ELASTICITY PROPERTIES OF DATE FRUITS UNDER DEFICIT IRRIGATION TO PREDICT PACKAGE HEIGHT

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ABSTRACT

The aim of this work was to determine the effect of deficit irrigation on the physical and elasticity properties of date fruits (Phoenix dactylifera, cv. Khudary) during three stages of repining (Khelaal, Rutab and Tamr) for two years (2014 and 2015) to predict the package height of date fruit. Four irrigation treatments were studied: (ET_1): 1.0 ET_c (one time potential crop evapotranspiration), ET_2: 0.85 ET_c, ET_3: 0.75 ET_c and ET_4 :0.65 ET_c). The physical properties included date mass, volume, dimensions, moisture content, bulk density, solid density, flesh thickness, flesh mass and elasticity of fruits. The elasticity properties of fruit included young's modulus of elasticity (E), firmness coefficient (FC), bio-yield stress point (σb), bio-yield strain point (εb), rupture stress point (σr) and rupture strain point (εr). The results showed that the deficit irrigation affected both physical and mechanical properties, therefore, affected on package height of date fruits. The maximum packing heights for Khellal, Rutab and Tamr were 6360.51, 654.2 and 1850 mm with ET_1, ET_2 and ET_3, respectively. While, the minimum packing heights for Khellal, Rutab and Tamr were 3738, 206.6 and 1411 mm with ET_4, ET_3 and ET_1, respectively.

Keywords: *Deficit irrigation, date palm, physical properties, mechanical properties, packing box*

1. INTRODUCTION

The date fruit is one of the most abundant fruits in the world, the palm date has played an important role as a food security crop in the Middle East and North Africa regions. Hundreds of varieties having different texture, color, and flavor are available for valorization and adoption in food processing operations. Such utilization should be based on the fruit valuable characteristics; mainly its richness in dietary fiber and phenolic *antioxidants (Ghonimy and Kassem, 2011).*

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Date fruit has traditionally been used as a medicine in many cultures for the treatment of a range of ailments, studies have confirmed that date fruit have beneficial health effects that can be attributed to the presence of natural bioactive compounds (Taleb et al., 2016).

Water shortage and the increasing competition for water resources between agriculture and other sectors compel the adoption of irrigation strategies in semi-arid Mediterranean regions, which may allow saving irrigation water and still maintain satisfactory levels of production (Costa et al., 2007).

The mechanical properties of the fruits and vegetables depend largely on its structure and composition, and any variations in structure will influence its mechanical properties and hence the texture. Biological materials are commonly anisotropic.

Hence, their mechanical properties differ according to the orientation in which it is tested. Fleshy fruit tissue, such as apple parenchyma, shows mechanical anisotropy depending on the shape and arrangement of the cells and other morphological components (Kubík, & Kažimírová, 2015).

Physical properties of fruits and vegetables are necessary data to design an agricultural machine for handling, cleaning, conveying, sorting and other treatments, also the size of individual units of a product can significantly affect consumer appeal, handling practice, storage potential, and market selection, thus; investigation of agricultural products physical characteristics is the subject of numerous researches and studies (Soltani et al, 2011).

Many studies have been reported about the physical and mechanical properties of fruits, such as bergamot (Jahromi et al, 2007), coconut (Terdwongworakula et al, 2009), date fruit (Jahromi et al, 2008), kiwi fruit (Lorestani and Tabatabaeefar, 2006), longan fruit (Varith et al, 2008), melon (Emadi et al, 2009), orange (Khojastehnazhand et al, 2009) and citrus fruits (Omid et al, 2010). Significant differences were reported between different production zones of date fruits for each of fruit concerning its mass, volume, moisture content, dimensions, flesh thickness, projected area as well as its elasticity (Ghonimy and Kassem, 2011).

Ghaziani et al. (2012) stated that the effect of different irrigation systems and plant density had significant effect on the characteristics of marigold.

Also; Pirzad et al. (2011) stated that different irrigation levels and plant density had significant effect on the characteristics of local chamomile.

The stress-strain uniaxial compression test shows the response of biomaterials to an externally applied force that deforms the body of the material, causing changes in dimension, shape, or volume. This test provides important information about elastic and plastic behavior (Babić et al., 2013).

Mohsenin (1978) described compression tests of cylindrical plugs from products such as apples and potatoes and bending tests of forage stems, vegetables stalks, and rectangular bars from cheese, butter and other homogeneous products. Three-point bending tests have been reported for corn cobs (Anazodo, 1983) and dry pecan shells (Tyson, 1979).

