Some Physical and Mechanical Properties of Loquat (*Eriobotrya japonica*) Fruit With Change of Moisture Content

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ABSTRACT

Sukary variety of loquat (*Eriobotrya Japonica, Rosaceae*) fruit was analyzed for several physical and mechanical properties with moisture content change from 84.62 to 22.71% (w.b.). The results indicated that, decreasing the loquat moisture content from 84.62 to 22.71% (w.b.), decreases fruit length, width, geometric mean diameter, surface area, sphericity, volume, weigh, fruit density and bulk density. Coefficient of static friction on fiberglass, steel and plywood surfaces was found to decrease linearly as moisture content decreased. Also, the highest coefficient of static friction was found on the fiberglass surface. Lowering the moisture content decreased the absorbed energy and toughness from 19.32 to 14.65 N.mm and from 0.405 to 0.349 mJ/cm^3, respectively and increase hardness from 8.52 to 16.81 N/mm.

***Keywords:** loquat fruit, physical and mechanical properties, absorbed energy, toughness, hardness.*

INTRODUCTION

The loquat (*Eriobotrya japonica, Rosaceae*) is a small, evergreen tree native to Central-Eastern China, introduced into Japan in very early times. In Europe, it was planted in the 18th century. It is grown both as an ornamental and for its fruit. The total world crop was estimated as 550,000 t (Lin, 2007). It has been cultivated extensively in the Mediterranean basin (Spain, Algeria, Turkey and Italy), Japan and China, to some extent in India and Brazil, and in a more limited fashion in Chile and the United States. Spain is the largest producer (40,000 t) and exporter of loquats, follow by Algeria (22,000 t) and Japan (18,000 t), (Llacer *et al.* 1994). The tree grows best in a subtropical to warm-temperate climate. It does well on a variety of soils but does best on clay loams with good drainage.

The fruits, which are borne in large loose clusters, are round or oval (pear shape) and in the best cultivars may reach a length of 7 cm. They vary in colour from pale yellow to deep orange and have a tough plum like skin, (Fig.1). The flesh is white to orange, firm or soft, juicy, and flavourful. Brown, smooth seeds (1- 4) are commonly found in each fruit. The seeds comprise about 20 to 30% of the weight of the whole fruit. Loquats are consumed largely as fresh fruit, although small amounts are used in jams, jellies, syrups, and pies. For the fresh market, loquats should not be picked before full maturity, otherwise they are too acidic. If properly handled, they can be shipped to distant markets. (Shaw 1980).

Generally, the loquat tree blooms in the autumn with fruits ripening in early spring (March.-April). They are normally pollinated by bees, but some cultivars such as 'Golden Yellow' from India is not self-fertile, and others such as 'Advance' and 'Tanaka' are partially self-fertile. It has been

Fig. 1: Loquat fruit (*Eriobotrya japonica***)**

observed that cross-pollination generally results in 10 to 17% more than the production of over self-pollination. A list of the important cultivars are: 'Advance', 'Algerie', 'Akko 13', 'Champagne', 'Magdall', 'Premier', 'Saint Michel', 'Tanaka', and 'Thales' (syn. 'Gold Nugget'), (Pathak & Gautam 1990).

In Egypt, the loquat tree grows well and it is not widely known. It is mainly cultivated at home gardens. In 2007, the total estimated area of the loquat was about 290 Feddan, with production of 1273 t. The cultivars grown included "El-Sukary, Advance, Premiere, and Tale victoria", (Leuven, 2007).

Physical properties of fruit are important in designing and fabricating equipment and structures for handling, transporting, processing and storage, and also for assessing quality (Khoshnam *et al.* 2007). Fruits are often graded by size, but it may be more economical to develop a machine which grades by weight and density. Sizing by a weighing mechanism is recommended for the irregular shaped products (Khoshnam *et al.* 2007). Among these physical characteristics, mass, volume and projected area are the most important ones in determining sizing systems (Khodabandehloo, 1999).

