Moisture dependent physical and mechanical properties of Mazafati date pit

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Abstract: Knowing the physical and mechanical properties is very important for automating the activities associated with the date pit. The objective of this study was to determine physical and mechanical properties of date pit of Mazafati cultivar as a function of moisture content. The physical properties of the pits were determined in the moisture content range of 7% to 40% (wb). The date pits was compressed along the width at 7% to 40% (wb) moisture contents to determine required force, deformation, and energy per volume (toughness) at rupture point. The results showed that the greatest length, width and thickness were 24.43 mm, 9.21 mm and 7.15 mm, respectively at 40% (wb) moisture content. With increase moisture from 7% to 40% (wb) the true density of pits decreased from 1380 to 1209 kg/m3, the bulk density decreased from 729 to 655 kg/m3, the porosity decreased from 42.60% to 46.31%, the emptying angle of repose increased from 31.04 °to 49.63 °, and the filling angle of repose increased from 29.82 ° to 42.79 °. The greatest friction coefficient of the date pits was obtained on plywood surface and the minimum value on iron surface at all moisture content levels. The greatest rupture force and toughness of the date pits were 1925.58 N and 5.34 mJ/mm^3, respectively at moisture content of 7% (wb). The pit rupture force and toughness decreased significantly ($P<0.01$) as the moisture content increased from 7% to 40% (wb). The greatest deformation at rupture point was 6.1 mm at moisture content of 30% (wb). Differences among the deformation at moisture content of 7%, 36% and 40% were not significant.

Keywords: date, pit, moisture content, Mazafati cultivar, physical properties, mechanical properties.

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1 Introduction

The date or date palm (*Phoenix dactyl lifera* L.) is a mono cotyledon plant of the family of the Palmaceae. The date is the most important crop in arid and semi-arid regions. Date is produced in about 35 countries worldwide. There are over 23.5 million trees and about 400 cultivars of date found in Iran, but only few of them are commercially important (Pezhman, 2002). At present, date is one of the most lucrative products in Iran. According to FAO reports, Iran with an annual production rate of 1,066,000 tons and an annual export of 68,837 tons, is the second largest producer and exporter of dates in the world (FAO, 2012). The date has a high nutritional value and is composed of the fruit flesh and pit. Figure 1 shows the date fruits and pits of Mazafati cultivar. The date pit weight is about 10% of the total weight of the fruit. The pit is composed of about 5%-7% moisture, 7%-10% protein, 10%-20% fiber, 55%-65% carbohydrate, 8%-12% oil, and 1%-2% ash (Besbes et al., 2004). Research works have shown that the date pit extracted oil has both saturated and unsaturated fatty acids (oleic, palmitic, linoleic, capric, myristic, lauric, etc.) that can be used in pharmaceuticals, cosmetics, and food industries as well as a source for biodiesel fuel (Ataye Salehi et al., 2011; Hojjati, 2008).

Figure 1 The Mazafati date fruits and pits

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Date pit is obtained as waste in many date processing plants such as syrup, sugar, citric acid, and alcohol as well as from waste dates during harvesting, transporting and packaging. Date pit was also obtained from replacement of pit with nuts. Date pit throws out as waste due to lack of mechanized equipment for processing. However, in some regions the pit is usually milled and used for animal feed or even making bread. In order to design and develop mechanized processing, handling and storage equipment for date pit, it is necessary to know about physical and mechanical properties of the pit such as length, width, thickness, mass, volume, true density, bulk density, geometric mean diameter, arithmetic mean diameter, porosity, repose angel, coefficient of friction, fracture force and fracture energy.

Size and shape of the pit are important factors for designing the handling systems and can be used to determine the minimum size limits of conveyors (Mohsenin, 1986). The size of the storage bin is affected by bulk density and true density is necessary parameter in the design of a pneumatic conveyor system. Porosity is an important parameter which is affected by the resistance to air flow through the bulk material bed and is also a necessary factor in the drying process. The friction coefficient affects the maximum inclination angle of conveyor and storage bin. Angle of repose is a useful parameter for calculation of belt conveyor width and for designing the shape of storage (Henderson and Perry, 1976; Mohsenin, 1986). Moisture content could affect the pit physical and mechanical properties (Sirisomboon et al., 2007; Fadavi et al., 2013). Mechanical properties such as rupture force, energy per volume (toughness), and deformation at rupture point were useful information in designing pit cracking machine (Pradhan et al., 2010; Fadavi et al., 2013).

The physical and mechanical properties have been determined by other researchers for many of agricultural products and food materials. The physical properties of hazelnuts and almond nut and its kernel were determined by Aydin (2002 and 2003). Some physical properties of Hacıhaliloglu apricot pit and its kernel were determined by Gezer et al. (2002). The dimensions and projected area of date fruit variety of Lasht were determined using image processing technique by Keramat Jahromi et al. (2007). Also, some physical properties of the date fruit Dairi cultivar were investigated by Keramat Jahromi et al. (2008). Hassan-Beygi et al. (2009) determined some physico-mechanical properties of Ordubad apricot fruits, pits and kernels. Some physical and mechanical properties of Ghermez-Shahrood apricot fruits, pits and kernels were determined by Ghaebi et al. (2010). Effect of moisture content on physical properties of different varieties of pistachio nut and kernel were determined by Razavi et al. (2007a,b,c). Fadavi et al. (2013) studied physical and mechanical properties of Syrjan region wild pistachio nut as a function of moisture content.

The literature survey revealed that there is limited published data concerning physical and mechanical properties of date pit. Therefore, the objective of this research was to determine moisture dependent physical and mechanical properties of date pit (Mazafati cultivar). This information can be used in the design and development of processing, handling, cracking, oil extraction and storage equipment.

2 Materials and methods

The Mazafati cultivar date pit was used in this study. The pits were supplied from a date sap producer in Bam, a city of Kerman province, the south east of Iran in 2014. Determination of physical and mechanical properties was done in the laboratory at Aboureihan College, University of Tehran, Pakdasht, Tehran, Iran. All foreign materials and damaged pits were manually excluded. The moisture content of pits was determined by using air convection oven method. The oven temperature was set at 105±3℃ and the samples weighed every 30 minute until the weight difference in two consecutive weighing was less than 0.2% of initial weight (Hassan-Beygi et al., 2009, 2010).

