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FULL LENGTH ARTICLE

Effect of storage duration on some physical properties of date palm (cv. Stamaran)

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Abstract Most of the date fruits are processed traditionally in Iran. It becomes imperative to characterize the fruits with a view of understanding the properties that may affect the design of machines to handle their processing. The objectives of this study were to find the basic physical properties of date fruit at different storage time. Some physical properties of the Iranian Stamaran date variety were measured at the tamr stage of maturity for pitted dates during 6 months storage (25 °C of temperature and 75% of humidity). The results showed that length of the samples decreased by 8.31% from 39.21 to 35.95 mm, and no significant change for width and thickness. Mean mass and volume of the fruit did not change significantly. The projected area along length (P_L) did not change significantly, but projected areas along width (P_W) and along thickness (P_T) decreased by 4.26% from 647.41 to 619.8, and 8.32% from 666.89 to 611.43 mm^2, respectively. The fruit density, bulk density, porosity and sphericity did not change significantly. The geometric mean diameter and surface area decreased by 5.01%, from 25.53 to 24.25 mm, and 9.57%, from 2049.3 to 1853.1 mm^2, respectively. The mean coefficients of static friction increased significantly from 0.36 to 0.38, 0.33 to 0.35 and 0.42 to 0.45 on steel, galvanized iron, and plywood, respectively.

1. Introduction

Good harvest, handling and storage practices of agricultural materials and proper processing and converting these materials into food and feed products, require a deep understanding of their physical properties. Size and shape are most often used to describe agricultural materials. Shape and physical dimensions are important in sorting and sizing of fruits, and determining how many fruits can be placed in shipping containers or plastic bags of a given size. Quality differences in fruits,

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vegetables, grains and seeds can often be detected from variations of their densities. When fruits and vegetables are transported hydraulically, the design fluid velocities are related to both density and shape. Volumes and surface areas of solids must be known for accurate modeling of heat and mass transfer during cooling and drying. Porosity, which is the percentage of air space in particulate solids, affects the resistance to air flow through bulk solids. Airflow resistance, in turn, affects the performance of systems designed for forced convection drying of bulk solids and aeration systems used to control the temperature of stored bulk solids. Knowledge of frictional properties is needed for design of handling equipment (Stroshine, 1998).

Many researchers have conducted experiments to find the physical properties of various fruits and crops. Owolarafe and Shotonde (2004) determined some physical properties for okra fruit at a moisture content of 11.42% (wet basis). Akar and Aydin (2005) evaluated some physical properties of gumbo fruit varieties as functions of moisture content. Kashaninejad et al. (2006) determined some physical and aerodynamic properties of pistachio nut and its kernel as a function of moisture content in order to design processing equipment and facilities. Topuz et al. (2005) determined and compared several properties of four orange varieties. Also, Keramat Jahromi et al. (2008) obtained some physical properties of date (cv. Dairi). Tigist et al. (2012) found the effect of variety on yield, physical properties and storability of tomato under ambient conditions. Results showed that fruit weight and volume decreased significantly during 32 days storage. Al-Mughrabi et al. (1995) researched on the effect of storage duration on fruit quality of pomegranate and results showed that weight loss gradually increased with time in storage and the physical properties of the fruits were affected by the storage treatments. Corrales and Canche (2008) have studied the effect of low-temperature-storage on physical and physiological of pitahaya fruit changes. Results showed that pitahaya sensitivity to low temperatures was manifested in undesirable appearance of the fruit due to slight browning, loss of firmness, and increase in the production of ethanol and acetaldehyde in the pulp, as well as to the scarce development of pinkish-red coloring in the peel and increased respiration rate of the fruit.

Determination of physical properties of date palm at storage duration is necessary to develop optimal process technology of storage material. The objectives of this study were to determine physical property variations of date (cv. Stamaran) during the storage and to determine the role of storage period on various fruit physical property models.

2. Materials and methods

In this study, Stamaran cultivar date fruit samples (Fig. 1) were selected randomly from a local market in Ahwaz (an important city in date production located in the south of Iran). The fruits were placed into a clear PET pack and stored in a room conventional store (25 °C of temperature and 75% of humidity). Physical properties of the samples were measured after 0.5, 1, 3, and 6 months of storage.