Mechanical properties of the tissue determine the susceptibility to mechanical damage that can occur during harvest, transport and storage and that eventually leads to a profound reduction in commercial value (Oey *et al.*, 2007). Mechanical properties such as failure stress and strain as well as modulus of elasticity can also be used to evaluate the behaviour of the fruits mechanically under the static loading. Firmness or hardness is another important attribute of fruits and it is often used for fruit quality assessment (Vursavus *et al.*, 2006).

The interest in loquat fruit in Egypt has been increasing year by year. The main problem is that the crop loss during transportation after harvest because of vulnerable nature of loquat fruits.

Many studies have been conducted on the physico-mechanical and chemical properties of different fruit species, such as kiwifruit (Celik *et al.*, 2007), orange (Topuz *et al.*, 2004), sweet cherry (Vursavus *et al.*, 2006). However, to the best of our knowledge, no study concerning physical and mechanical properties as affected by moisture content of loquat has been performed in the literature. Therefore, the present research aimed to investigate the physical and mechanical properties of the loquat fruits at a range of moisture content varying from 84.62 to 22.71 % (w.b).

MATERIALS AND METHODS

Sukary variety of loquat fruits, grown in private orchard, located at West of Alexandria, Alexandria governorate, Egypt was used in this study. In 2011 harvest season, 100 fruits were randomly harvested carefully by hand at their commercial maturity stage and transferred to the laboratory in cooled polythene bags to reduce water loss during transport. The fruits were cleaned to remove all foreign matters such as dust, dirt and chaff as well as immature and damage fruits. The samples were kept at room temperature for two days. Moisture content was immediately determined on arrival. All experiments were carried out at room temperature of 25°±3°C. The fruits were divided into five batches in order to obtain five moisture levels for the experiments. The moisture of fruit samples was determined at five days intervals after harvesting. The water content of the fruits after harvesting was 84.62% (w.b) on the second, third fourth and fifth day, it was fallen down to 72.03, 52.13, 36.43 and 22.71% (w.b.), respectively. Moisture content was determined by a standard method, and the following formula was used for calculating:

$$Mc\ (W.b.) = (W_t - W_d)/W_t \times 100 = W_w/W_t \times 100 \quad (1)$$

Where W_t is the total fruit weight before drying process (g), W_d is the weight of the dried fruit (g), W_w is the weight of water removed ($W_w = W_t - W_d$) (g), and Mc is the fruit moisture content in wet basis (%).

Physical and mechanical properties of fruits were determined by the following methods:

Fruit length (L, mm), and width (*w*, mm) were measured using a digital caliper gauge with a sensitivity of 0.01 mm.

The aspect ratio (γ_a, %) of fruit was calculated by using the following equation (Omobuwajo *et al.*, 2000):

$$\gamma_a = (w/L) \times 100 \quad (2)$$

Geometric mean diameter (d_g, mm) and sphericity (ϕ, %) of fruit were calculated by using the following equations (Mohsenin, 1986).

$$\delta_g = (L \cdot w^2)^{1/3} \quad (3)$$

$$\phi = (d_g / L) \times 100 \quad (4)$$

The surface area (S, cm^2) of the fruit was calculated from the relationship given by Baryeh, (2001).

$S = \pi \cdot \delta_g^2$ .... (5)

Projected area (A, cm^2) of the loquats was determined from pictures taken by a digital camera (Kodak EZ200, 6.0 Mpixels)), and then comparing the reference area to a sample area using the image tool for windows (v.3) software. Projected area was divided into length projected area (A_L) and width projected area (A_w).

Fruit weight (W, g) was measured using a digital balance with a sensitivity of 0.001 g.

Fruit volume (V, cm^3) and true density (r_f, kg/m^3) were determined using the liquid displacement method (Mohsenin, 1986).

Bulk density (r_b, kg/m^3) was determined with a weigh per hectoliter tester, which was calibrated in kg/cm^3 (Deshpande *et al*, 1993).

Density ratio (g_d., %) is the ratio of bulk density to true density expressed as percentage (Omobuwajo *et al*., 2000).