The date pits were divided into four portions labeled A, B, C, and D. The sample A was left at the initial stable storage moisture content (about 7%, wb), while B, C and D were soaked in distilled water at room temperature for 60, 120 and 180 hours, respectively in order to obtain pits at different moisture levels. After soaking, the pits were air dried to eliminate the free water from the sample surface (Oluwole et al., 2007; Fadavi et al., 2013). The sample was packed in sealed polyethylene bags and kept in a refrigerator for 72 h to enable the moisture to distribute uniformly throughout the samples. The moisture content of samples labeled B, C, and D were determined using air convection oven drying set at 105±3°C until the weight difference in two consecutive weighing was less than 0.2% of initial weight. The average values of three replications were reported as moisture content for each sample. The samples with different moisture contents were stored in refrigerator until the test. Before starting each test, the required quantities of sample were allowed to warm up to room temperature.

Three mutually perpendicular axes were defined, length (L, the longest intercept), width (W, the longest intercept normal to L) and thickness (T, the longest intercept normal to L and W) in order to determine the size of the pits (Figure 2). The dimensions of each sample were measured along the axes by a micrometer with an accuracy of ±0.01 mm. The mass of each date pit was measured by a digital balance with an accuracy of ±0.01 g. The dimensions and mass were measured for 70 samples per each moisture level.

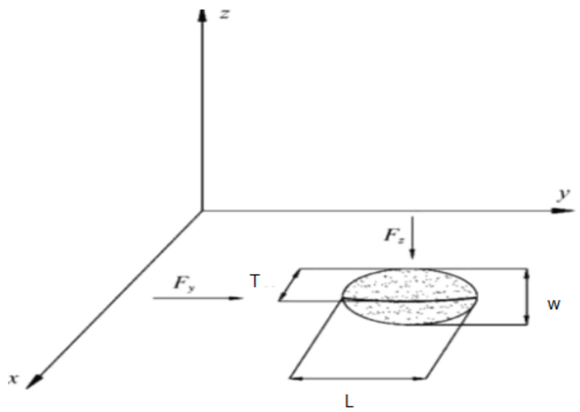

Figure 2 Defined dimensions for date pit

The actual volume of pit was determined by the water displacement technique (Mohsenin, 1986). The date pit with known mass were submerged using very thin metal wire into a cylinder containing known volume of water and the mass of water displaced by the samples were recorded. The volume of each fruit was calculated by Equation 1 (Mohsenin, 1986). The volumes of 20 samples were determined for the each pit moisture level.

$$V_w = \frac{m_w}{\rho_w} \tag{1}$$

where, V_w is volume of displaced water (m^3), m_w is mass of displaced water (kg) and ρ_w is density of water (kg/m^3).

The true density was calculated from the measured mass and volume by Equation 2 (Mohsenin, 1986):

$$\rho_t = \frac{m}{V_w} \tag{2}$$

where, ρ_t is true density (kg/m^3) and m is mass of the samples (kg).

The bulk density, ρ_b, was determined using the mass and volume relationship by filling an empty container of predetermined volume and mass. The date pit was dropped into the containers with volumes of 475 cm^3 from a height of 10 cm. The excess pits were removed by sweeping the surface of the container so that the samples were not compressed in any way. The samples bulk density values are mass of the samples within the containers divided by the volume of the containers. The bulk density was determined using five replications for each pit moisture level. Porosity of the samples, ε, was calculated using Equation 3 (Stroshine and Hamann, 1995; Mohsenin, 1986):

$$\varepsilon = \left(1 - \frac{\rho_b}{\rho_t}\right) \times 100 \tag{3}$$

The arithmetic mean diameter (D_a), geometric mean diameter (D_g), sphericity (φ) and surface area (S.A.) values were determined using Equations 4- Equation 8 (Mohsenin, 1986):

$$D_a = \frac{L + W + T}{3} \quad (4)$$

$$D_g = (L \times W \times T)^{1/3} \quad (5)$$

$$\phi = \frac{D_g}{L} \quad (6)$$

$$S.A. = \frac{\pi \times (W \times T)^{1/2} \times L^2}{2L - (W \times T)^{1/2}} \quad (7)$$

where, L is pit length (mm), W is pit width (mm), T is pit thickness (mm), D_a is pit arithmetic mean diameter (mm), D_g is pit geometric mean diameter (mm), φ is pit sphericity (dimensionless) and S.A. is pit surface area (mm^2).

The coefficient of static friction of the date pit was determined using inclined plane method on steel, galvanized steel and plywood sheet surfaces. The end of the friction surface (inclined plane) was attached to an endless screw. The date pits were arranged in a topless and bottomless cubic with dimensions of 20×20×10 cm^3 and the cubic placed on the surfaces. The cubic was slowly lifted up to avoid friction between the cubic and surfaces. The friction surfaces were gradually raised by the screw when the samples started sliding over the surfaces. Both horizontal and vertical height values were measured by a ruler and, using the tangent of that angle, the coefficient of static frication was calculated by Equation 8 (Suthar and Das, 1996; Fadavi et al., 2013). The experiments were replicated five (5) times for the each moisture level.

$$\mu_s = \tan\alpha \quad (8)$$

where, μ_s is coefficient of static friction, α is angle that the incline makes with the horizontal when sliding begins.

The filling and emptying repose angle of the date pits were measured using a device is shown in Figure 3. The device consists of two boxes, upper and lower boxes, with 700 mm length, 400 mm height, and 70 mm width. The upper box was filled with the sample pit. The material of upper box can flow down through a removable square port, the filling or static repose angle is the angle of surface with the horizontal at which the pits will stand when piled on the ground. The emptying or dynamic repose angle is the angle of surface of residual with horizontal in the upper box. The height of the sample pits were measured and the filling repose angle, θ_F, and emptying repose angle, θ_E, were calculated by Equations 9 and 10 (Sirisomboon et al., 2007):

$$\theta_F = \tan^{-1}\left(\frac{h}{a}\right) \quad (9)$$

$$\theta_E = \tan^{-1}\left(\frac{H}{A}\right) \quad (10)$$

where, H and h are the height (mm); and A and a (mm) are horizontal distance.

