasing degrees of mechanical damage of tomato. A full factorial design was performed, as shown in Table 1. In total, 120 tomatoes (10 tomatoes × 3 loading positions×4 compressibility levels) were loaded in the test.

At first, the physical properties of tomato fruits were measured at room temperature. The principal dimensions of tomatoes in each group, namely, the longitudinal axis through the stem containing the major dimension (length, *L*), the transverse axis containing the minor dimension (width, *W*), and the transverse axis containing the minimum dimension (thickness, *T*) were measured by using a micrometer to an accuracy of 0.01 mm. The fresh mass M_0 (g) of fruit was measured by an electronic balance to an accuracy of 0.01 g. From the principal dimensions, the geometric mean diameter, D_g, sphericity, Φ, and surface areas, *S,* were calculated by using the related equations (Kilickan and Guner, 2008).

Then three-locular tomatoes and four-locular tomatoes were sorted into five groups and nine groups respectively, and labelled. The first group had five medium tomatoes and five large tomatoes, respectively, other groups were medium tomatoes. The first group was defined as group 1 and group 2, respectively. The residual groups were randomly defined as group 3 ~ group 14.

After being grouped, the loading-unloading tests of tomatoes from group 3 to group 14 were conducted at room temperature on a *TA-TX*2 Texture Analyser (Texture Technologies Corp., NY, USA). The analyser was calibrated with a 5 kg weigh prior to the first test. It was equipped with an 80 mm diameter plate for the loading-unloading test. Equipment settings were as follows: test speed - 0.5 mm s^{-1}, distance – 10 mm into the tomato. Compressibility and test points on a tomato sample followed Table 1. All loadings were located at equatorial region.

T a b l e 1. Experimental factors and their levels

Factors	Levels			
	1	2	3	4
Loading positions	*T*RW*	*F*RW*	*F*L*	–
Compressibility (%)	4	8	12	16

At last, all grouped tomatoes were put in a phytotron for five days of storage at 24 and 26.2% RH, and the mass of the fruits *ie* M_1, M_2, M_3, M_4 and M_5 was measured and recorded once a day. Subsequently, the tomatoes were placed in a vacuum drying oven (DZF-6050) set to 85°C to determine the dry mass M_d (g) of tomato fruit. The water content, *WC*, and mass loss, *ML*, were determined using the related formulates (Sessiz *et al*., 2007).

RESULTS AND DISCUSSION

The fresh mass and water content of 10 three-locular tomatoes (group 1) and 10 four-locular tomatoes (group 2) are shown in Table 2. These tomatoes were not damaged. Values of the coefficient of variation of the fresh mass and water content of group 1 and group 2 are presented in Fig. 2. Obviously, the coefficient of variation of the fruit fresh mass was bigger than that of fruit water content, whether for three-locular tomato or four-locular tomato, and the difference was slight in the coefficient of variation of fruit water content. The fresh mass of tomato had no significant effect on the water content. The average water content of three-locular and four-locular tomato was 95.13±0.28% and 95.21±0.38%, respectively. The fruit structure type had no significant effect (P>0.05) on the water content of tomato at $\alpha = 0.05$ according to one-way ANOVA. This also illustrates that the fruit structure had no significant effect on the dry matter content of tomato.

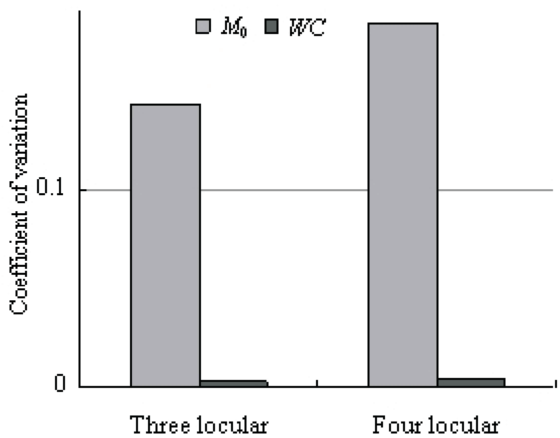

Fig. 2. Coefficient of variation of fresh mass (M_0) and water content (*WC*) of group 1 and group 2.