$\gamma_d = (\rho_b / \rho_f) \times 100$ .... (6)

The coefficients of static friction (m_s) on three different frictional surfaces (steel, plywood and fiberglass) were measured for loquat fruits using the inclined plate method, (Fig. 2). A topless and bottomless cartoon box was filled with a sample of about 7.5 kg and was placed on an adjustable inclined plate in contact with the frictional surface. The frictional surface was raised gradually until the sample just started to slide down and the tilt angle (a) was read from a graduated scale (Dutta *et al*., 1988). The friction test was repeated five times. The coefficient of static friction was calculated from the following equation:

$\mu_s = \tan \alpha$ .... (7)

The rupture properties of the loquat fruits were determined by quasi-static loading device (Turgut *et al*., 1998). The device (Fig. 3) consists of three main units. A load cell connected to a stationary cylindrical plunger with 8 mm diameter. A plate mounted to a driving unit and a PC equipped with DAS software. A half- one fruit was placed on the plate and the plate moved up with a fixed speed of 25 mm/min compressing the sample until it ruptures. The load cell sensed the force applied to the sample which increased with time and transmitted the data to the DAS software. The test was re-

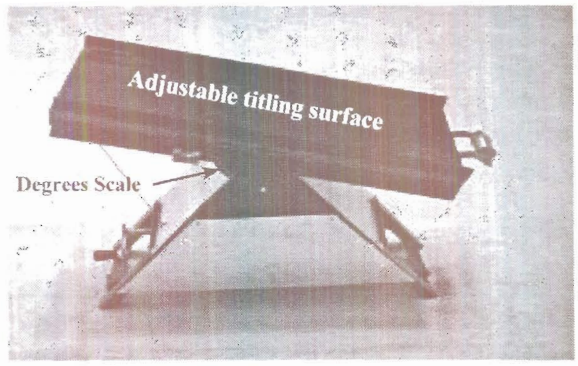

Fig. 2: The apparatus used for static coefficient of friction determination

peated ten times. From the fixed loading speed and time of the deformation, which occurred during the loading (Altuntas & Yildiz, 2007).

The absorbed energy (E, N.mm) during the loading up to rupture was calculated from the area under the load deformation curve (Mohsenin, 1986), using the following equation:

$E = \frac{1}{2}\ (Fr \cdot Dr)$ .... (8)

Where, Fr is the rupture force (N), and Dr is the deformation at rupture (mm).

Toughness (P, mJ/cm^3) is the ratio of absorbed energy (E) by the fruit up to the rupture point to the fruit volume (V). It was calculated from the following equation (Gupta & Das, 2000):

$P = E / V$ .... (9)

Hardness (H, N/mm) was determined by dividing the rupture force (Fr) to deformation at rupture (Dr), (Sirisomboon *et al*., 2007), as follows:

$H = Fr / Dr$ .... (10)

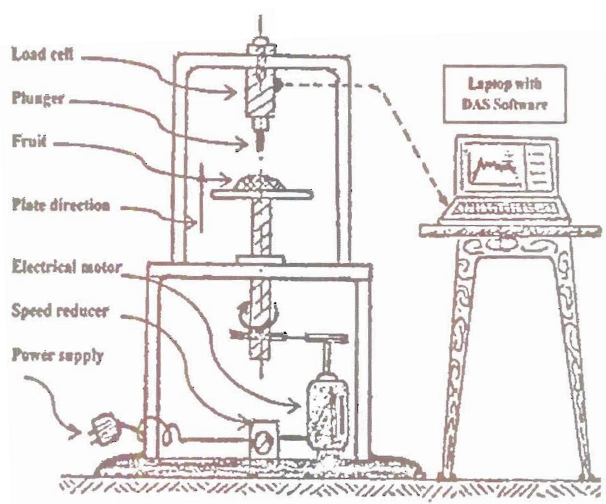

Fig. 3: Schematic drawing setup for measuring the ruptures properties

RESULTS AND DISCUSSIONS

The results of some physical and mechanical parameters of loquat fruits (Sukary variety) after harvesting (the mean values of 100 fruit samples) are shown in Table (1).