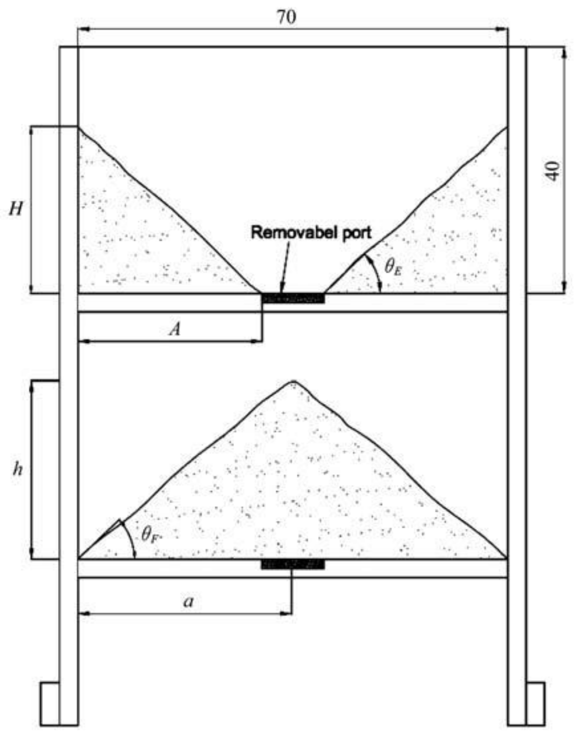

Figure 3 Device used to measure emptying and filling repose angle

The rupture force and deformation at rupture point of the date pit were determined using a biological material test (BMT) device (Figure 4), which was developed by Ghaebi et al. (2008). This device has three main components, which are a stable force and moving platform, a driving unit (AC electric motor, inverter and reduction unit) and a data acquisition (load cell with resolution of 0.5 N, indicator, PC interface and software).

Figure 4 Biological material test device developed by Ghaebi et al. (2008)

The date pit was placed on the fixed base of the BMT device and pressed along the sample width, Z, with a plate fixed on the load cell at 25 mm/min speed until the pit ruptured. It was assumed that rupture occurred at the bio-yield point that is the point in the force–deformation curve where there is a sudden decrease in force. As soon as the bio-yield point was detected, the compression was stopped. The force–deformation curve was determined for the date pit at different moisture content levels (7%, 30%, 36% and 40%). Energy absorbed, E_a, by the sample at rupture was determined by calculating the area under the force–deformation curve from Equation 11 (Hassan-Beygi et al., 2009, 2010; Braga et al., 1999; Mohsenin, 1986).

$$E_a = \frac{F_r \times D_r}{2} \qquad (11)$$

where, F_r is the rupture force (N) and D_r is the deformation at rupture point (mm).

Toughness, P, is expressed as the energy absorbed by the date pit up to rupture point per unit volume of the pit. This was calculated using Equation 12 (Hassan-Beygi et al., 2009; Olaniyan and Oje, 2002).

$$P = \frac{E_a}{V} \qquad (12)$$

where, E_a is the energy absorbed by the date pit (mJ) and V is the volume of the pit (mm^3), which can be estimated using Equation 13 (Vursavus and Ozguven, 2004).

$$V = \frac{\pi L}{16}\left(W + T\right)^2 \qquad (13)$$

where, L is the length (mm); W is the width (mm) and T is the thickness of pit (mm).

Spreadsheet software of Microsoft EXCEL 2007 and SAS were used to analyze the data. The data was statistically analyzed using the one factor completely randomized design to study the effects of four moisture contents on the rupture force, deformation at rupture point and toughness of the date pit under the compression load. Further, Duncan's multiple range tests was used to compare the means. Each experiment was replicated 10 times making a total of 40 date pits that were individually measured and tested.

3 Results and discussion

The variations of physical properties of the date pit with moisture content which were investigated in this study were as follows: length, width, thickness, arithmetic mean diameter, geometric mean diameter, mass, volume, sphericity, bulk density, true density, porosity, angle of repose, coefficient of friction and surface area. The investigated mechanical properties of the pit as a function of moisture content were: rupture force, deformation at rupture and toughness.

3.1 Dimensions

The effect of moisture content on the linear dimensions of the date pit is shown in Figure 5. The length, width and thickness of the date samples were increased linearly in the ranges of 20.17 to 24.43 mm, 7.76 to 9.26 mm, and 6.23 to 7.15 mm, respectively with increasing moisture content from 7% to 40% (wb). It is observed that the length, width and thickness of the pits increased about 21%, 19%, and 16%, respectively with moisture content. The increase in axial dimensions of the pits with moisture content could be attributed to filling of capillaries and voids upon absorption of moisture and subsequent swelling.

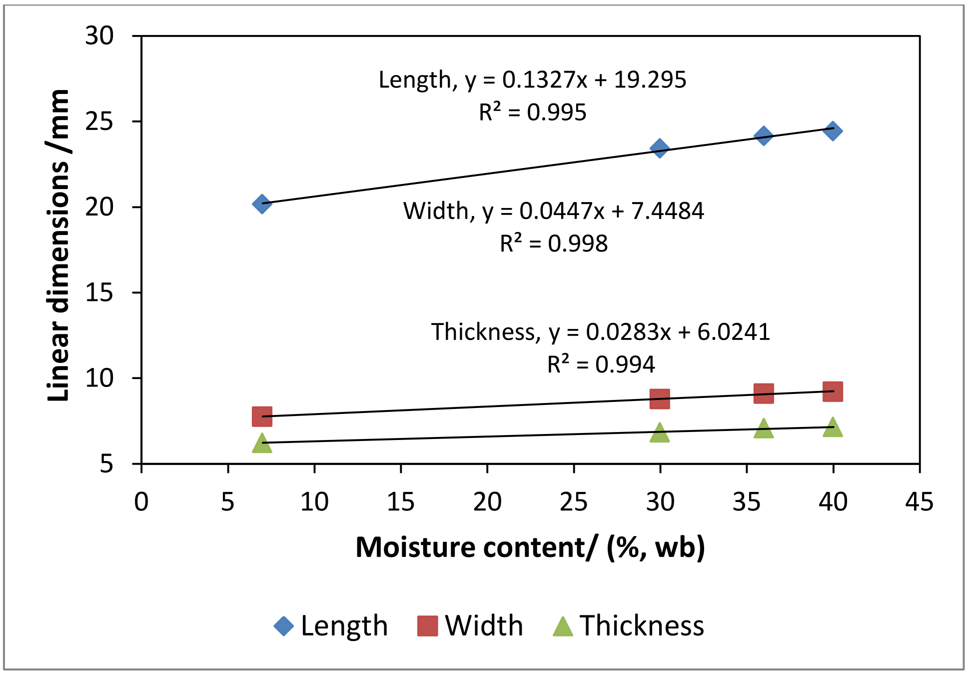

Figure 5 Effect of moisture content on the dimensions of date pit

Figure 6 shows the effect of moisture content on the mean diameters of the pit. The arithmetic mean diameter and geometric mean diameter of the pit were also linearly increased (about 19%) from 11.38 to13.59 mm and 9.85 to 11.68 mm, respectively with moisture content increasing in the range of 7% to 40% (wb).The geometric and arithmetic mean diameters of the pit sample were greater than values reported for wild pistachio nut (Fadavi et al., 2013) and smaller than values reported for Ourdubad apricot pit (Hassan-Beygi et al., 2009) and Jatropha nut (Pradhan et al., 2009).

