

ELASTIC PROPERTIES OF THREE VARIETIES OF DATE FRUITS DURING THREE DIFFERENT RIPENING STAGES

M. M. Ibrahim* and A. M. Hassan*

ABSTRACT

*The aim of this research work was to determine the physical and elastic properties of date fruits (*Phoenix dactylifera*) cv (Talees, Khudari and Taghit) during three ripening stages (Khalaal, Rutab and Tamr) to develop a technique that can predict the packing height to protect fruits from mechanical damage. The physical properties include date mass, volume, dimensions, moisture content, bulk density, flesh thickness, and kernel mass. The elastic properties of date fruit include Young's modulus of elasticity (E), firmness coefficient (FC), bioyield stress (σ_b), bioyield strain (ϵ_b), rupture stress (σ_r), rupture strain (ϵ_r) and rupture energy (RE). For different varieties, the results showed that ripening stages have a significant effect on physical and elasticity properties. The values of E , FC , σ_b , σ_r and RE were decreased from Khalaal to Rutab stage, while they increased from Rutab to Tamr stage. Accordingly, the maximum heights of packing box were 141, 106, and 121 mm for Talees, Khudari and Taghit respectively.*

Keywords: Date palm, ripening, elasticity, modulus, bioyield, rupture, and stress.

INTRODUCTION

Date palm (*Phoenix dactylifera*, L.) is one of the most important horticultural crops rich in vitamins. Date production in the world is only confined to a small number of countries, most of them being the Arab countries. Date palm is the economic crop in Libya, where production was approximately 150 thousand tons (*Arab Agricultural Statistics Yearbook, 2009*).

In Libya date palms are distributed mainly in three areas: coastal, middle and southern districts. There are about (6) million date palm trees in Libya grown of about (400) cultivars.

Date fruits pass through several maturity stages, traditionally described by changes in color, texture and taste.

* Assist. Prof., Ag. Eng. Dept., Fac. of Agric., Cairo University.

Several investigations have shown some of the chemical compositional changes that take place during maturation, including free sugars and tannins (*Myhara et al., 1999; Sawaya et al., 1983; Sawaya et al., 1982*). Green dates stage (kimri الجمري) are firm in texture with highest moisture and tannin contents. At the Khalaal (حلال) stage, dates begin to lose moisture and form considerable quantities of sucrose. In the Rutab (رطب) stage, the loss of moisture is accelerated, and the fruits become softer in texture, and sucrose is converted into sugars. Dates at Rutab stage are the most desirable since they are at their softest and sweetest states. In the final maturity stage (Tamr - تمر) the fruits contain the least amount of moisture and maintain a soft texture with a sweet taste. *Ismail et al., (2001)* studied the consumer preference for quality attributes of date (maturity of Tamr stage). Consumer gave weight on the acceptance as: high (color, appearance, and sweetness), medium (fruit size, flesh thickness, chewiness, and solubility).

Knowledge of the physical properties of date fruit is necessary for the design of post harvesting equipment such as cleaning, sorting, grading, kernel removing, and packing. The importance of dimensions is in determining the aperture size of machines, particularly in separation of materials as discussed by *Mohsenin (1986)*. These dimensions can be used in designing machine components and parameters.

Grading fruit, based on weight, reduces packing and handling costs and also provides suitable packing patterns (*Khoshnam et al., 2007*).

Many studies have been reported on the physical and mechanical properties of fruits, such as bergamot (*Rafiee et al., 2007*), coconut (*Terdwongworakul et al., 2009*), date fruit (*Jahorni et al., 2008*), kiwi fruit (*Lorestani and Tabatabaeefar, 2006*), melon (*Emadi et al., 2009*), orange (*Khojastehnazhand et al., 2009*) and citrus fruits (*Omid et al., 2010*). *Akar and Aydin (2005)* evaluated some physical properties of gumbo fruit varieties as functions of moisture content. *Kashaninejad et al. (2006)* and *Awady and Sayed (1994)* determined some physical and aerodynamic properties of peanuts pistachio nuts and kernels as functions of moisture content in order to design processing equipment and

facilities. **Ghonimy and Kassem. (2011)** reported that there are significant differences between different production zones of date fruits for each of fruit mass, flesh mass, fruit volume, fruit moisture content, fruit dimensions, flesh thickness, fruit projected area and elasticity of fruits.

Fecete (1994) found that the coefficient of elasticity for tomato and apple can be used to characterize the fruit firmness. **Cenkowski et al. (1995)** studied the effect of moisture sorption hysteresis on the mechanical behaviour of canola and showed that the modulus of elasticity of the product brought into equilibrium through adsorption was higher than that of the one obtained through desorption at the same moisture content. The other products whose mechanical properties have been studied include kiwi fruit (**Abbott and Massie, 1995**), apples (**Abbott and Lu, 1996**) and sea buckthorn berries (**Khazaei and Mann, 2004**). **Anazodo and Chikwendu (1983)** developed equations for the calculation of the Poisson's ratio and elastic modulus of circular bodies subjected to radial compression and **Dinrifo and Faborode (1993)** applied the Hertz's theory of contact stresses to cocoa pod deformation. **Anazodo and Norris (1981)** noted that the modulus of elasticity, crushing strength and modulus of toughness of corncob all decreased with moisture content.

The aim of this research was to investigate some physical and elastic properties for three varieties of date fruits (Talees, Khudari and Taghit) during three stages of ripening (Khalaal, Rutab and Tamr) to develop a technique that can predict the packing height to protect fruits from mechanical damage.

MATERIAL AND METHODS

1. Sample preparation

This study was carried out at the Faculty of Agriculture, Omar El-Mukhtar University, Libya, during season 2010. Physical and mechanical properties of date fruits (*Phoenix dactylifera*) were determined at three ripening stages. Three varieties (Talees, Khudari, and Taghit) were selected randomly from Sabha (←) (located in the western south of Libya). For each variety, 100 date fruits were randomly selected at each ripening stage. The dates were collected from different farms. Dates were

sorted to discard the damaged fruits, and immediately kept for less than 24 hours in a cold storage at 5 °C.