In order to measure moisture content, the samples were dried in an oven at 105 °C. The weight loss on drying to a final constant weight was recorded as the moisture content (AOAC, 2005). Mass of individual fruit was determined using an electronic balance with an accuracy of 0.001 g.

Figure 1 Packed date samples (cv. Stamaran).

Fruit unit volume was measured by water displacement method. The fruit is forced into the water by means of a sinker rod or thread then reading of the scale with the fruit submerged minus the weight of the container and water is the weight of the displaced water which will be used in Eq. (1) to calculate volume (Fig. 2). Finally, fruit densities (ρ_f) were calculated by dividing unit mass to the unit volume (Mohsenin, 1986):

$$\text{Fruit unit volume (cm}^3) = \frac{\text{Weight of displaced water (g)}}{\text{Density of water (g cm}^{-3})} \tag{1}$$

where, density of water = 1 g cm^{-3}

Bulk density (ρ_b) was determined using the mass/volume relationship by filling an empty plastic container of predetermined volume and mass with fruits that were poured from a constant height, and weighed. Porosity (ε) was then calculated using Eq. (2), as the ratio of the differences in the fruit and bulk densities to the fruit density (Owolarafe et al., 2007):

$$\varepsilon = \left(\frac{\rho_f - \rho_b}{\rho_f}\right) \times 100 \tag{2}$$

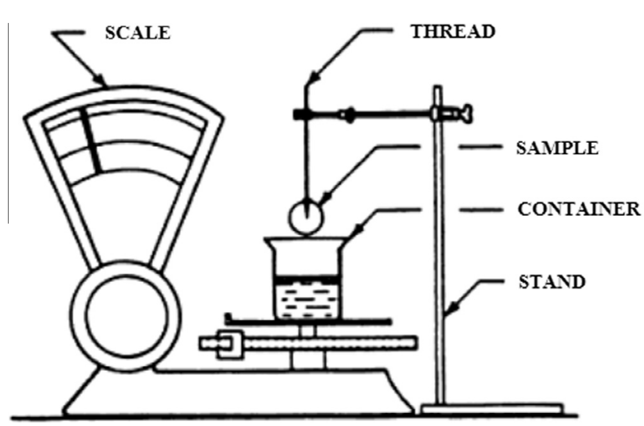

Figure 2 Platform scale for measurement of volume (Mohsenin, 1986).

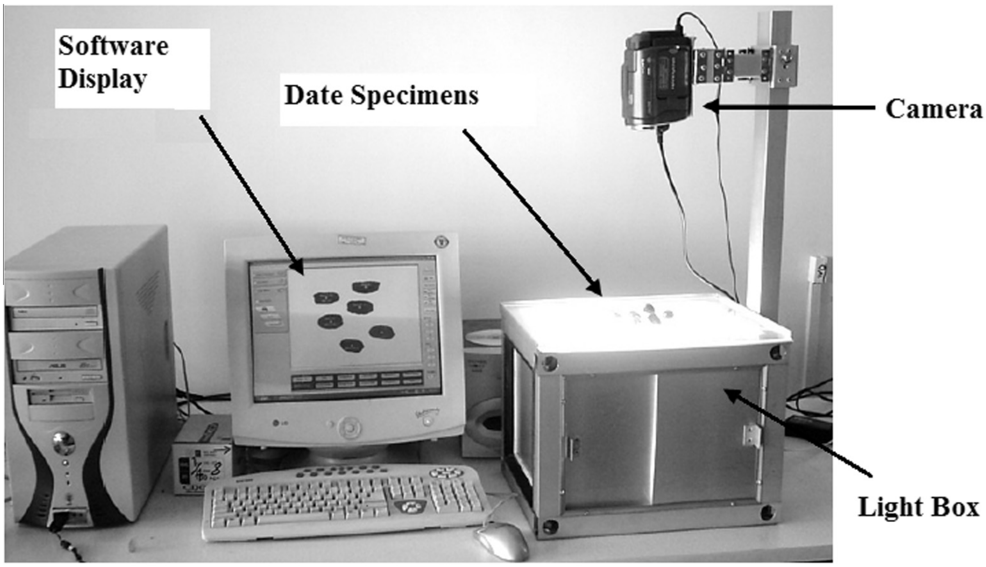

Figure 3 WinArea_UT_06 system (Keramat Jahromi et al., 2008).