Surface area of the date pit increased linearly from 267.38 to 373.9 mm^2 with increasing moisture content in the range of 7% to 40%. This increasing trend could be attributed to increase of the date dimensions with moisture content.

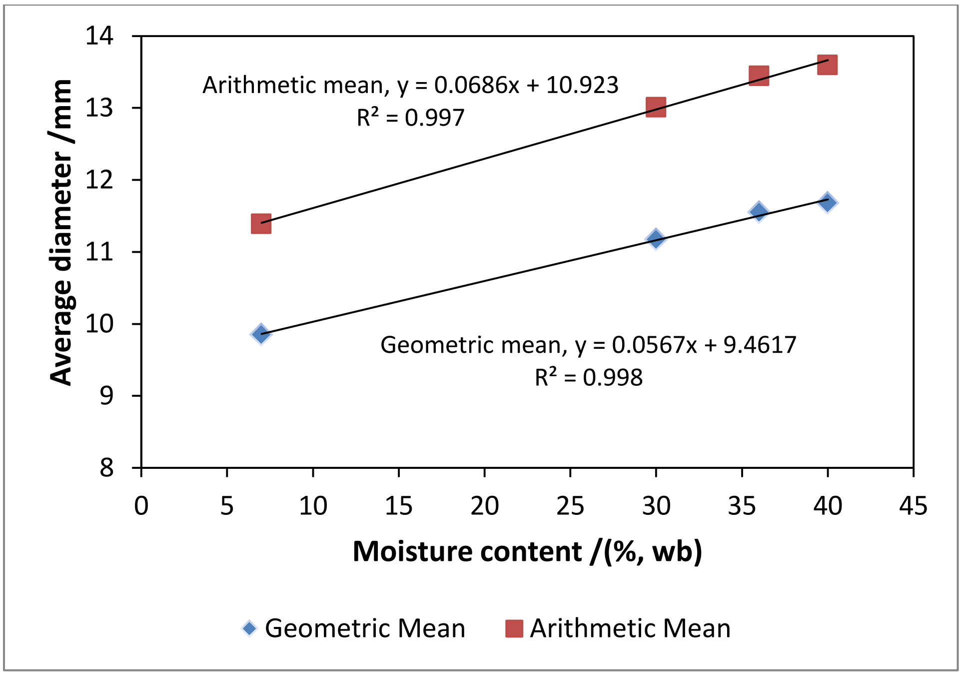

Figure 6 Effect of moisture content on the mean diameters of date pit

3.2 Mass and volume

Figure 7 shows the effect of moisture content on the mass and volume of the pit. The mass and volume of the pit were linearly increased from 0.78 to 1.13 g and 0.601 to 0.991 cm^3, respectively with moisture content increasing in the range of 7% to 40% (wb). It is observed that the mass and volume of the pits increased about 45% and 65%, respectively with moisture content. The increase in mass and volume with moisture content could be attributed to filling of capillaries and voids upon absorption of moisture and subsequent swelling. This indicates that the date mass and volume will be decreased considerably during the moisture desorption process. Similar trends have been reported for other agricultural products (Sonawane et al., 2014; Fadavi et al., 2013; Seifi et al., 2010).

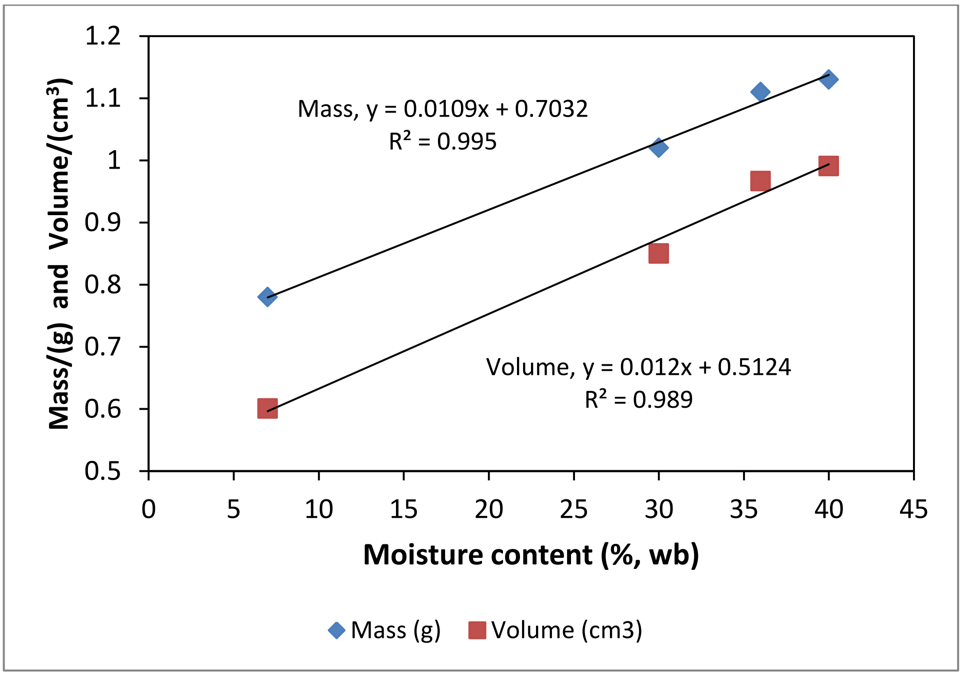

Figure 7 Effect of moisture content on the mass and volume of date pit

3.3 Sphericity

The impact of moisture content on the date sphericity is shown in Figure 8. The pit sphericity decreased from 0.5 to 0.48 with increasing moisture content in the range of 7% to 30%. However, further increase in moisture content did not change the pit sphericity. Considering the values of pit sphericity (0.5-0.48) it could be stated that the pit shape was far from sphere and near to cylindrical shape. The trend of reduction in sphericity with increasing moisture content was also observed for Syrjan wild pistachio nut. The sphericity reduced from 83% to 81% by increasing moisture content in the range of 5.5% to 14.14% (wb) (Fadavi et al., 2013). Seifi and Alimardani (2010) reported that the sphericity of two varieties of corn (Sc 704 and Dc 370) decreased with increasing moisture content in the range of 5% to 22%.