Table 1: Some physical and mechanical properties of loquat fruits at harvest.

Properties	Value (mean ± SD)
Physical	
Moisture, Mc, (w.b %)	83.35 ± 2.3
Fruit length, L, (mm)	42.16 ± 5.63
Fruit width, *w*, (mm)	30.52 ± 4.13
Aspect ratio, g_a, (%)	72.39 ± 5.21
Fruit weight, W, (gr)	36.21 ± 8.40
Fruit volume, V, (cm^3)	35.86 ± 6.11
True density, r_f, (kg/m^3)	1009.7 ± 13.04
Bulk density, r_b, (kg/m^3)	418.21 ± 6.18
Density ratio, g_d, (%)	41.42 ± 7.14
Geometric mean diameter, d_g, (mm)	33.99 ± 2.32
Sphericity, f, (%)	88.62 ± 1.34
Surface area, S, (cm^2)	36.27 ± 3.13
Projected area A_L (cm^2)	12.86 ± 4.56
A_w (cm^2)	7.31 ± 3.82
Mechanical	
Coefficient of static friction, m_s	
Fiberglass	0.414 ± 0.03
Steel	0.366 ± 0.01
Plywood	0.298 ± 0.01
Rupture force, Fr, (N)	18.12 ± 6.22
Deformation, Dr, (mm)	2.13 ± 0.53
Absorbed energy, E, (N.mm)	19.29 ± 8.16
Fruit toughness, P, (mJ/cm^3)	0.537 ± 0.08
Fruit hardness, H, (N/mm)	8.51 ± 1.82

Geometric properties (length, width, geometric mean diameter and surface area):

Loquat length, width and geometric mean diameter at different moisture contents were shown in Fig. (4). It is clear that, as the moisture content decreased from 84.62 to 22.71%(w.b), fruit length, width and geometric mean diameter decreased. Similar trends were reported by Razavi *et al* (2007) for pistachio fruit. The following relationships between fruit (length, width and geometric mean diameter) and moisture content were resulted as the best fit data using Excel-2010 Software:

$$L = 32.992 + 0.1303Mc \qquad R^2 = 0.9706 \quad ...(11)$$

$$w = 24.724 + 0.1112Mc \qquad R^2 = 0.9844 \quad ..(12)$$

$$\delta_g = 27.220 + 0.1173Mc \qquad R^2 = 0.983 \quad ....(13)$$

Surface area variation with changing of loquat moisture content is plotted in Fig. (4). It was obvious that, the surface area decreases along with the decrease of loquat fruits moisture content. The following formula was obtained by Excel-2010 to show the relationship between fruit surface area and moisture content:

$$S = 27.036 + 0.0288Mc + 0.002Mc^2 \qquad R^2 = 0.995 \quad ....(14)$$

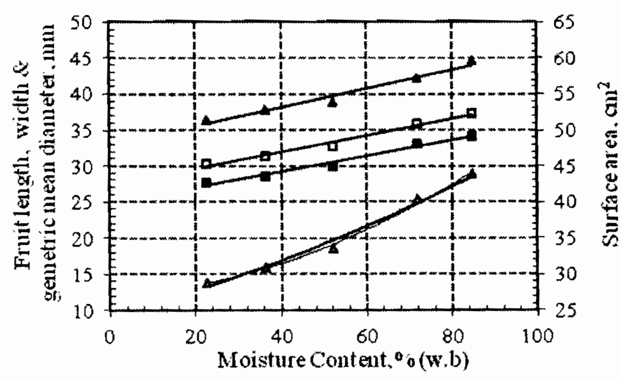

Fig. 4: Effect of moisture content on fruit length, width, geometric mean diameter and surface area

Loquat weight and volume versus moisture content were plotted (Fig. 5). It is observed that; lowered loquat moisture content from 84.62 to 22.71% (w.b.) decreased the fruit weight and volume in quadratic equations as the following relationships:

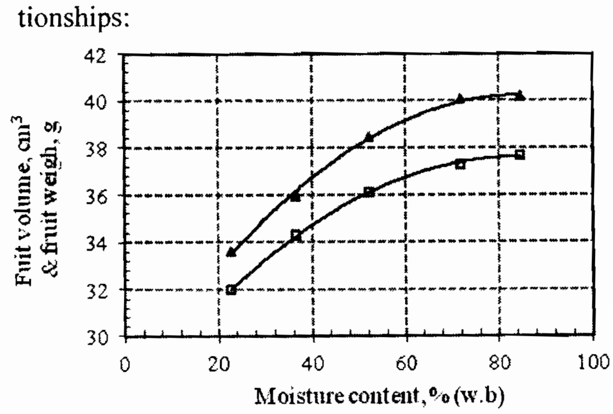

Fig. 5: Effect of moisture content on fruit weight and volume

$W = 27.655 + 0.2968Mc - 0.0018Mc^2$ ..

$R^2 = 0.9973$ ....(15)

$V = 27.129 + 0.2488Mc - 0.0015Mc^2$ ..

$R^2 = 0.999$ ....(16)

Fruit true density and its bulk density were illustrated in Fig. (6). Decreased fruit density from 1066.38 to 1050.65 kg/m³ and bulk density from 507.63 to 458.26 kg/m³ is detected as the moisture content decreased from 84.62 to 22.71%. The variations in fruit and bulk density with moisture content of loquat were presented by the following linear equations:

$\rho_f = 1040.8 + 0.375\ Mc$ $R^2 = 0.90$ .... (17)

$\rho_b = 439.83 + 0.6635\ Mc$ R2 = 0.92 .... (18)

The positive trends of fruit and bulk density with moisture content were observed by Sessiz *et al.* (2007).

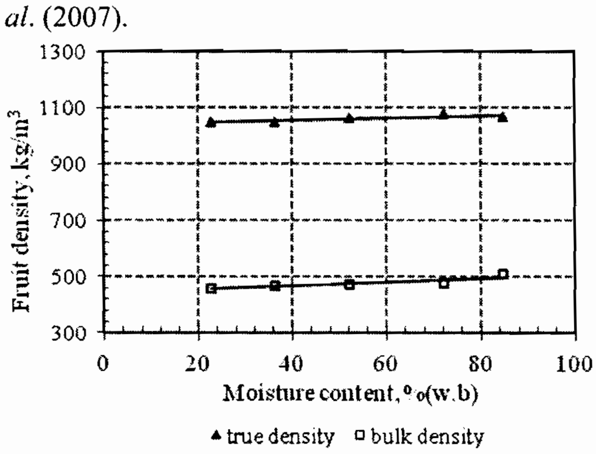

Fig. 6: Effect of moisture content on true and bulk density

Coefficient of static friction of loquat versus moisture content was presented in Figure (7). It is clear that, as moisture content decreased the coefficient of static friction decreased linearly. The relationships between coefficient of static friction against various surfaces and moisture content of loquat fruits are presented in the following formulas:

$\mu_{s(glass)} = 0.309 + 0.0012\ Mc$ $R^2 = 0.976$....... (19)

$\mu_{s(steel)} = 0.2038 + 0.0019\ Mc$ $R^2 = 0.9875$ .... (20)

$\mu_{s(wood)} = 0.1607 + 0.0016\ Mc$ $R^2 = 0.9701$........ (21)

The highest coefficient of static friction was obtained on fiberglass (0.414) and followed by steel (0.366), then plywood surface (0.298). In comparison with other fruit species, the static friction of loquat fruit was higher than those of kiwi fruit (Celik *et al.*, 2007) and sweet cherry fruit (Vursavus *et al.*, 2006).On the other hand the coefficient static friction of apple had a nearly values to loquat fruit, (Kheiralipour *et al.*, 2008). These results should be considered in the harvesting, handling and processing of loquat fruits.