Perpendicular dimensions and also projected areas were determined by the image processing method. In order to obtain dimensions and projected areas, WinArea_UT_06 system (Fig. 3) was used (Keramat Jahromi et al., 2008). By this system, captured images from the camera are transmitted to the computer card which works as an analog to digital converter. Digital images are then processed in the software to show dimension and projected area. This method has been used and reported by several researchers (Keramat Jahromi et al., 2008; Khoshnam et al., 2007). The L, W and T are perpendicular dimensions of date fruit, namely length, width and thickness, and P_L, P_W and P_T are the projected areas taken along these three mutually perpendicular axes (Fig. 4). Geometric mean diameter, D_g (g); sphericity index, ø; and surface areas, S (mm^2); were calculated by using the following equations (Kabas et al., 2006; Golmohammadi and Afkari-Sayyah, 2013):

$$D_g = (LWT)^{1/3} \quad (3)$$

$$\phi = \frac{D_g}{L} \quad (4)$$

$$S = \pi D_g^2 \quad (5)$$

The coefficients of static friction were obtained with respect to three different surfaces, namely galvanized iron, plywood and steel surfaces, by using an inclined plane apparatus (Dutta et al., 1998). The inclined plane was gently raised and the angle of inclination at which the sample started sliding was read off the protractor with sensitivity of one degree (Fig. 5). Tangent of the angle was reported as the coefficient of friction:

$$\mu = \tan\theta \quad (6)$$

where, μ is the coefficient of friction and θ is the tilt angle of the device. All the friction experiments were conducted in five replications for each surface.

The treatments were analyzed using a completely randomized design. To find the variation of all significant treatments during storage time, the means of variables were compared by a multiple ranges Duncan's test.

3. Results and discussion

Results of analysis of variance showed that the storage duration had a significant effect ($P < 0.05$) on the moisture content, length, geometric mean diameter, projected area along two dimensions (along width and thickness), surface area,

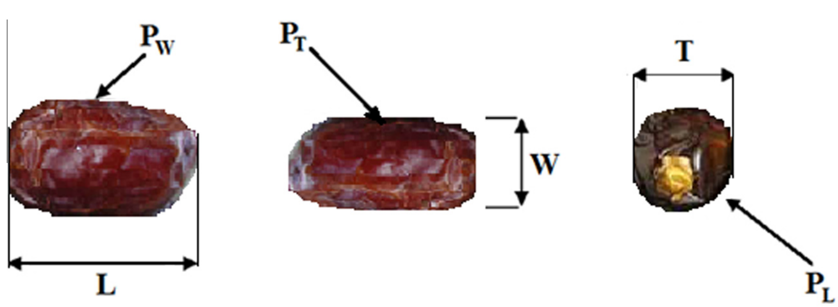

Figure 4 Three major dimensions and projected areas of date fruit.

Figure 5 Apparatus for measuring static coefficient of friction (Dutta et al., 1998).

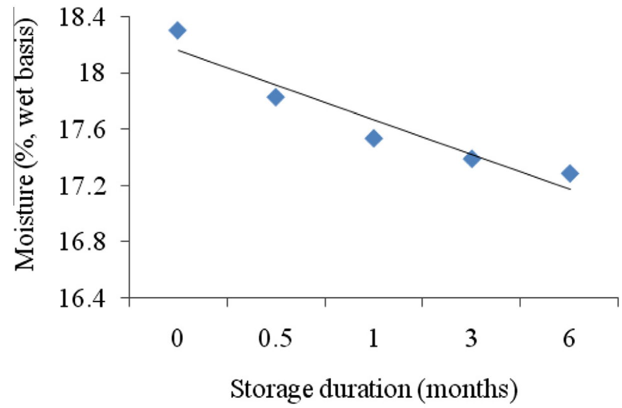

Figure 6 Effect of storage duration on moisture content.

porosity and all static coefficients of friction. Table 1 shows the result of compared mean of quality variables during storage time which was concluded from the Duncan's test ($P < 0.05$). A significant change with 5.57% reduction from 18.3% to 17.28% in moisture content was observed due to prolonged storage for 6 months (Fig. 6). This reduction was due to transpiration and water loses from fruit skin. When the fruit is harvested, it no longer depends on its root system. Therefore, water loss in fruit cannot be replaced from the root and moisture content will be reduced (Pantastico et al., 1975). This result confirm the findings of Yousef et al. (2012) who reported rapid moisture loss in mango fruit during storage and also our results are further in line with Johnston et al. (2001) in apple fruit.