T a b l e 2. Fresh mass (M_0) and water content (*WC*) of 10 three-locular tomatoes and 10 four-locular tomatoes

Internal structure	Parameter	1	2	3	4	5	6	7	8	9	10
Three locular	M_0 (g)	104.2	118.0	145.3	154.4	146.2	162.0	162.3	169.1	165.1	147.4
	WC (%)	95.0	94.8	94.9	95.4	94.8	95.7	95.1	95.3	95.2	95.1
Four locular	M_0 (g)	100.5	151.3	121.4	134.5	157.8	139.2	169.1	181.6	170.8	137.8
	WC (%)	95.3	95.4	94.3	94.9	95.5	95.6	95.1	95.5	95.3	95.2

Group 1 and group 2 were sorted into two sets based on the masses according to the CNS SB/T 10331-2000; medium fruit: $100 \leq M_0 \leq 149$ and large fruit: $150 \leq M_0 \leq 199$, respectively. The water content of medium and large fruit for three-locular and four-locular tomatoes is presented in Fig. 3. The size of the tomatoes had no significant effect on water content of three-locular tomato and four-locular tomato. This was in accordance with the obtained conclusion by coefficient of variation in last section. Therefore, this further illustrated that the fresh mass of tomato had no significant effect on water content.

The water content of fruits and vegetables is mainly affected by their growing environment (Rashid *et al*., 2005; Wu, 2009). In this experiment, the study tomatoes were from the same growing station, so the water content of the fruit had small variance and was not significantly affected by the structure types of the fruits. This also showed that the volume of three-locular tomato would be bigger than four-locular tomato when the tomatoes had the same fresh mass. The relationship between water content and fresh mass had been widely studied in fruits. Wu (2009) reported the water content of ‘Classical 1’ cucumber fruit had no relation with the fresh mass and Liu *et al*. (2002) reported the water content decreased with increasing fresh mass of ‘Zuohe 2’ strawberry. Akar and Aydin (2005), Aviara *et al*. (2007), and Sessiz *et al*. (2007) showed the water content of gumbo, capper and guna increased with fresh mass respectively, and these followed linear regression equations. The tomato fruit had the same property of water content with the cucumber but was different from the above mentioned other fruits in this paragraph. Therefore, the tomato fresh mass increased with dry mass but not water content, and this followed linear regression equations.

The water content of loaded tomatoes after 5 days of storage is presented in Table 3. Tomatoes were loaded at all the combinations of four compressibility levels: 4, 8, 12, and 16% and three positions: *T*RW, F*RW* and *F*L*. Joint data represent average values ± standard deviations of the water content for ten tomatoes per compressibility level and position. According to a MANOVA, the compressibility and the loading position had no significant effect (P>0.05) on the water content of tomato at $\alpha = 0.05$.

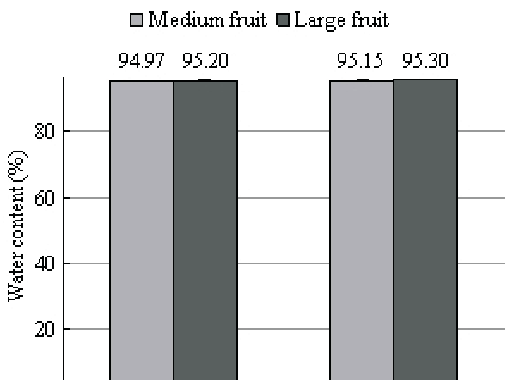

Fig. 3. Water content of medium and large fruit for three-locular and four-locular tomatoes.