2. Physical properties of date fruit

2.1. Date fruits dimensions (length and diameter)

All dimensions of date fruit and kernels were measured by Vernier calliper to an accuracy of 0.1 mm.

2.2. Date fruit moisture content

The moisture content was determined for the flesh of dates using AOAC procedures (AOAC, 1995) where the samples were dried at 70°C for 48 hours.

2.3. Mass and bulk density

The mass of date fruit was determined using a digital balance with an accuracy of 0.01 g. The bulk density of date fruits was calculated using equation (1) by determining the mass of the date and its volume.

$$D_b = \frac{m}{V} \quad (1)$$

Where;

D_b = The bulk density of date fruit, g/cm³;

m = Mass of date fruit, g;

V = Volume of date fruit, cm³.

3. Mechanical properties of date fruit

3.1. Compression test

The parallel-plate compressive test was carried out to determine the mechanical properties using a universal testing machine (Instron-1000 N). Individual date fruits were uniaxially compressed at a cross-head speed of 0.5 mm/s to a total deformation 10 mm. A plate (diameter 7.5 cm) compressed a date flesh slab placed on a mounted fixed table. The contact surfaces were oriented parallel to the compression surfaces during loading (Fig. 1). A random 10 fruits sample of each cultivar at each ripening stage were taken for compression tests. All experiments were carried out at room temperature (23 °C).

The contact area between the parallel-plate disk surface and each tested fruit surface was determined experimentally. The plunger disk surface was covered with a white paper, followed by gently pressing the horizontally oriented upper longitudinal fruit surface in an ink stamp, and

then allowing the plunger to contact the fruit surface. The resulting contact area traced on the white paper was scanned, and specially developed software that accurately estimates the scanned surface area was used to determine the contact area.

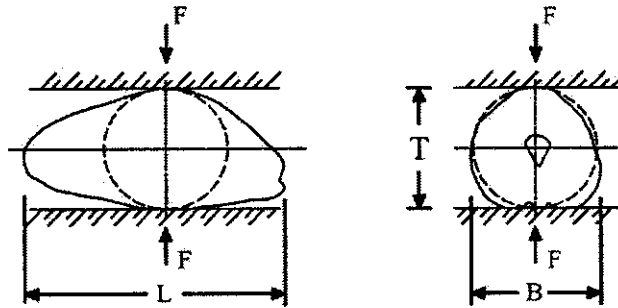


Fig. (1): Date fruit loaded between the two parallel plates

3.2. Elastic property of date fruit

A typical force-deformation curve (Mohsenin 1986) is shown in Figure (2). As it is shown, the force-deformation curve exhibited two peak points. The first peak corresponds to the yield point at which kernel damage was initiated. The second peak corresponds to the maximum compressive force.

For stress-strain tests, the following mechanical properties were calculated; the modulus of elasticity (E), firmness coefficient (FC), bioyield stress (σ_b), bioyield strain (ϵ_b), rupture stress (σ_r), rupture strain (ϵ_r) and rupture energy toughness (RE).

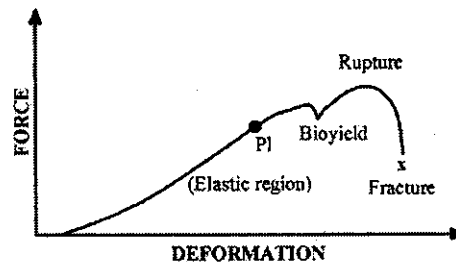


Fig. (2): A typical force-deformation plot for agricultural materials (Mohsenin 1986).

The Young's modulus of elasticity is a good measure of the elasticity of ideal materials. The behavior of ideal materials is described by the Hooke's law and the model of which is a spring without damper.

The Young's modulus of elasticity (E) for compressive stress is expressed by equation (2).

$$E = \frac{\sigma}{\varepsilon} \quad (2)$$

Where;

E = Young's modulus of elasticity, kPa;

σ = Compressive stress, kPa;

ε = Strain, mm/mm.

The strain was calculated by dividing the deformation of the fruit by the initial fruit average thickness.

$$\varepsilon = \frac{\Delta l}{l} \quad (3)$$

Where;

Δl = Variation in the thickness (deformation), mm;

l = Original thickness, mm.

The average stress was calculated by dividing the force on one fruit by the projected area of the fruit as follows:

$$\sigma = \frac{F}{1000A_p} \quad (4)$$

Where;

F = force on one fruit, N,

A_p = Contact area of date fruit, mm².

Firmness coefficient (FC) is calculated as the average slope of force – deformation curve from zero to point of rupture or failure (*Shafiee et al., 2008*). FC was calculated by applying the following equation (5) :

$$FC = \frac{F}{\Delta l} \quad (5)$$

Toughness (RE) or mechanical energy or work required for rupture was determined by calculating the area under the force – deformation curve from the following equation (*Braga et al., 1999*):

$$RE = \frac{F_r D_r}{2} \quad (6)$$

Where;

RE = Toughness, J;

F_r = the rupture force, N;

D_r = the deformation at rupture point, m.

The area was measured by using a computer software program (AutoCAD), then, to relate the rupture energy to date fruit volume, it was divided it by date fruit volume.

3.3. Statistical analysis

Statistical analysis was carried out using a randomized complete block procedure of the MStat-c statistical package. LSD and Duncan multiple range comparison were used to identify means that were different at probabilities of 5 % or less (*Snedecor and Cochran 1976*).

4. Determination of the height of packing box

The force acting on stacks of fruit may be used to estimate the force acting on a date fruit at the bottom layer of a bulk bin. Figure (3) shows the force (F) acting on date fruit somewhere in stack. In this study, the date fruits are represented by cylinders of an average diameter (d) and a square arrangement which depends on their characteristic diameter and number of fruits.

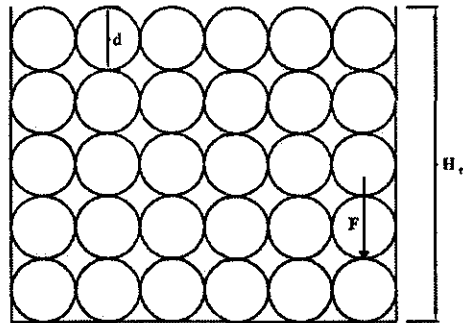


Fig. (3): An elevation view through the stack of date fruits in arrangement.