No significant change was showed in mass of dry matter during storage which was 6.72–6.48 g ($P < 0.05$). Constant dry matter can be from no respiration or no microorganism activity on the storage sample. The same result was concluded by Al-Yahyai and Al-Kharus (2012) for working on date palm storage (during 10 months). Also during storage, there were no significant changes in dimensions (width and thickness) and volume of the date samples, but slight changes in length (Fig. 7) and geometric mean diameter (Fig. 10) were observed. This shows the date samples had slightly (not significant) shrunk during storage. This result is consistent with Al-Yahyai and Al-Kharus (2012) research for no volume change (no shrinkage) in date palm after 10 months storage. Also no significant changes were observed in sphericity which is related to the constant dimensions ratio of geometric mean diameter and length (Eq. 4). Dimensions, volume and sphericity variations were 39.21–35.95 mm in length, 22.05–21.11 mm in width, 19.33–18.9 mm in thickness, 8.11–7.59 cm^3 in volume and 0.652–0.676 in sphericity during storage. The importance of dimensions and volume is in determining the aperture size of machines, particularly in separation of materials as

Table 1 Physical property variations of date palm (cv. Stamaran) during 6 months of storage.

Properties		N	Storage period (month)				
			0	0.5	1	3	6
Moisture content (%, wet basis)		5	$18.3^{a} \pm 1.7$	$17.83^{b} \pm 1.5$	$17.53^{c} \pm 1.3$	$17.39^{cd} \pm 1.2$	$17.28^{d} \pm 1.1$
Length, L (mm)		100	$39.21^{a} \pm 2.3$	$38.01^{ab} \pm 1.4$	$36.99^{b} \pm 1.6$	$36.23^{b} \pm 2.8$	$35.95^{b} \pm 2.7$
Width, W (mm)		100	$22.05^{a} \pm 0.9$	$21.73^{a} \pm 0.8$	$21.44^{a} \pm 1.1$	$21.21^{a} \pm 0.8$	$21.11^{a} \pm 1.1$
Thickness, T (mm)		100	$19.33^{a} \pm 1.1$	$19.17^{a} \pm 1.3$	$19.06^{a} \pm 1.1$	$18.96^{a} \pm 1.2$	$18.9^{a} \pm 1.4$
Geometric mean diameter (mm)		100	$25.53^{a} \pm 1.2$	$25.09^{ab} \pm 1.1$	$24.67^{ab} \pm 0.9$	$24.41^{ab} \pm 0.8$	$24.25^{b} \pm 0.8$
Mass of dry matter (g)		100	$6.72^{a} \pm 0.7$	$6.59^{a} \pm 0.7$	$6.53^{a} \pm 0.6$	$6.5^{a} \pm 0.6$	$6.48^{a} \pm 0.5$
Volume (cm^3)		100	$8.11^{a} \pm 0.7$	$7.87^{a} \pm 0.6$	$7.74^{a} \pm 0.5$	$7.65^{a} \pm 0.5$	$7.59^{a} \pm 0.5$
Fruit density ($g\,cm^{-3}$)		100	$1.015^{a} \pm 0.07$	$1.019^{a} \pm 0.07$	$1.025^{a} \pm 0.08$	$1.029^{a} \pm 0.08$	$1.032^{a} \pm 0.09$
Bulk density ($g\,cm^{-3}$)		5	$0.51^{a} \pm 0.02$	$0.52^{a} \pm 0.02$	$0.54^{a} \pm 0.03$	$0.55^{a} \pm 0.03$	$0.56^{a} \pm 0.03$
Projected area along, L (mm^2)		100	$341.52^{a} \pm 28.2$	$338.69^{a} \pm 26.5$	$336.75^{a} \pm 25.1$	$334.98^{a} \pm 23.6$	$333.92^{a} \pm 21.7$
Projected area along, W (mm^2)		100	$647.41^{a} \pm 52.3$	$638.01^{ab} \pm 50.7$	$629.49^{bc} \pm 47.1$	$622.74^{c} \pm 45.9$	$619.80^{c} \pm 42.8$
Projected area along, T (mm^2)		100	$666.89^{a} \pm 54.6$	$646.48^{ab} \pm 52.1$	$629.13^{bc} \pm 49.3$	$616.2^{c} \pm 46.8$	$611.43^{c} \pm 44.7$
Surface area (mm^2)		100	$2049.3^{a} \pm 152.7$	$1980.8^{ab} \pm 144.2$	$1919.4^{ab} \pm 139.5$	$1879.3^{ab} \pm 131.1$	$1853.1^{b} \pm 127.6$
Sphericity (decimal)		100	$0.652^{a} \pm 0.02$	$0.661^{a} \pm 0.02$	$0.667^{a} \pm 0.03$	$0.672^{a} \pm 0.03$	$0.676^{a} \pm 0.02$
Porosity (%)		5	$49.73^{a} \pm 3.5$	$48.94^{a} \pm 2.9$	$47.29^{a} \pm 2.7$	$46.54^{a} \pm 2.6$	$45.71^{a} \pm 2.1$
Static coefficient of friction	Steel	5	$0.361^{b} \pm 0.02$	$0.37^{ab} \pm 0.02$	$0.376^{ab} \pm 0.02$	$0.38^{ab} \pm 0.02$	$0.383^{a} \pm 0.02$
	Galvanized iron	5	$0.33^{a} \pm 0.01$	$0.339^{ab} \pm 0.01$	$0.344^{ab} \pm 0.01$	$0.348^{a} \pm 0.01$	$0.351^{a} \pm 0.01$
	Plywood	5	$0.42^{b} \pm 0.02$	$0.432^{ab} \pm 0.02$	$0.438^{ab} \pm 0.02$	$0.443^{a} \pm 0.02$	$0.446^{a} \pm 0.02$