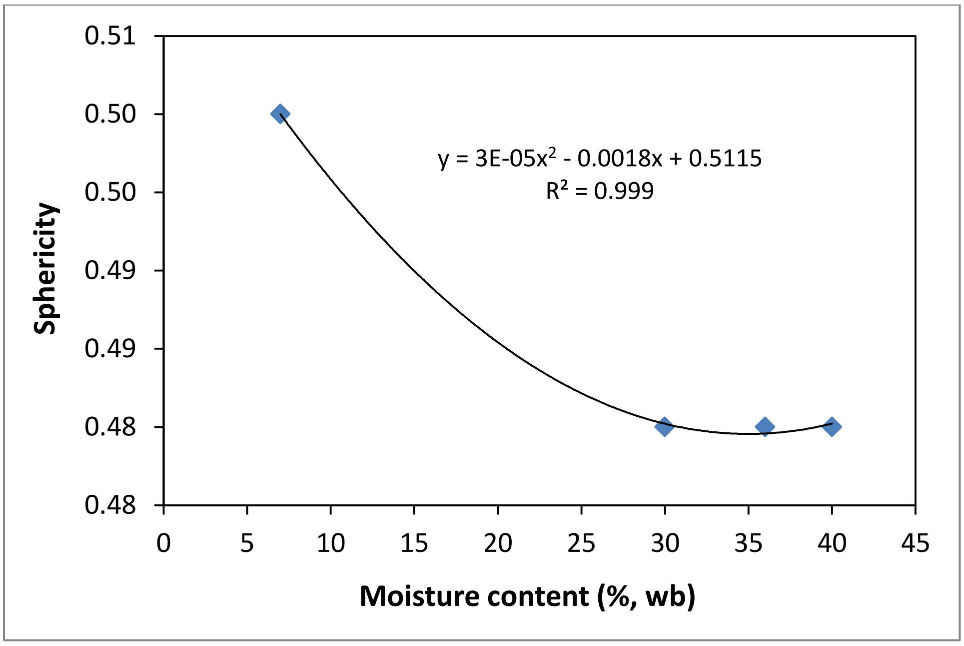

Figure 8 Effect of moisture content on the sphericity of date pit

3.4 Bulk and true densities

The pit bulk density decreased from 792 to 655 kg/m^3 with increasing moisture content as shown in Figure 9. With increasing moisture content of the pit the required space would be increased for the pit storage. The decreasing trend of bulk density with moisture content is also observed by other researchers (Fadavi et al., 2013; Seifi and Alimardani, 2010; Pradhan et al., 2009; Rezaiefar et al., 2008).

The true density of the pit decreased from 1380 to 1209 kg/m^3 with increasing moisture content (Figure 10). The decreasing trend of the pit true density with increase in moisture content could be attributed to more increase in the pit volume compared to the corresponding mass of the pit due to the adsorption of water. The results were in conformity with work reported by Dutta et al. (1988) for gram, Deshpande et al. (1993) for soybean, Seifi et al. (2010) for safflower grains and Fadavi et al. (2013) for wild pistachio nut.