The most important physiological processes in post-harvest fruits are respiration and transpiration. Respiration is the process by which fruits take in oxygen and give out carbon dioxide. The oxygen from the air breaks down carbohydrates in the fruit into carbon dioxide and water (Paliyath *et al*., 2008). The carbohydrate content in fruit decreases with increase in storage period, so the overall fruit quality is reduced. The fruit respiration rate increases after mechanical damage, and the consumption rate of carbohydrate dry matter such as cellulose and pectin substance in the fruit is raised. For the water content of damaged tomato after 5 days of storage, the M_d was residual dry matter mass in tomato. Transpiration is a process of water evaporation in fruit (Bartz and Brecht, 2003). Transpiration accounts for most of the mass loss in the majority of horticultural produce. In tomatoes, transpiration accounts for 92-97% of mass loss. The mass loss due to respiration is considered negligible compared to that due to transpiration (Shirazi and Cameron, 1993). So, the change of tomato dry matter mass due to respiration was slight in five days. Therefore, compressibility and loading position showed no significant effect on the tomato dry matter content, which also had no significant effect on the tomato water content accordingly.

The mass loss on the fifth day after the tomatoes were loaded under the conditions of four compressibility levels and three loading positions is presented in Table 3. Joint data represent average values ± standard deviations of the mass loss for ten tomatoes per compressibility level and position. Obviously, the highest mass loss in tomatoes was observed at *F*RW* for 12 and 16%, followed at *T*RW*, and lowest mass loss at *F*L*. However, the mass losses were no significantly different among three loading positions for 4 and 8%. For instance, the ratio of mass losses was 1.48 at 16% for *F*RW* and *F*L*, and about 1 at 4% for *F*RW* and *F*L*. The reason might be that the deformations were in the elastic region of tomato at 4 and 8% but beyond the elastic region at 12 and 16%. Certainly, there would be an elastic limit value between 8 and 12% for tomato fruit. At three loading positions, the degree of mechanical damage was the greatest at *F*RW* and the lowest at *F*L* when one tomato had the same deformation which was beyond the elastic region (Li *et al*., 2010). Mechanical damage showed a significant positive effect on mass loss (Assi *et al*., 2009). Therefore, loading position had no significant effect on the mass loss at 4 and 8% but had a significant effect on it at 12 and 16%. The mass loss rate was the largest at *F*RW* and the lowest at *F*L* for 12 and 16%.

Furthermore, compressibility showed a significant effect (P>0.05) on the mass loss in tomato fruit at $\alpha = 0.05$ according to one-way ANOVA. Obviously, the mass loss increased with higher compressibility at the same loading position. One exception was the mass loss at *F*L* for 8%.

Table 3. Water content and mass loss for loaded tomatoes after 5 days of storage

Properties	Position	Compressibility (%)			
		4	8	12	16
Water content	*T*RW*	0.954±0.002	0.955±0.003	0.949±0.002	0.948±0.011
	*F*RW*	0.959±0.001	0.950±0.003	0.956±0.001	0.952±0.002
	*F*L*	0.955±0.001	0.955±0.013	0.952±0.001	0.956±0.006
Mass loss	*T*RW*	0.035±0.006	0.046±0.001	0.055±0.014	0.107±0.052
	*F*RW*	0.034±0.046	0.046±0.002	0.078±0.001	0.121±0.001
	*F*L*	0.035±0.027	0.049±0.007	0.044±0.014	0.082±0.030

The value was expected to be less than 0.044 but was at 0.049. There was no reasonable explanation for this exceptionally large variation in fruit sensitivity. The change of mass loss rate was found to be higher when the compressibility ranged from 12 to 16% compared to the compressibility ranging from 4 to 8%. For example, the ratio of mass loss rate was 1.55 at *F*RW* for 16 and 12%, but it was only 1.35 for 8 and 4%. Four different compressibility levels at the same loading position corresponded with four degrees of mechanical damage in tomato fruit. Consequently, this further illustrated that the relationship between the degree of mechanical damage and the mass loss did not follow the simple linear regression equations. However, not much is known about the detail relationship at various positions so far. Finally, compared with several nonlinear regression equations, the best relationships between these mass losses on the fifth day against various positions and compressibility levels of tomato were shown in below equations:

$$ML_{5F*RW} = 0.021e^{10.84C} \quad R^2=0.99, \qquad (1)$$

$$ML_{5T*RW} = 0.023e^{8.83C} \quad R^2=0.92, \qquad (2)$$

$$ML_{5F*L} = 0.027e^{6.12C} \quad R^2=0.77, \qquad (3)$$

where: ML_{5F*RW}, ML_{5T*RW} and ML_{5F*L} are the mass loss of tomato fruit at the fifth day at *F*RW*, *T*RW* and *F*L*, respectively; *C* is compressibility (%). The above parameters will be necessary in the quality evaluation of mechanical properties of postharvest tomato during storage.

The reason for the increased mass loss at higher compressibility might be that mechanical damage of tomato fruits broke down the surface organization of the tissues, thereby leading to greater flux of water vapour through the damaged area (Elshiekh and Abugoukh, 2008). As the degree of mechanical damage increased, the damaged area increased, leading to greater evaporation during transpiration. Thus mechanical damage greatly accelerates the rate of mass loss from fruit.The cumulative mass loss rate of tomatoes at 4, 8, 12 and 16% for 5 days of storage is presented in Fig. 4. The mass loss increased with the storage period at all the combinations of compressibility and loading position. It has been shown that storage period has a significant effect on mass loss (Javanmardi and Kubota, 2006). Similar trend in mass loss rate of tomato fruits with storage period is in agreement with previous studies on oranges (Singh and Reddy, 2006) and mango (Abbasi *et al*., 2009). Transpiration rate is influenced by factors such as temperature, humidity, surface area, respiration rate, and air movement (Mahajan *et al*., 2008). The mass loss due to respiration is considered negligible compared to that due to transpiration (Shirazi and Cameron, 1993). So, the transpiration rate was nearly constant when the tomato was stored in a phytotron at 24 and 26.2% *RH*. In addition, tomatoes from group 3 to group 14 had no significant difference (P>0.05) in the geometric mean diameter D_g, sphericity Φ and surface areas *S* at α = 0.05 according to a MANOVA. Therefore the trend in mass loss with storage period followed linear regression equations.

The loading position had no significant effect on mass loss during storage at 4 and 8% compressibility; the rate of mass loss at 4% was 0.63% per day and for 8% was 8.4%. But the loading position had a gradual significant effect on mass loss during storage at 12 and 16%. *F*RW* showed a significant greatest mass loss during 5 days at a rate of 1.04% per day at 12 and 2.14% per day at 16%. *F*L* showed a significant lowest mass loss during 5days in a rate of 0.83% per day at 12 and 1.54% per day at 16%. At the end of 5 days storage, the cumulative mass losses were 12.1, 10.7 and 8.2% at *F*RW*, *T*RW* and *F*L* for 16% compressibility, respectively. Internal structure showed a significant effect on the degree of mechanical damage in tomato fruit. The statistical results showed the split probability of tomato being loaded at radial wall tissue and locular tissue was 33.33 and 16.67%, respectively at 12%, for 50 and 16.67%, respectively at 16% and for 100 and 83.33%, respectively at 20% (Li *et al*., 2010). Obviously, the loading position showed a significant effect on the split probability of tomato. The surface wax is broken down after tomatoes have cracked, thereby leading to the transpiration rate being increased (Bauer *et al*., 2004). As a consequence, a crack greatly accelerates the rate of mass loss from tomato fruit. Therefore, the loading position can have a considerable effect on mass loss in tomato fruit during storage.