Means in each row followed by the same letter do not differ significantly ($P < 0.05$).

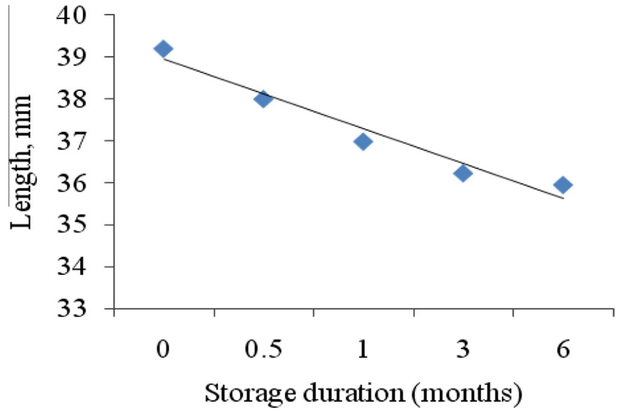

Figure 7 Effect of storage duration on length.

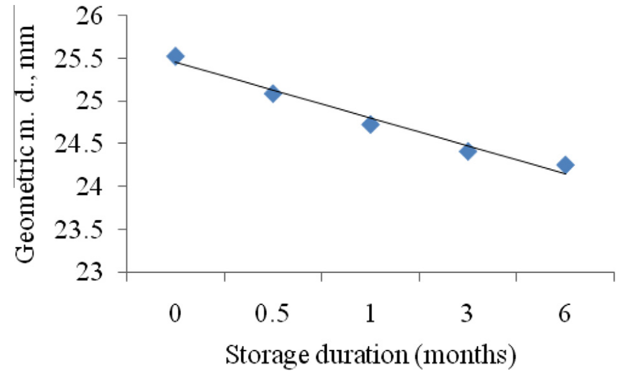

Figure 10 Effect of storage duration on geometric mean diameter.

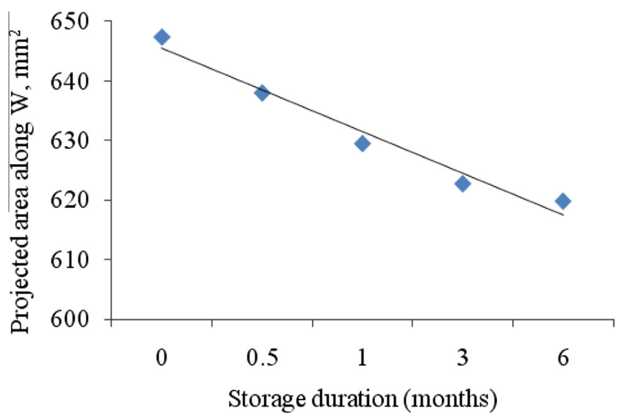

Figure 8 Effect of storage duration on projected areas along width.