The following equations (7, 8, and 9) calculated the number of fruit of fruits above the bottom layer and consequently the height of the packing box.

$$F_{\max} = n \cdot m \quad (7)$$

$$H_{th} = d \cdot (n + 1) \quad (8)$$

$$H_{act} = \frac{H_{th}}{S.F.} \quad (9)$$

Where:

- F_{max} = Maximum allowable force on a date fruit at the bottom layer, N.
 H_{th} = Maximum depth of fruit in box, (without mechanical damage), mm.
 H_{act} = Actual depth of fruit in box, mm.
 n = Number of fruits above the last fruit at bottom layer.
 m = Fruit weight, N.
 d = Fruit diameter, mm.
 $S.F.$ = Safety factor (≈ 1.5) as design factor to avoid any unexpected risk.

4.1. Determination of the contact stress

Heinrich Hertz (*Shigley et al., 2008*) proposed a solution for contact stress in two elastic isotropic bodies, such as the case of two cylinders (line contact) of the same material touching each other and attempted to find the magnitude of the maximum pressure. Figure (4) shows two cylinders of length l (the length of cylinder = fruit length) and diameters d_1 and d_2 . The area of contact is a narrow rectangle of width $2b$ and length l , and the pressure distribution is elliptical.

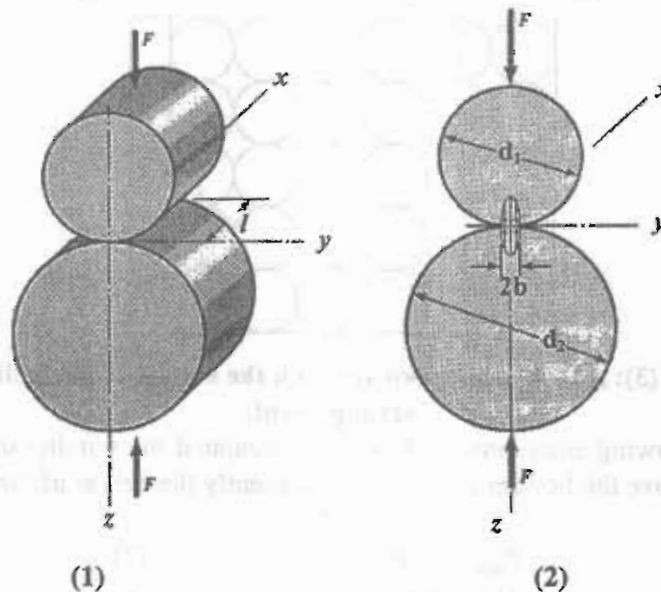


Fig. (4): Line contact of two cylinders: (1) Two circular cylinders held in contact by forces F uniformly distributed along cylinder length l . (2) Contact stress has an elliptical distribution across the contact zone width $2b$.

The half-width b is given by the equation (Shigley et al., 2008):

$$b = \sqrt{\frac{2F(1-\mu_1^2)/E_1 + (1-\mu_2^2)/E_2}{\pi l(1/d_1 + 1/d_2)}} \quad (10)$$

Where:

b = half of contact width, mm.

F = Acting force on the two cylinders, N.

l = contact length, mm.

E_1, E_2 = Modulus of elasticity for cylinders (1) and (2), Pa.

μ_1, μ_2 = Poisson ratio for cylinders (1) and (2), dimensionless.

d_1, d_2 = Diameter for cylinder (1) and (2), mm.

The maximum pressure (P_{max} , Pa) is called the Hertz (compressive) stress, which occurs at the center and is given by following equation:

$$P_{max} = \frac{2F}{\pi bl} \quad (11)$$

RESULTS AND DISCUSSIONS

1. Physical properties of date fruit

The averages values of date fruit mass, flesh mass, kernel mass, fruit volume, bulk density, moisture content, fruit length, fruit diameter and flesh thickness are shown in table (1).

For Talees variety, moisture contents were measured as 70.87, 60.6 and 21.79 % w.b. for Khalaal, Rutab and Tamr respectively. Results showed that the moisture content decreased by increasing the ripening. The average of dimensions were 27.4 mm in length, 17.4 mm in width and 10.11 mm in thickness for Khalaal stage, 36.5 mm in length, 19.1 mm in width and 11.5 mm in thickness for Rutab stage, and 35.3 mm in length, 19.4 mm in width and 11.57 mm in thickness for Tamr stage. Date dimensions increased from Khalaal stage to Rutab stage, while decreased from Rutab to Tamr. Average fruit mass was 7.5, 11.5 and 10.6 g for Khalaal, Rutab and Tamr respectively. Results showed that the fruit mass increased from Khalaal stage to Rutab stage, while decreased from Rutab to Tamr. The same trend was found for Khudari and Taghit varieties. With Taghit variety the fruit mass was less than Talees and Khudari.

Data proved that the physical properties of date fruit were greatly influenced by ripening stage with all varieties.

For the three varieties, the statistical analysis (at 5% level) showed significant differences for most physical properties of date fruits during three stages of ripening (Khalaal, Rutab and Tamr).

2. Mechanical properties of date fruit

The mechanical properties of date fruit varieties at different ripening stages included modulus of elasticity (E), firmness coefficient (FC), bioyield stress (σ_b), bioyield strain (ϵ_b), rupture stress (σ_r), rupture strain (ϵ_r), and rupture energy (RE) as shown in table (1). Ripening stages for date fruit showed a significant effect on mechanical properties ($P < 0.01$).

2.1. Stress (σ) – Strain (ϵ) curve

Figure (5: a, b, c) shows the stress-strain curve of date palm (*Talees*, *Khudari* and *Taghit* varieties) during different ripening stages. It is clear that, before the point called proportional limit (P_1). Generally, the elastic limit is the limit beyond which the date will no longer go back to its original shape when the load is removed, or it is the maximum stress that may be developed such that there is no permanent setting when the load is entirely removed. For the three varieties, the statistical analysis (at 5% level) showed significant differences for most elasticity properties of date fruits during three stages of ripening (Khalaal, Rutab and Tamr).