The aim of this research was to investigate some physical and elastic properties for Khudary date fruits during three stages of ripening (khalaal, Rutab and Tamr) under different water regimes to predict the packing height of fruit which protect the date from mechanical damage.

2. MATERIAL AND METHODS

2.1. Location, plant materials and treatments

Two season experiments (2014 and 2015) were conducted to determine elasticity properties of date fruits (*Phoenix dactylifera*) at three ripening stages (Khelaal, Rutab and Tamr) were taken from Sabha privet farm, western south of Libya. The average monthly climatic data (1962 – 2015) of the experimental area are shown in table 1. The date palms were irrigated under four levels of irrigation {ET_1: 1 ET_c (time of date palm requirements), ET_2: 0.9 ET_c, ET_3: 0.8 ET_c and ET_4: 0.7 ET_c}. Each irrigation level plot consists of 6 rows with length 48 m and the distance between plants was 8 × 8 m., irrigation water was delivered via a trickle system. Four emitters per plant were established with flow rate 8 l/h. per emitter. 16 mm in external diameter polyethylene tubes were used to deliver water to emitters. 100 date fruits were randomly selected for each irrigation level treatment and at three ripening stages.

2.2. Date palm irrigation requirement

The reference evapotranspiration was determined by CROPWAT 8 Program. The following equation was used to calculate crop water requirements over the growing season (Ouda et al., 2016):

$$ET_c = K_C\ ET_o \tag{1}$$

Where: ET_c is the crop water requirements, ETo is the reference evapotranspiration, mm, and K_c is the crop coefficient. Each treatment received total amount of water annually 1976.2 mm in ET_1, 1778.6 mm in ET_2, 1581 mm in ET_3 and 1383.3 mm in ET_4 for the date palms.

Table 1. Average monthly climate data for Sabha (1962–2015)*.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
T_{max} (°C)	20.0	22.1	26.0	30.5	33.2	37.7	38.2	38.2	36.6	32.1	26.0	21.0
T_{min} (°C)	2.7	5.0	7.1	10.5	15.0	18.8	19.3	19.3	18.2	14.3	9.3	5.5
Rain (mm)	2	3	5	2	2	0	0	0	3	6	2	3
RH (%)	59	53	47	39	37	33	37	40	45	52	55	50
Sunshine, (h/month)	208	210	226	195	267	246	338	326	261	223	219	198

***** World Meteorological Organization (2016)

2.3. Date fruit Physical properties

Dimensions, mass, volume and density of date fruit were measured، the dimensions (length, diameter and thickness) were measured by Vernier caliper (0.1 mm accuracy). A digital balance (0.01 g accuracy) was used to determine the mass of fruit. Date fruit volumes were measured by the water displacement method. Fruits were immersed in a graduated beaker containing water with needle and the volume of the fruit in the water was recorded. The following equation was used to calculate the bulk density (ρ_b) of fruits:

$$\rho_b = m/V \tag{2}$$

Where: m is the fruit mass (g), and V is the fruit volume (cm^3).

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.

2.4. Mechanical properties

Random 10 date fruit samples at each ripening stage were taken for compression tests. Compression (stress-strain) test was carried out to determine the mechanical properties of fruits using universal machine

(Instron-1000N-USA). The calculated mechanical properties of the date fruit by stress-strain test were the firmness coefficient (FC), bio-yield stress (σb), bio-yield strain (εb), rupture stress (σr), rupture strain (εr), modulus of elasticity (E), and rupture energy toughness (RE). All previous mechanical properties were calculated by the following equations (Mohsenin, 1978):

$$FC = \frac{F}{\Delta l} \quad , \mathrm{N} \tag{3}$$

$$\varepsilon b = \frac{\Delta l}{l} \quad , mm/mm \tag{4}$$

$$\sigma b = \frac{F}{1000 A_p} \quad , \mathrm{kPa} \tag{5}$$

$$E = \frac{\sigma b}{\varepsilon b} \quad , \mathrm{kPa} \tag{6}$$

$$RE = \frac{F_r\, D_r}{2} \quad , \mathrm{J} \tag{7}$$

Where: F is force on one fruit (N) , Δl is the variation in the thickness (deformation) in (mm), εb is the strain (mm/mm), l is the original thickness (mm), σb is the compressive stress (kPa), A_p is the contact area of date fruit (mm^2), E is the Young's modulus of elasticity (kPa), RE is the toughness (J), F_r is the rupture force (N), and D_r is the deformation at rupture point (m).