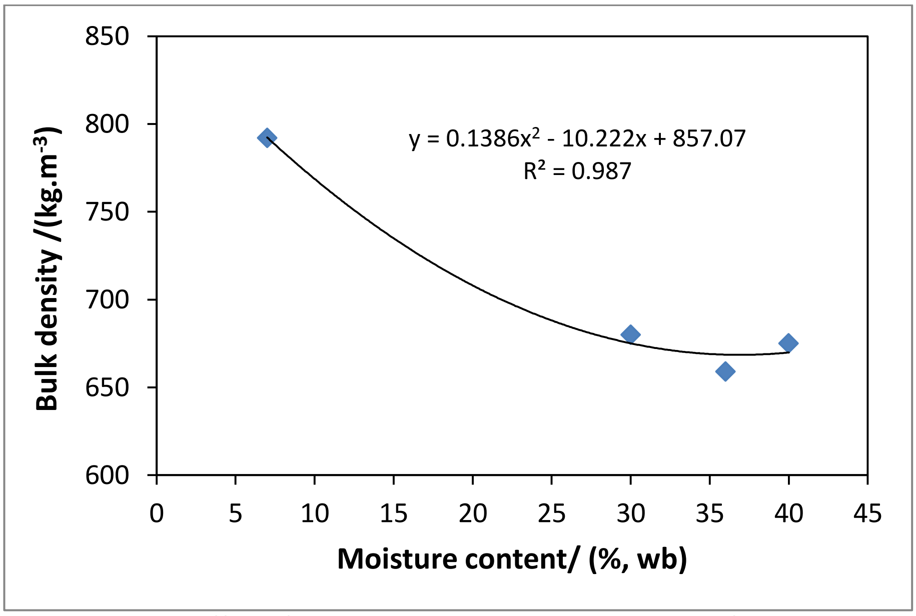

Figure 9 Effect of moisture content on the bulk density of date pit

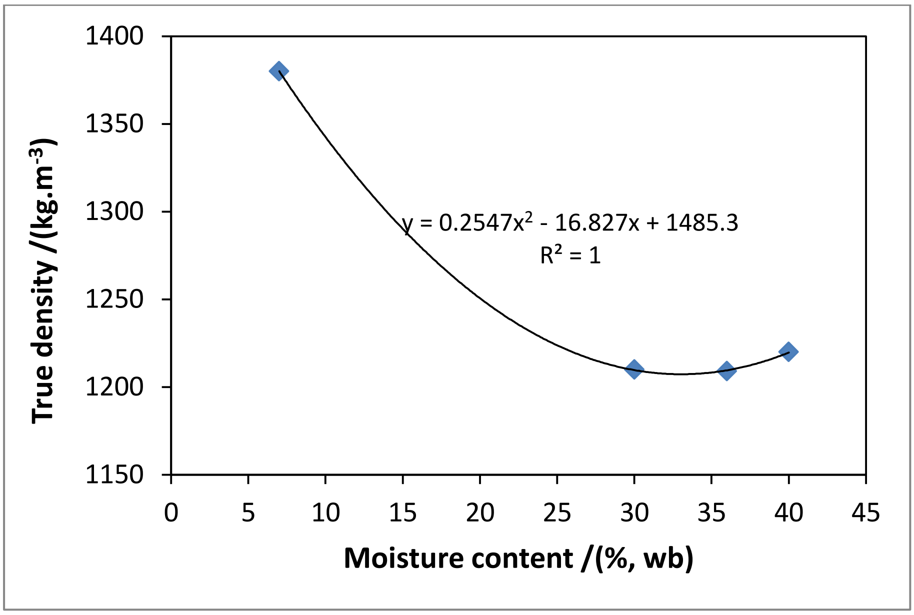

Figure 10 Effect of moisture content on the true density of date pit

3.5 Porosity

Porosity was calculated using the bulk density and true density by Equation 3. The impact of moisture content on the pit porosity was shown in Figure 11. The pit porosity was increased from 42.61% to 46.31% in the specified moisture levels. The porosity value is often needed in aeration and heat flow studies. As depicted from this figure with increasing moisture content from 7% to 40%, resistance to air flow was reduced. The increasing trend of the date porosity with moisture content was in conformity with work reported by Seifi and Alimardani (2010) for corn and Sonawane et al. (2014) for kokum seed.

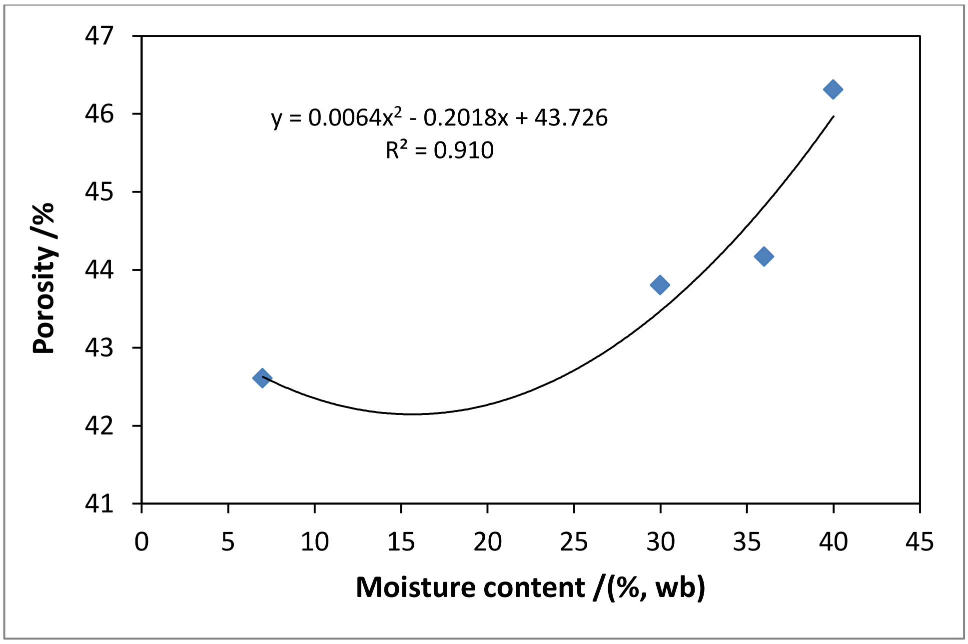

Figure 11 Effect of moisture content on the porosity of date pit

3.6 Angle of repose

Figure 12 shows the impact of moisture content on the pit angle of repose. The values are found to increase from 31.04 ° to 49.63 ° and 29.82 ° to 42.79 ° for emptying and filling repose of angle in the moisture range of 7%-40% (wb), respectively. These values implied the flow ability of the date pit decreased with increasing moisture content. The variation of angle of repose with moisture content could be attributed to the fact that the surface layer of moisture surrounding the particle holds the aggregate of pits together by the surface tension. Furthermore, the viscous surface of pit with more moisture content lead to the greater cohesion among the pits and therefore the angle of repose might be increased with moisture content. The greater angle of repose for emptying method than filling method could be attributed to adhesion between container wall and the date pit. The increase in repose angle with moisture content was also reported by other researchers (Sonawane et al., 2014; Fadavi et al., 2013; Seifi and Alimardani, 2010; Seifi et al., 2010).

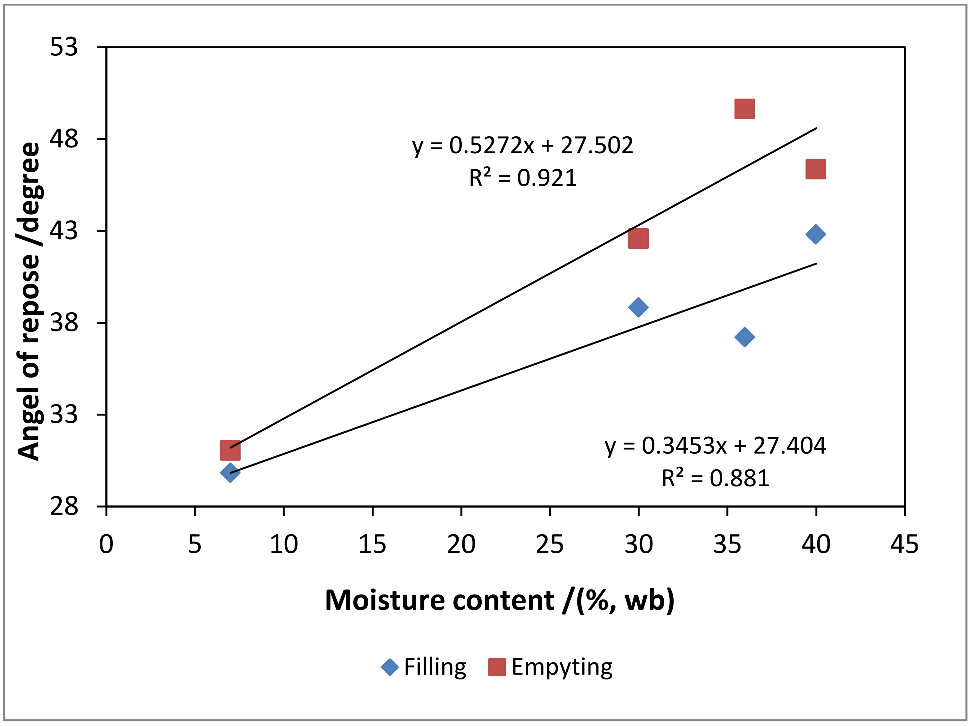

Figure 12 Effect of moisture content on the filling and emptying repose angle of pit

3.7 Coefficient of friction

Figure 13 depicts the effect of moisture content on the pit static coefficient of friction for different surfaces. As illustrated in Figure 13, the static coefficient of friction of pits on plywood, steel and galvanized steel sheets increased with moisture content in the ranges of 0.36 to 0.58, 0.33 to 0.59 and 0.27 to 0.59, respectively. The increasing trend of friction coefficient with moisture content might be contributed to increase in adhesive force and decrease of sphericity that made pits difficult to move on any surfaces. The static coefficient of friction of pits on the plywood was greater than that of other surfaces in the moisture content range of 7% to 36% and this could be attributed to higher adhesiveness of this surface. Other researchers have found similar trend for increasing static coefficient of friction with moisture content (Fadavi et al., 2013; Gezer et al., 2002; Razavi et al., 2007c).