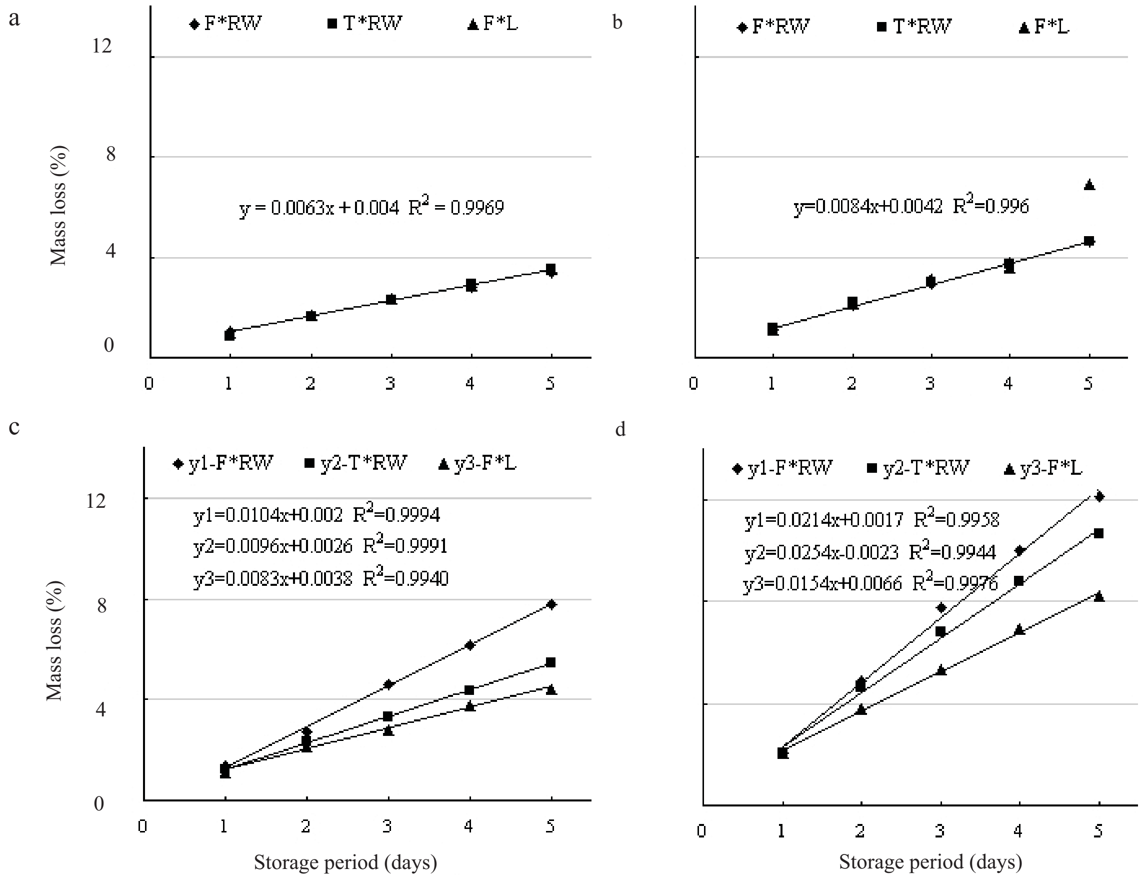

Fig. 4. Mass loss of tomato fruits after 5 days of storage: a – 4, b – 8, c – 12, and d – 16% compressibility.

CONCLUSIONS

1. For non-damaged tomatoes, the average water content of three-locular and four-locular tomato was 95.13 ±0.28% and 95.21±0.38%, respectively. The fruit structure type had no significant effect on the water content of tomato. The fresh mass of tomato had no significant effect on the water content according to the coefficient of variation.

2. The compressibility and loading position had no significant effect on the water content of loaded tomato.

3. The highest mass loss in tomatoes on the fifth day was observed at *F*RW* for 12 and 16% compressibility, followed by *T*RW*, and the lowest mass loss at *F*L*. However, the mass losses were no significantly different among three loading positions for 4 and 8%.

4. The mass loss after storage increased with increase in compressibility at the same loading position and these followed nature exponential regression equations.

5. The mass loss was increasing with storage period for all the combinations of compressibility and loading position, and these followed linear regression equations. The loading position had no significant effect on mass loss during storage at 4 and 8% compressibility; the rate of mass loss at 4% was 0.63% per day and for 8% was 8.4%. But the loading position had a gradual significant effect on mass loss during storage at 12 and 16%.

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