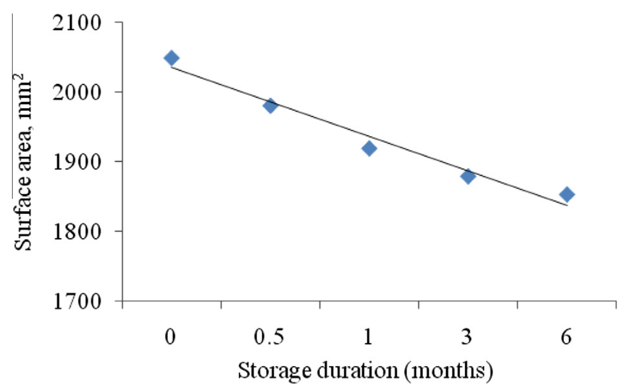

Figure 11 Effect of storage duration on surface area.

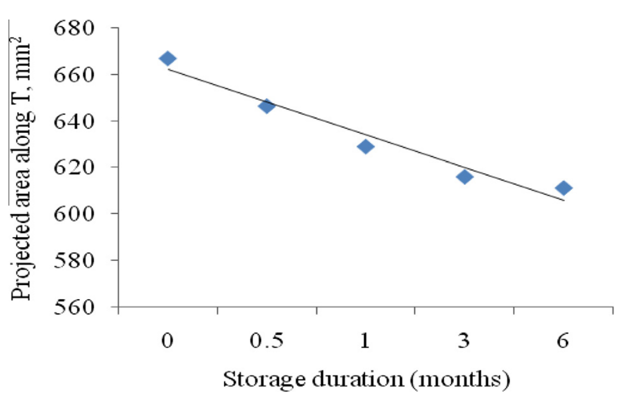

Figure 9 Effect of storage duration on projected areas along thickness.

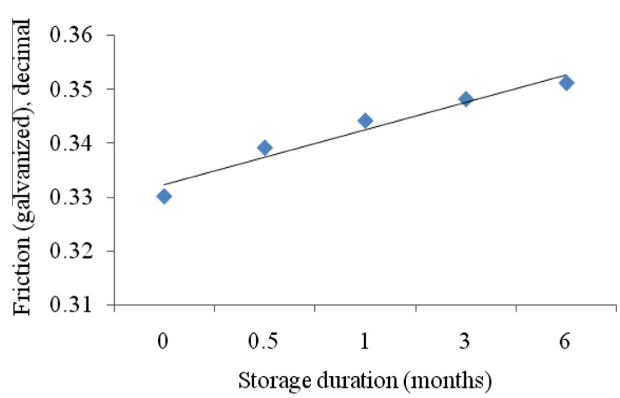

Figure 12 Effect of storage duration on coefficient of static friction on galvanized iron.

discussed by Mohsenin (1986). Almost constant dimensions and volume should be considered for designing separation machine components and parameters. The mean projected areas along length, width, and thickness were obtained as 341.52–333.92, 647.41–619.8 and 666.89–611.43 mm^2, respectively (Figs. 8 and 9). Only the projected area along length had no significant change (Table 1). It may be mainly due to low shrinkage in the fruits because of moisture loss during storage (Jha et al., 2006).

Fruit and bulk densities showed no significant change and found to be 1.015–1.032 and 0.51–0.56 g cm^{-3}, respectively. This was due to no change in mass and volume of the samples during the storage. Finally the porosity which was calculated from fruit and bulk densities (Eq. 2) did not change significantly (Table 1). Ismail et al. (2008) and Mohammadi et al. (2011)concluded the same results for constant density and porosity (no changed) of date during 6 months storage. A significant decrease was observed in surface area (9.57% from 2049.3 to 1853.1 mm^2). This can be due to slight changes in longitudinal dimension (Fig. 11). The obtained results are the same with those presented by Al-Mughrabi et al. (1995) working on pomegranate fruit and Jha et al. (2006) on mango fruit.

Values of mean coefficient of static friction increased on steel, galvanized iron and plywood surfaces from 0.36 to 0.38 (5.5%), 0.33 to 0.35 (6.06%) and 0.42 to 0.45 (7.14%), respectively (Figs. 12–14). Results of analysis showed that the surface of materials had a significant effect ($P < 0.05$) on the static coefficient of friction during 6 months storage of date palm.