The elastic limits were (110.5, 40 and 50 kPa), (3.3, 3.3, and 4.4 kPa), and (5.1, 15, and 10.4 kPa) for Talees, Khudari, and Taghit respectively. The results showed that the elastic limit decreased from Khalaal to Rutab stage, while increased from Rutab to Tamr. The reason may be due to the major changes which take place in the structural tissues during the ongoing maturation process and change from Khalaal to Rutab to Tamr stage of maturity. The most significant changes are in sugar type which converts from sucrose to fructose and glucose as a result of enzymatic action during the maturation process. The changes in pectin by pectinase enzyme lead to softness in the date structure at the Rutab stage compared to the Khalaal stage despite the reduction in moisture content at the Rutab stage. for Talees is greater than Taghit and Khudria at Khalaal and Rutab stages, but Tamr stage, the elastic limit with Kudria is greater than Taghit and Talees.

Table (1). Physical and mechanical properties of the date fruits.

Property	Talees (a)			Khudari (a)			Taghit (a)		
	Khalaal	Rutab	Tamr	Khalaal	Rutab	Tamr	Khalaal	Rutab	Tamr
Physical properties									
Fruit mass, g	7.5 B	11.5 A	10.6 A	7.6 C	10.2 A	9.5 B	4.0 B	7.8 A	7.2 A
Flesh mass, g	3.98 B	5.22 A	6.24 A	3.3 C	4.5 B	5.12 A	4.23 A	5.86 A	5.32 A
Kernel mass, g	0.69 C	1.39 A	1.21 B	1.2 A	1.41 A	1.35 A	0.95 B	1.41 A	1.03 B
Fruit volume, cm ³	7.0 C	10.8 B	12.0 A	6.2 C	10.8 A	9.1 B	5.15 B	8.0 A	7.1 A
Kernel volume, cm ³	1.9 B	2.1 A	2.2 A	1.8 B	2.32 A	2.33 A	1.76 C	2.15 B	2.35 A
Solid density, g/cm ³	0.9 B	1.0 B	1.2 A	1.0 C	1.2 B	1.4 A	0.9 A	1.1 A	1.3 A
Bulk density, g.cm ⁻³	0.61 A	0.64 A	0.67 A	0.66 A	0.65 A	0.69 A	0.59 A	0.62 A	0.65 A
Moisture content, %	70.87 A	30.60 B	21.79 C	66.44 A	29.37 B	20.13 C	62.57 A	31.59 B	21.15 C
Fruit length, mm	27.4 B	36.5 A	35.3 A	30.4 B	36.7 A	35.7 A	27.6 B	33.4 A	32.8 A
Fruit diameter, mm	17.4 B	19.1 A	19.4 A	18.7 B	21.8 A	20.2 A	18.4 B	20.4 A	19.2 A
Fruit thickness, mm	10.11 B	11.5 A	11.57 A	15.3 B	20.3 A	19.5 A	12.15 B	15.2 A	15.3 A
Mechanical properties									
Elasticity Modulus (kPa)	1035.7 A	4.59 C	57.24 B	585.42 A	21.50 C	76.47 B	866.41 A	22.01 C	46.18 B
Firmness Coeff. (N/mm)	0.76 A	0.15 C	0.14 B	0.62 A	0.22 B	0.13 C	0.64 A	0.26 B	0.17 B
Biyield point stress (kPa)	261.83 A	4.08 C	7.78 B	237.33 A	2.54 C	22.38 B	467.73 A	5.30 C	15.70 B
Strain	0.4 A	0.2 B	0.19 B	0.48 A	0.38 A	0.3 A	0.7 A	0.47 B	0.3 B
Rupture point stress (kPa)	411.80 A	6.58 B	7.78 B	272.09 A	5.61 C	30.0 B	485.43 A	6.40 C	20.2 B
Strain	0.57 A	0.38 B	0.19 C	0.55 A	0.75 A	0.7 A	0.8 A	0.47 B	0.37 B
Rupture energy (MJ/m ³)	0.1071 A	0.0015 C	0.0115 B	0.1073 A	0.0074 C	0.0318 B	0.2603 A	0.0094 C	0.0121 B

(a) Mean values with different letters are significantly different (< 5% level).