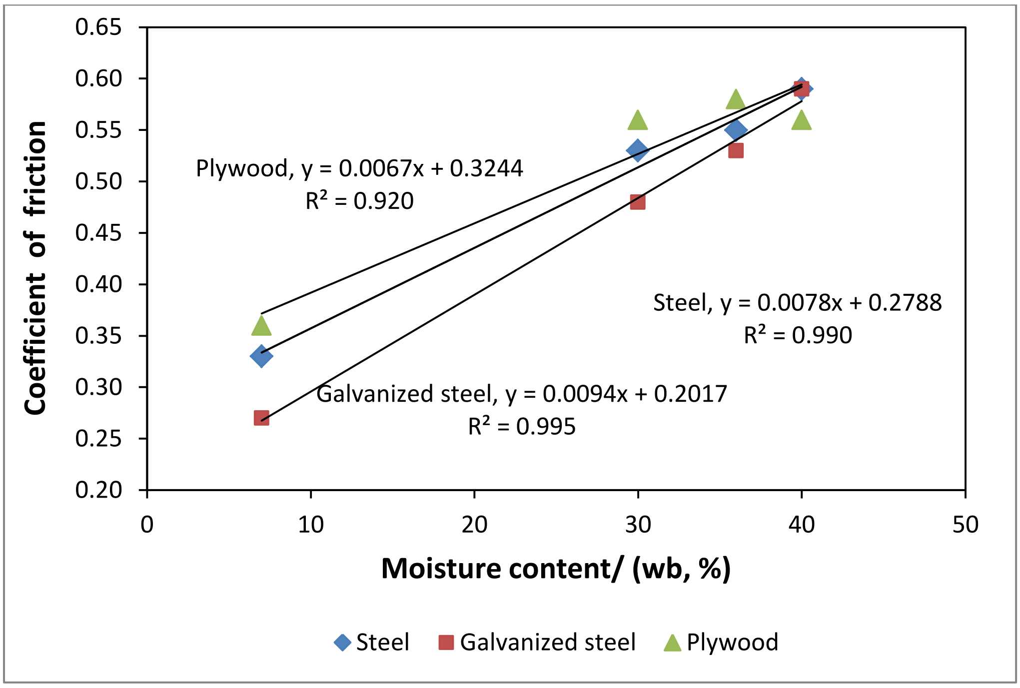

Figure 13 Effect of moisture content on the pit static coefficient of friction

3.8 Rupture force

Statistical analysis (ANOVA) revealed that the effect of moisture content was significant (P<0.01) on the date pit rupture force. Similar results were reported by Hassan-Beygi et al. (2009) for Ordubad apricot pit, Ghaebi et al. (2010) for Ghermez-Shahrood apricot pit and Fadavi et al. (2013) for wild pistachio nut. The effect of moisture content on the pit rupture force is shown in Figure 14. The required force to initiate pit rupture along the width (Z-axis) decreased significantly (P<0.01) from 1925.58 to 951.08 N as the moisture content increased from 7% to 40% (wb). However, the differences between rupture forces of the pit at moisture content of 7% with 30% as well as 36% with 40% were not significant. At greater moisture contents, the pit became soft and weak, and this was responsible for the reduction of rupture force. Reducing the rupture force with increasing moisture content was reported by Fadavi et al. (2013) for wild pistachio nut along the length from 370.46 to 222.15 N as the moisture content increased from 0.045 to 0.188 (db). Hassan-Beygi et al. (2009) also reported that the rupture force for Ordubad apricot pit along the width decreased significantly from 511.11 to 163.51 N as the moisture content increased from 0.085 to 0.3 (db). Generally, it can be stated that soaking the date pits for 180 hours in the water could reduce the rupture force during the process of crushing.

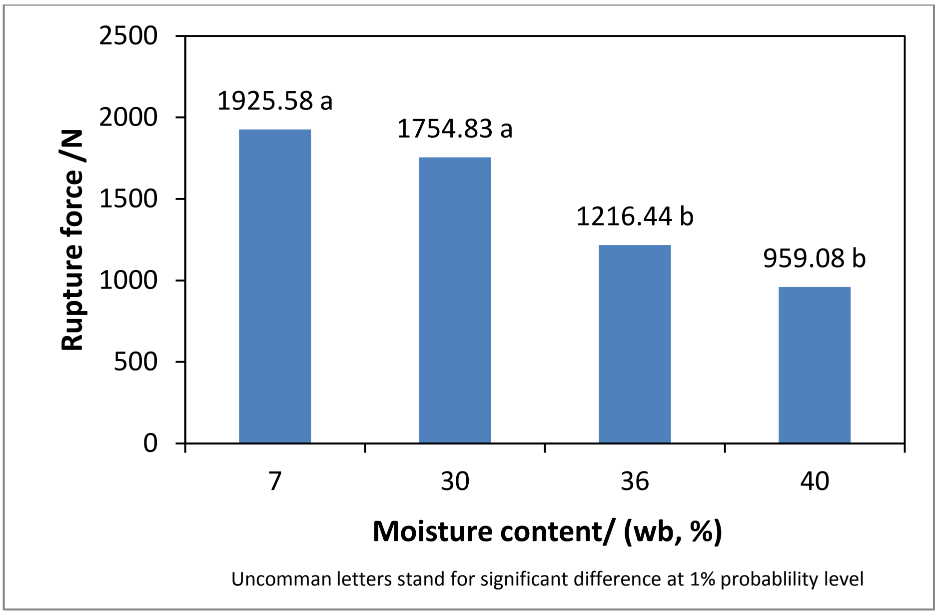

Figure 14 Effect of moisture content on the pit rupture force

3.9 Deformation at rupture point

Statistical analysis revealed that the effect of moisture content on deformation at rupture was significant ($P<0.01$). Similar results were reported by Ghaebi et al. (2010) for Ghermez-Shahrood variety apricot pit. Figure 15 shows the effect of moisture content on the deformation at rupture of pit. The deformation at rupture along the width (Z-axis) increased significantly ($P<0.01$) from 4.01 to 6.1 mm as the moisture content increased from 7% to 30% (wb). With further increase in moisture content, from 30% to 40%, the deformation decreased significantly from 6.1 mm to 3.87 mm. However, differences among deformation at moisture content of 7%, 36% and 40% were not significant. Fadavi et al. (2013) reported that the deformation variations of wild pistachio nut along the width were not significant with increase in moisture content from 0.045 to 0.188 (db).