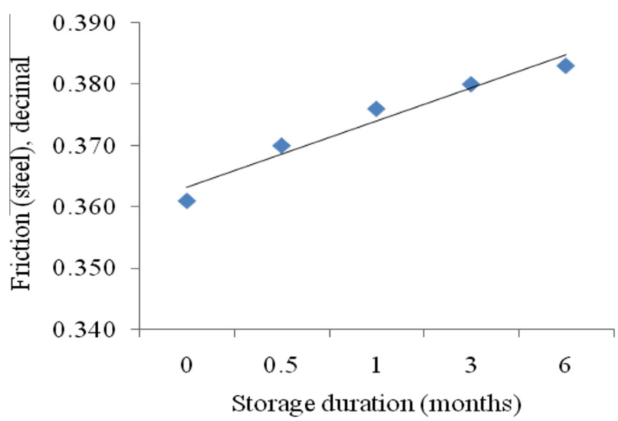

Figure 13 Effect of storage duration on coefficient of static friction on steel.

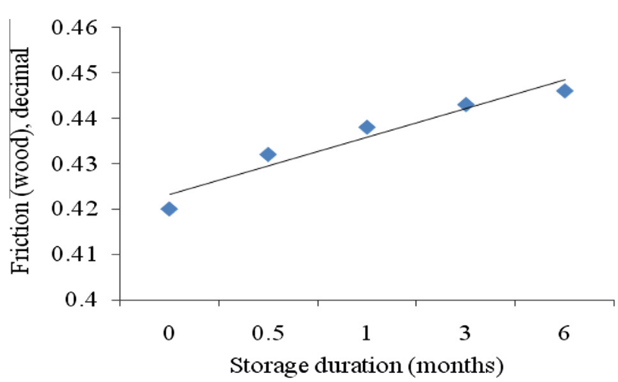

Figure 14 Effect of storage duration on coefficient of static friction on plywood.

The static coefficient of friction on steel was higher than that on galvanized iron and lower than that of plywood surface. The change of coefficients was due to the frictional property changes between the fruits and surface materials. It was reported that firmness of fruits during storage was reduced (Jha and Matsuoka, 2002; Kvikliene et al., 2006; Zhang et al., 2010). As a result, the surface of fruit becomes more involved. This result could be the reason of increasing in static coefficient friction of date palm during storage. These results confirm the findings of Puchalski and Brusewitz (2001) who reported that static coefficient friction of apple fruit increased during storage. Also an increase in static coefficient of friction might be from slight shrinkage of fruit skin during storage (Jha et al., 2006).

The relationships between physical properties and storage duration are presented in Table 2. As shown in this table, all changes in the physical properties were linear with increase in storage duration ($R^2 \geqslant 0.912$). These equations can be used to find the variations of Stamaran physical properties during storage in room conventional condition.

4. Conclusions

During 6 months storage of Stamaran cultivar date palm in a room conventional store (25 °C of temperature and 75% of humidity) following conclusions were found: Mass and volume of date palm did not change significantly. Dimensions were changed from 39.21 to 35.95 mm for length and no significant change for width, and thickness. Fruit density and bulk density did not change significantly. Porosity changed from 49.73 to 45.71 and no significant change for sphericity and surface area. The static coefficient of friction on steel surface changed from 0.36 to 0.38 and was higher than that on galvanized iron and lower than that of plywood surface. Decreasing moisture content and therefore, slight shrinkage was found to be the main reason for change in most of these physical properties. The measured physical properties of Stamaran date changed linear with time of storage in room conventional condition.

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Table 2 Relationships between physical properties and storage duration of date palm.

Property	Equation	R^2
Moisture content	$M_C = -0.248S + 18.41$	0.912
Length	$L = -0.829S + 39.76$	0.954
Projected areas along width	$P_W = -7.049S + 652.6$	0.968
Projected areas along thickness	$P_T = -14.12S + 676.3$	0.955
Geometric mean diameter	$D_g = -0.324S + 25.77$	0.974
Surface area	$S_a = -49.39S + 2084$	0.967
Coefficient of static friction on galvanized	$F_g = 0.005S + 0.327$	0.952
Coefficient of static friction on steel	$F_S = 0.005S + 0.357$	0.952
Coefficient of static friction on plywood	$F_W = 0.006S + 0.416$	0.934

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