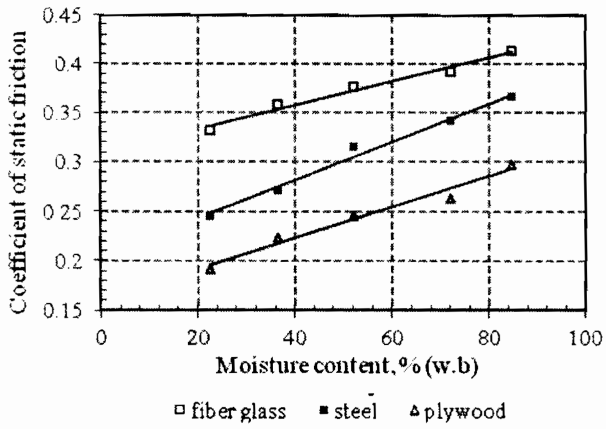

Fig. 7: Effect of moisture content on coefficient of static friction against different surfaces

The absorbed energy versus moisture content of loquat was plotted in Fig. (8). It showed that, the absorbed energy of loquat decreased from 19.32 to 14.65 N.mm as moisture content decreased from 84.62 to 22.71% (w.b). The variations in absorbed energy with moisture content of loquat fruits can be represented by the following quadratic relationship:

$E = 11.31 + 0.1727Mc - 0.0009Mc^2$..

$R^2 = 0.9831$ ....(22)

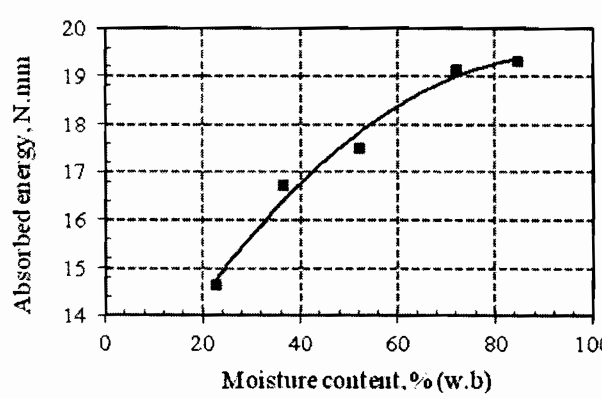

Fig. 8: Effect of moisture content on absorbed energy

Fruit toughness of loquat fruit was shown in Fig. (9). It was cleared that decreasing the fruit moisture content from 84.62 to 22.71%, lowered the fruit toughness from 0.405 to 0.349 mJ/cm³. The following equation was obtained by Excel-2010:

$P = 0.3124 + 0.0019Mc - 1E\text{-}5\ Mc^2$

$R^2 = 0.94$ .... (23)

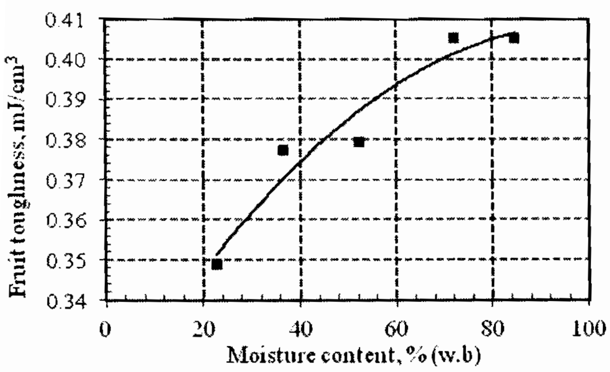

Fig. 9: Effect of moisture content on fruit toughness

Loquat fruits hardness versus moisture content was plotted in Fig. (10). It is clear that, decrease of moisture content from 84.61 to 22.71%, caused evaluation of fruit hardness from 8.52 to 16.81 N/mm. The following equation shows the relationship between fruit hardness and the moisture content:

$$H = 22.44 - 0.2752Mc + 0.0013\ Mc$$

$R^2 = 0.999$ ....(24)