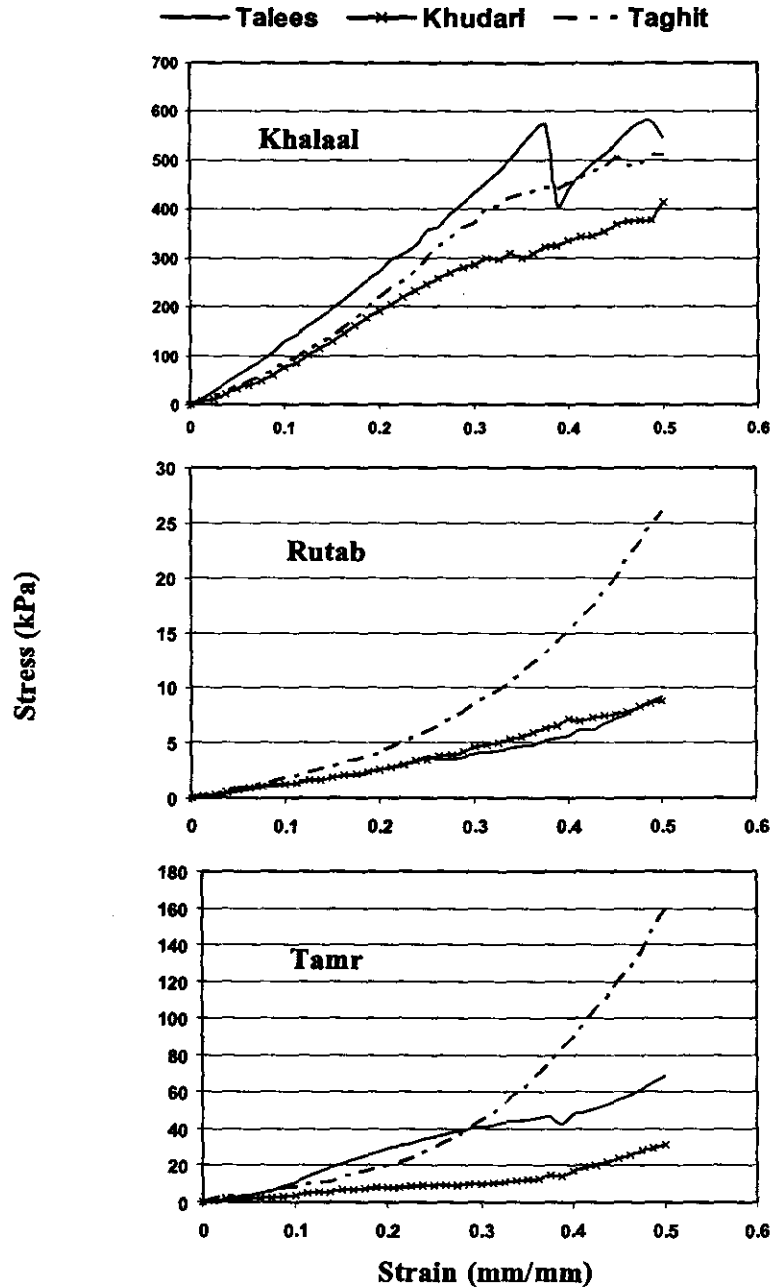


Fig. (5): Stress- strain curves of date fruit varieties at different ripening stages.

2.2. Modulus of elasticity (E)

The average values of Young's modulus of elasticity (E) for date fruits at different ripening stages and varieties are shown in table (1) and figure (6-a). It is clear that the modulus of elasticity (E) decreased from Khalaal to Rutab stage, while increased from Rutab to Tamr which was common trend for all varieties.

For Talees variety, the values of modulus of elasticity were 1035.7 kPa, 4.59 kPa and 57.27 kPa for Khalaal, Rutab and Tamr stages respectively. For Khudari variety, the values of modulus of elasticity were 585.42 kPa, 21.50 kPa and 76.47 kPa for Khalaal, Rutab and Tamr stages respectively. For Taghit variety, the values of E were 866.41 kPa, 22.01 kPa and 46.18 kPa for Khalaal, Rutab and Tamr stages respectively.

In case of Khalaal stage of ripening; E of Talees was greater than Taghit and Khudari, In case of Rutab stage; E of Taghit was greater than Khudari and Talees, but in case of Tamr stage; E of Khudari was greater than Talees and Taghit.

For the three varieties, the statistical analysis (at 5% level) showed significant differences for E of date fruits during the three stages of ripening (Khalaal, Rutab and Tamr).

2.3. Firmness Coefficient (FC)

The average values of firmness coefficient (FC) for date fruits at different ripening stages and varieties are shown in table (1) and figure (6-b). It is clear that the firmness coefficient (FC) decreased from Khalaal to Tamr stage, for all different varieties.

For Talees variety, the values of FC were 0.76, 0.15, and 0.14 N/mm for Khalaal, Rutab and Tamr stages respectively. For Khudari variety, the values of FC were 0.62, 0.23, and 0.13 N/mm for Khalaal, Rutab and Tamr stages respectively. For Taghit variety, the values of FC were 0.64, 0.26, and 0.17 N/mm for Khalaal, Rutab and Tamr stages respectively.

The results show that the FC of Talees variety is greater than Taghit and Khudari with Khalaal stage of ripening, for Taghit variety; the FC is greater than Khudari and Talees with Rutab stage of ripening, but for Khudari, the FC was greater than Talees and Taghit with Tamr stage of ripening.

For the three varieties, the statistical analysis (at 5% level) showed significant differences for FC of date fruits during the three stages of ripening (Khalaal, Rutab and Tamr).

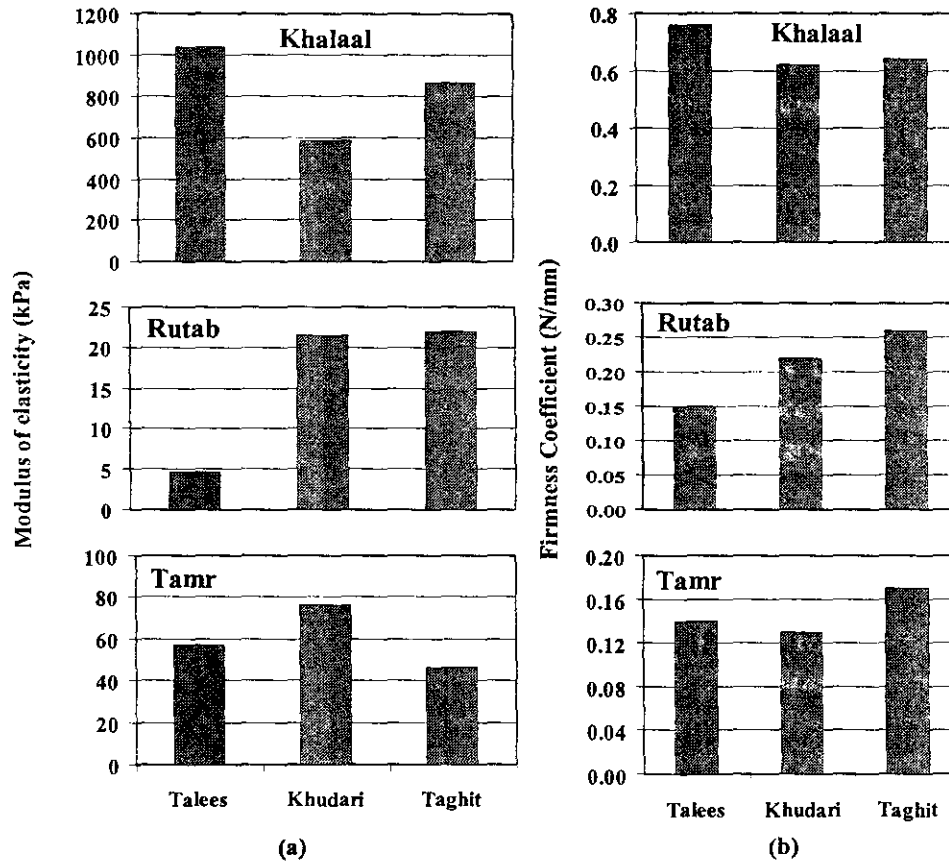


Fig. (6): Modulus of elasticity (E) and firmness coefficient (FC) for date fruit varieties under study at different ripening stages.