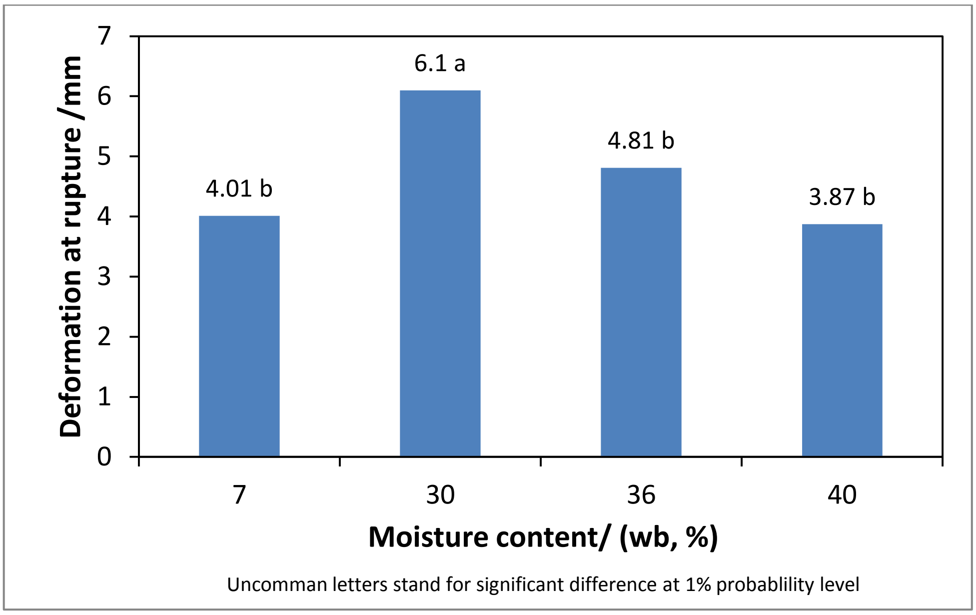

Figure 15 Effect of moisture content on the pit deformation at rupture

3.10 Toughness

Statistical analysis showed that the effect of moisture content on the date pit toughness was significant ($P<0.01$). Figure 16 shows the effect of moisture content on the date pit toughness. According to Duncan's multiple range test the toughness of pit along the width (Z–axis) decreased significantly from 5.34 to 1.58 mJ/mm^3 with increase in moisture from 7% to 40% (wb). However, differences between average values of the pit toughness were not significant at moisture content of 7% and 30% (db). The reason for decreasing the pit toughness with increasing moisture content could be attributed to the fact that the rupture force of pit decreased with increasing moisture content. Reducing the toughness with increasing moisture content was reported by Fadavi et al. (2013) for wild pistachio nut along the length and by Hassan-Beygi et al. (2009) for Ordubad apricot pit along the width. Generally, it can be stated that the minimum required energy per volume for the pit cracking could be achieved by soaking the date pits within the water for 180 hours.

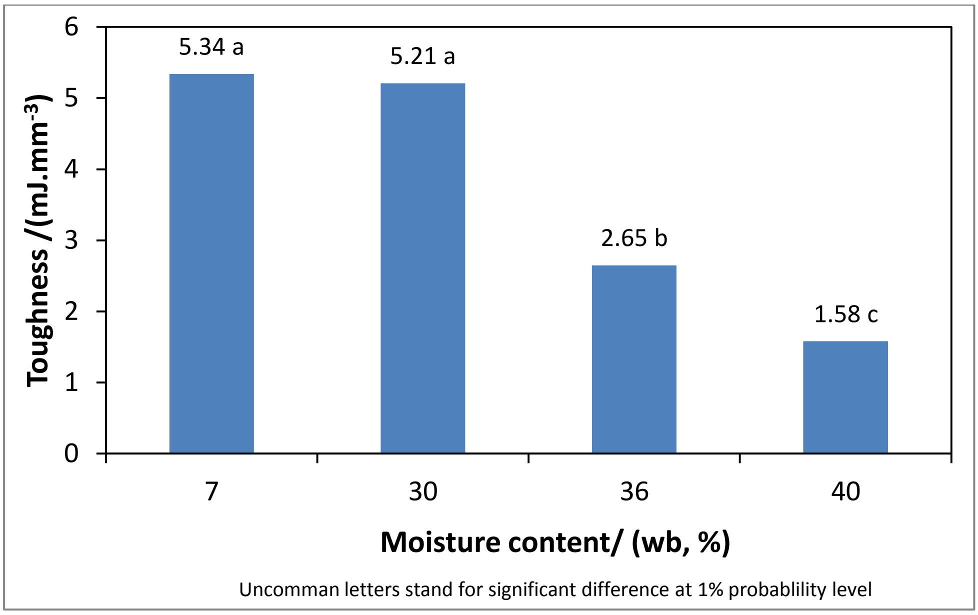

Figure 16 Effect of moisture content on the pit toughness

4 Conclusions

1. The average values of length, width, thickness, volume and mass of the date pit increased linearly in the range of 20.17-24.43 mm, 7.76-9.26 mm,6.23-7.15 mm, 0.78-1.13 g and 0.601-0.991 cm^3, respectively with increasing moisture content from 7% to 40% (wb).
2. The sphericity of pit showed that the pit shape was far from sphere and near to cylindrical shape.
3. The pit bulk and true densities had decreasing trend with moisture content but the pit porosity had increasing trend with moisture content.
4. The pit emptying and filling angle of repose increased with increasing moisture content.
5. The pit static coefficient of friction was increased with moisture content on steel, galvanized steel and plywood surfaces.
6. The rupture force and toughness of pit along the width (Z-axis) decreased significantly with increasing moisture content. Therefore, the required energy per volume for cracking the pit decreased with increasing soaking time of the pits in the water.

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