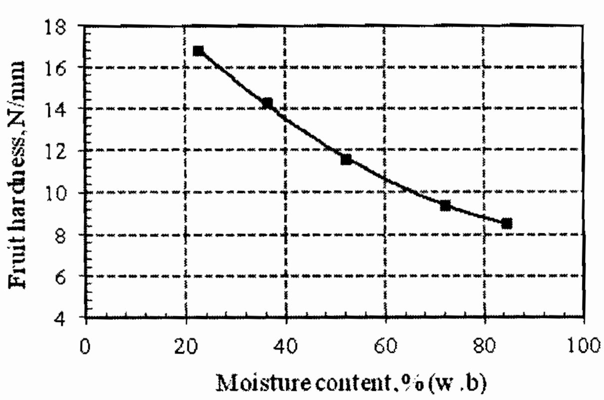

Fig. 10: Effect of moisture content on fruit hardness

CONCLUSION

The investigations of different physical and mechanical properties of loquat fruits revealed the following:

- Decrease of fruit length, width and geometric mean diameter linearly with moisture content decrease.
- Decrease of fruit and bulk density as moisture content decreases.
- The coefficient of static friction had a maximum value on fiberglass surface as compared with steel and plywood. Coefficient on all surfaces decreased linearly as moisture content decreased from 84.62 to 22.71% (w.b).
- Decrease of absorbed energy (from 19.32 to 14.65 N.mm), fruit toughness (from 0.405 to 0.349 mJ/cm3) and increase of fruit hardness (from 8.52 to 16.81 N/mm) linearly go with moisture content decrease from 84.62 to 22.71 % (w.b).

In conclusion the importance of the present study was to identify changes in some physical and mechanical properties of loquat fruits as a result of the decrease of moisture content after harvesting and transport processes, whereas, these results have great importance for determining the design specifications of certain machinery used in sorting, classification and packing of loquat fruits.

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بعض الخصائص الطبيعية والميكانيكية لفاكهة الاسكدينا (البشملة) مع تغير المحتوي الرطوبي

رجب إسماعيل مراد

قسم الهندسة الزراعية - كلية الزراعة - جامعة الفيوم

أجري هذا البحث بهدف دراسة بعض الخصائص الطبيعية والميكانيكية لفاكهة الاسكدينا (البشملة) كنتيجة لإنخفاض المحتوي الرطوبي للثمار. أوضحت النتائج انه بإنخفاض المحتوي الرطوبي من ٨٤,٦٢ إلي ٢٢,٧١٪ (علي أساس رطب) إنخفض كل من طول الثمرة. عرضها، القطر المتوسط الهندسي ، المساحة السطحية والمسقطة ، الحجم ، الوزن و الكثافة. كما أظهرت النتائج أنه يوجد إنخفاض خطي لمعامل الاحتكاك للأسطح الفيبرجلاس، الاستيل والخشب مع إنخفاض المحتوي الرطوبي للثمار. كما أن القيمة الأعلي لمعامل الاحتكاك سجلت مع الفيبرجلاس. كما أنه بإنخفاض المحتوي الرطوبي من ٨٤,٦٢ إلي ٢٢,٧١ ٪، أدي ذلك إلي إنخفاض الطاقة الممتصة من ١٩,٣٢ إلي ١٤,٦٥ نيوتن.مم، كما إنخفضت المتانة من ٠,٤٠٥ إلي ٠,٣٤٩ م جول/سم٣ ، وعلي الجانب الأخر زادت الصلابة من ٨,٥٢ إلي ١٦,٨١ نيوتن/مم.

ترجع أهمية هذه الدراسة إلي الوقوف علي التغيرات التي تطرأ علي بعض الخصائص الطبيعية والميكانيكية لثمار فاكهة الاسكدينا كنتيجة لإنخفاض المحتوي الرطوبي للثمار خلال عمليات التخزين لفترات معينة بعد عمليات الحصاد والنقل ، حيث تعتبر تلك النتائج ذات أهمية كبيرة لتحديد المواصفات التصميمية لبعض الألات المستخدمة في فرز وتصنيف وتعبئة ثمار الفاكهة.