2.4. Bioyield stress (σ_b)

The average values of bioyield stress (σ_b) for date fruits at different ripening stage and varieties are shown in table (1) and figure (7-a). It is clear that the bioyield stress (σ_b) decreased from Khalaal to Rutab stage, while increased from Rutab to Tamr, with all varieties. In case of Talees variety, the values of (σ_b) were 261.83, 4.08, and 7.78 kPa for Khalaal, Rutab and Tamr stages respectively. In case of Khudari variety, the

values of (σb) were 237.33, 2.54, and 22.38 kPa for Khalaal, Rutab and Tamr stage respectively. In the case of Taghit variety, the values of (σb) were 467.75, 5.30, and 15.70 kPa for Khalaal, Rutab and Tamr stages respectively.

For the three varieties, the statistical analysis (at 5% level) showed significant differences for σb of date fruits during the three stages of ripening (Khalaal, Rutab and Tamr).

2.5. Bioyield strain (ϵb)

The average values of bioyield strain (ϵb) for date fruits at different ripening stages and varieties are shown in table (1). It is clear that the bioyield strain (ϵb) decreased from Khalaal to Tamr stage, with all different varieties.

In the case of Talees variety, the values of ϵb were 0.4, 0.2, and 0.19 mm/mm for Khalaal, Rutab and Tamr stages respectively. In the case of Khudari variety, the values of ϵb were 0.48, 0.38, and 0.3 mm/mm for Khalaal, Rutab and Tamr stages respectively. In case of Taghit variety the values of ϵb were 0.7, 0.47, and 0.3 mm/mm for Khalaal, Rutab and Tamr stages respectively.

The results show that the ϵb of Taghit variety was greater than Khudari and Talees in all ripening stages.

The results show that the (σb) of Taghit variety was greater than Talees and Khudari with Khalaal and Rutab stages of ripening. However for Khudari, the (σb) was greater than Talees and Taghit with Tamr stage of ripening.

For the three varieties, the statistical analysis (at 5% level) showed significant differences for ϵb of date fruits during the three stages of ripening (Khalaal, Rutab and Tamr).

2.6. Rupture stress (σr)

The average values of rupture stress (σr) for date fruits at different ripening stages for the different varieties are shown in table (1) and figure (7-b). It is clear that the rupture stress (σr) decreased from Khalaal to Rutab stage, while increased from Rutab to Tamr, with all different varieties.

In case of Talees variety, the values of σ_r were 411.80, 6.58, and 7.78 kPa for Khalaal, Rutab and Tamr stages respectively. In case of Khudari variety, the values of σ_r were 272.09, 5.61, and 30 kPa for Khalaal, Rutab and Tamr stages respectively. In case of Taghit variety, the values of σ_r were 485.43, 7.40, and 20.20 kPa for Khalaal, Rutab and Tamr stages respectively.

The results showed that the σ_r of Taghit variety was greater than Talees and Khudari with Khalaal and Rutab stages of ripening, but for Khudari, the rupture stress was greater than Talees and Taghit with Tamr stage of ripening.

For the three varieties, the statistical analysis (at 5% level) showed significant differences for σ_r of date fruits during the three stages of ripening (Khalaal, Rutab and Tamr).

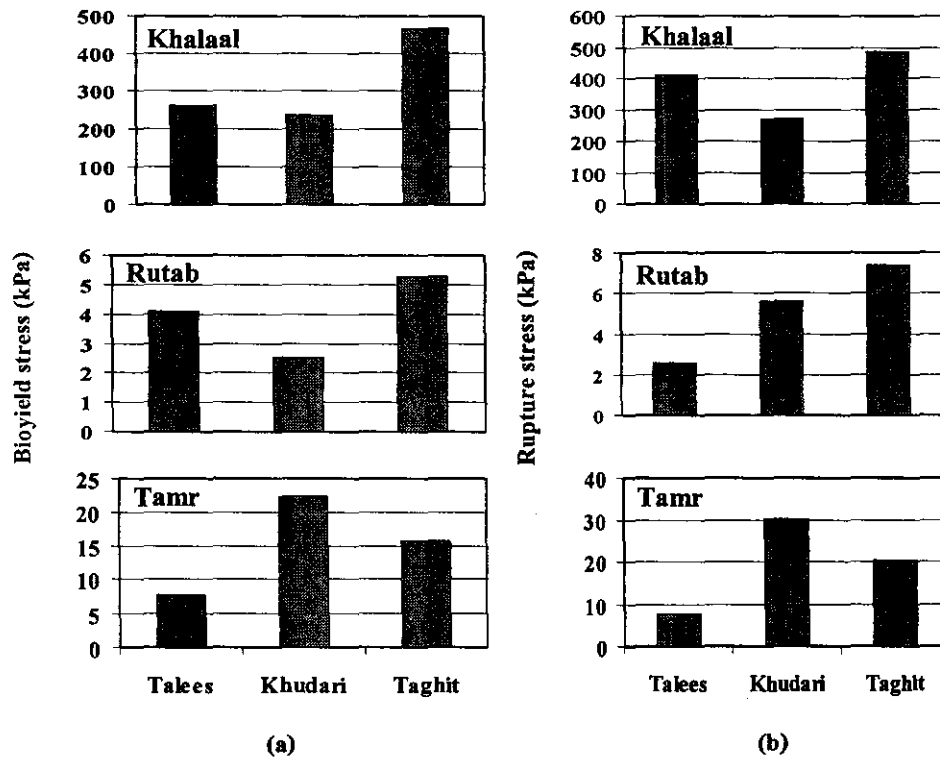


Fig. (7): Bioyield stress (σ_b) and rupture stress (σ_r) for date fruit varieties under study at different ripening stages.

2.7. Rupture strain (ϵ_r)

From the calculated results of rupture strain for date fruits at different ripening stages with different varieties, as shown in table (1) and figure (8-a), it can be found that the rupture strain decreased from Khalaal to Tamr stages, with Talees and Taghit varieties, but in the case of Khudari variety the rupture strain increased from Khalaal to Rutab stages then decreased in Tamr stage.

In the case of Talees variety, the values of rupture strain were 0.57, 0.38, and 0.19 mm/mm for Khalaal, Rutab and Tamr stages respectively. In case of Khudari variety, the values of rupture strain were 0.55, 0.75, and 0.7 mm/mm for Khalaal, Rutab and Tamr stages respectively. In the case of Taghit variety, the values of rupture strain were 0.8, 0.47, and 0.37 mm/mm for Khalaal, Rutab and Tamr stages respectively.

The results showed that the rupture strain of Taghit variety was greater than Talees and Khudari with Khalaal stage of ripening, but for Khudari, the rupture strain was greater than Talees and Taghit with Rutab and Tamr stages of ripening.

For the three varieties, the statistical analysis (at 5% level) showed significant differences for ϵ_r of date fruits during the three stages of ripening (Khalaal, Rutab and Tamr).

2.8. Rupture energy (RE)

The average values of rupture energy (RE) for date fruits at different ripening stages and varieties are shown in table (1) and figure (8-b). It is clear that, the rupture energy (RE) decreased from Khalaal to Rutab stage, while increased from Rutab to Tamr, with all different varieties.

In case of Talees variety, the values of RE were 0.1071, 0.0015, and 0.0115 MJ/m³ for Khalaal, Rutab and Tamr stages respectively. In the case of Khudari variety, the values of RE were 0.1073, 0.0074, and 0.0318 MJ/m³ for Khalaal, Rutab and Tamr stages respectively, where for Taghit variety, the values of RE were 0.2603, 0.0094, and 0.0121 MJ/m³ for Khalaal, Rutab and Tamr stages respectively.

The results show that the RE of Taghit variety was greater than Talees and Khudari with Khalaal stage of ripening, but for Khudari, the rupture

energy was greater than Talees and Taghit with Rutab and Tamr stages of ripening.

For the three varieties, the statistical analysis (at 5% level) showed significant differences for RE of date fruits during the three stages of ripening (Khalaal, Rutab and Tamr).

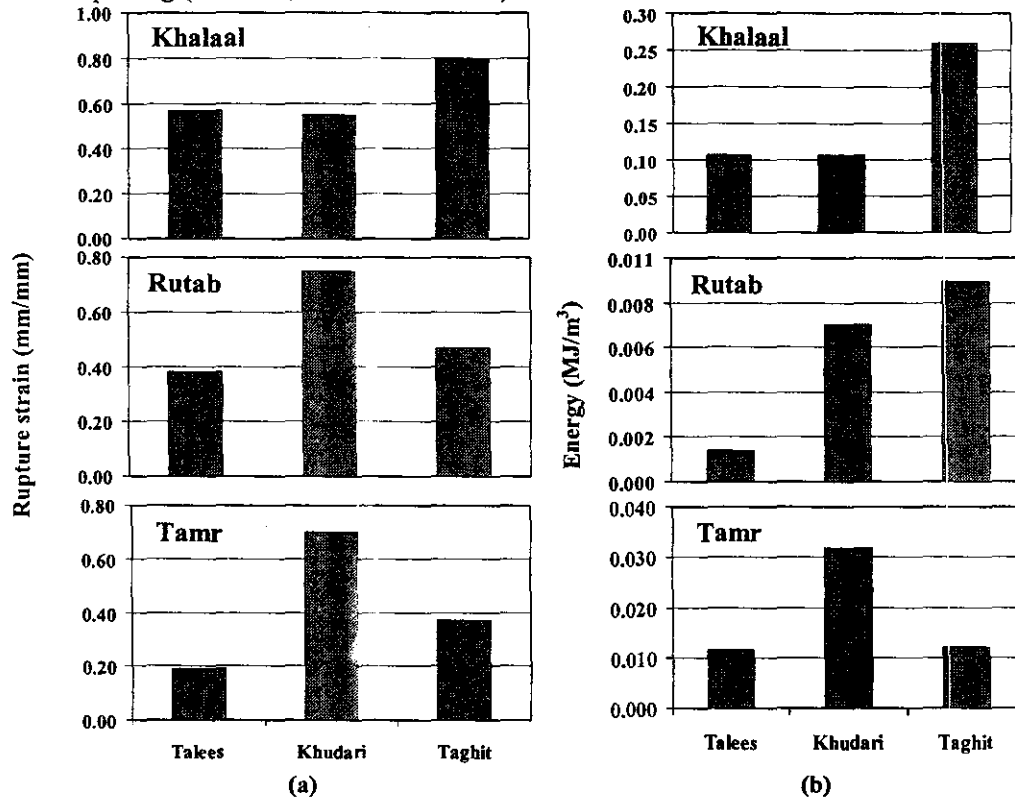


Fig. (8): Rupture strain (ϵ_r) and energy (RE) for date fruit varieties under study at different ripening stages.

In general, the mechanical properties of date fruit are influenced by varieties and ripening stage. As concluded from the results of the present study, each of E , FC , σ_b , σ_r and RE decreased from Khalaal to Rutab stage then increased at Tamr stage. The physical and mechanical properties of the three date fruit varieties namely, Talees, Khudari and Taghit are important in designing machine used for harvesting and post harvest handling of dates during ripening stages.

3. Predicting the height of packing box

In order to get optimum (prediction) of the height of packing box the following procedure was applied.

Applying equations (10) and (11) considering the following assumption:

$d_1 = d_2 =$ fruit thickness.

$E_1 = E_2 =$ Modulus of elasticity for date fruit.

$\mu_1 = \mu_2 =$ Poisson ratio of date fruit (the absolute value of the transverse strain to the corresponding axial strain resulting from uniformly distributed axial stress below the proportional limit of the material, it was measured ≈ 0.4 .

$l =$ Fruit length.

$P_{max} =$ Bioyield stress of date fruit.

Substitute equation (10) in equation (11) use try and error method to calculate the maximum allowable force (F_{max}) for the three varieties in Rutab stage (the bioyield stress in Rutab stage is less than other stages), the values of n , H_{th} , and H_{act} can be calculated as shown in table (2).

Table (2): The calculation results of F_{max} , H_{th} , and H_{act} .

	Talees	Khudari	Taghit
F_{max}, N	2.00	0.70	0.855
N	17.391	6.8627	10.962
H_{th}, mm	211.50	159.61	181.82
H_{act}, mm	141	106.41	121.21

Therefore, the maximum heights of packing box which does not result in mechanical damage were 141, 106, and 121 mm for Talees, Khudari and Taghit respectively.

CONCLUSION

The obtained results of physical and mechanical properties of the three date fruit varieties during three stages of ripening can be summarized as follows:

1. There were significant differences between ripening stages of date fruits for most physical properties.

2. There were significant differences between ripening stages of date fruits for mechanical properties.
3. For different varieties, the values of E, FC, σ_b , σ_r and RE decreased from Khalaal to Rutab stage then increased from Rutab to Tamr stages.
4. The different measured mechanical properties followed the same trend which reflected their state behaviour at the three stages same of ripening for the three tested varieties: decreasing through Khalaal to Rutab stages then increasing through Rutab to Tamr stages.
5. The maximum heights of packing box are 141, 106, and 121 mm for Talees, Khudari and Taghit respectively.

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الملخص العربي

خواص المرونة لثلاثة أصناف من ثمار التمر خلال ثلاث مراحل مختلفة للنضج

محمد محمود إبراهيم* احمد محروس حسن*

يهدف هذا البحث إلى تقدير الخواص الطبيعية وخواص المرونة لثلاثة أصناف من ثمار التمر (تاليس - خضري - تغيات) أثناء مراحل النضج (خلال، رطب، تمر) المنزرعة في سبها ليبيا، لما تمثله هذه الخواص من أهمية في عمليات حصاد وتداول ثمار التمر في المراحل المختلفة للنضج، وبغرض المساهمة في تقليل الأضرار الميكانيكية التي تتعرض لها الثمر خلال عملية النقل والتخزين من خلال التنبؤ بارتفاع عبوات قدرة على الحفاظ على الثمار من هذه الأضرار. وقد تم تقدير كل من الخواص البعدية للثمرة، سمك اللحم، المحتوى الرطوبي للثمرة، الكثافة الظاهرية للثمار، كتلة وحجم البذرة، وأيضاً خواص المرونة للثمرة مثل معامل "يانج" للمرونة، معامل الصلابة، وإجهاد الخضوع الحيوي، انفعال الخضوع الحيوي، إجهاد التحطم، انفعال التحطم، والطاقة اللازمة للتحطيم.

وقد بينت الدراسة ما يلي:

1. توجد فروق معنوية بين مراحل نضج الثمرة في معظم الخصائص الطبيعية للثلاثة أصناف.
2. توجد فروق معنوية بين مراحل نضج الثمرة في الخصائص الميكانيكية للثلاثة أصناف: معامل يانج للمرونة ومعامل الصلابة وإجهاد الخضوع الحيوي وانفعال الخضوع الحيوي وإجهاد التحطم وانفعال التحطم والطاقة اللازمة للتحطيم.
3. وجد أن خواص معامل يانج للمرونة ومعامل الصلابة وإجهاد الخضوع الحيوي وإجهاد التحطم والطاقة اللازمة للتحطيم تقل من مرحلة الخلال إلى مرحلة الرطب ثم بعد ذلك تزيد من مرحلة الرطب إلى مرحلة التمر وذلك مع أصناف التمر الثلاثة.
4. معامل يانج للمرونة للثلاثة أصناف في مرحلة الخلال يتراوح من ٥٨٥.٤٢ إلى ١٠٣٥.٧ كيلوباسكال، وفي مرحلة الرطب يتراوح من ٤.٥٩ إلى ٢٢.٠١ كيلوباسكال، وفي مرحلة التمر يتراوح من ٤٦.١٨ إلى ٧٦.٥٠ كيلوباسكال.
5. معامل الصلابة للثلاثة أصناف في مرحلة الخلال يتراوح من ٠.٦٢ إلى ٠.٧٦ نيوتن/مم، وفي مرحلة الرطب يتراوح من ٠.١٥ إلى ٠.٢٦ نيوتن/مم، وفي مرحلة التمر يتراوح من ٠.١٣ إلى ٠.١٧ نيوتن/مم.

* مدرس الهندسة الزراعية - كلية الزراعة - جامعة القاهرة.

٦. إجهاد الخضوع الحيوى للثلاثة أصناف فى مرحلة الخلال يتراوح من ٢٣٧.٣٣ الى ٤٦٧.٧٨ كيلوباسكال، وفى مرحلة الرطب يتراوح من ٢.٥٤ الى ٥.٣٠ كيلوباسكال، وفى مرحلة التمر يتراوح من ٧.٧٨ الى ٢٢.٣٨ كيلو باسكال.
٧. إجهاد التحطم للثلاثة أصناف فى مرحلة الخلال يتراوح من ٢٧٢.٠٩ الى ٤٨٥.٤٥ كيلوباسكال، وفى مرحلة الرطب يتراوح من ٥.٦١ الى ٦.٥٨ كيلوباسكال، وفى مرحلة التمر يتراوح من ٧.٧٨ الى ٣٠.٠ كيلوباسكال.
٨. الطاقة اللازمة للتحطيم للثلاثة أصناف فى مرحلة الخلال يتراوح من ٠.١٠٧١ الى ٠.٢٦٠٣ ميغا جول / م^٣، وفى مرحلة الرطب يتراوح من ٠.٠٠١٥ الى ٠.٠٠٩٤ ميغا جول / م^٣، وفى مرحلة التمر يتراوح من ٠.٠١١٥ الى ٠.٠٣١٨ ميغا جول / م^٣.
٩. أقصى ارتفاع مأمون للعبوات كانت ١٤١، ١٠٦، ١٢١ مم للاصناف تاليس، خضري، تغيات على الترتيب.