The contact area between the parallel-plate disk surface and each tested fruit surface was determined by plunger disk surface covered with a white paper fig.1, 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 AutoCAD 9 program that accurately estimates the scanned surface area.

2.5. The height of packing box

The force acting on a fruit at the bottom layer of the bulk box fig. 2 was determined by the force acting on the stacks of fruit. The date fruits represented by cylinders with an average diameter (d) and a square arrangement, which depends on the number and diameter of fruits.

The number of fruits above the bottom layer and the height of packing box can be calculated by equations (8, 9 and 10):

$$F_{\max} = n \cdot m \quad , N \tag{8}$$

$$H_{th} = d \cdot (n+1)\ , mm \tag{9}$$

$$H_{act} = \frac{H_{th}}{S.F.}\ , mm \tag{10}$$

Where, F_{max} is the maximum allowable force on a date fruit at the bottom layer (N), H_{th} is the maximum depth of fruit in box without mechanical damage (mm), H_{act} is the actual depth of fruit in box, mm, the fruit weight (N), n is the number of fruits above the last bottom layer, S.F. is the safety factor ($\approx$ 1.5 – 2) and d is the average fruit diameter, mm (Mohsenin, 1978).

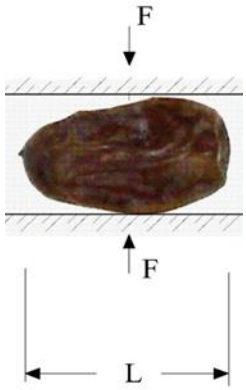


Fig. 1. Date fruit loaded between the two parallel plates

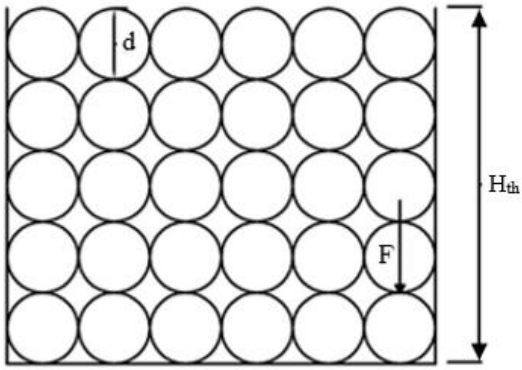


Fig. 2. The height of date fruits in the box

The contact stress can be estimated as a magnitude of the maximum pressure P_{max}, (Pa) between two elastic isotropic bodies (Shigley et al., 2014), which can be calculated by equation 11. As shown in fig. 3, the length of two cylinders (l = fruit length) and diameters d_1 and d_2 used in equation (12) to calculate the narrow rectangle width (2b) of the contact area.

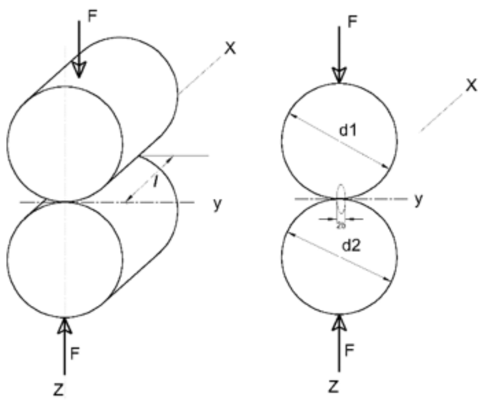
$$p_{\max} = \frac{2F}{\pi b l}\ , \text{Pa} \tag{11}$$

$$b = \sqrt{\frac{2F}{\pi\, l}\frac{\left(1-\mu_1^2\right)/E_1 + \left(1-\mu_2^2\right)/E_2}{1/d_1 + 1/d_2}}\ , \text{mm} \tag{12}$$

Where, b is the half of contact width (mm), F is the acting force on the two cylinders (N), l is the contact length (mm), E_1, E_2 are the modulus of elasticity for cylinders 1 and 2 (Pa), μ_1, μ_2 are the Poisson ratio for cylinders (1) and (2), dimensionless, and d_1, d_2 are the diameter for cylinders 1 and 2 (mm).

2.6. Statistical analysis

Statistical analysis was carried out using a randomized complete block procedure of the M-Stat statistical package. LSD and Duncan multiple range comparison were used to identify means that were different at probabilities of 5 % or less (Mead et al., 2002).



(1) (2)

(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.

Fig. 3. Line contact of two cylinders

3. RESULTS AND DISCUSSION

3.1. Physical characteristics

Some physical properties values of date fruits are shown in table 2. The results showed that the mean values of fruit mass, flesh mass, fruit volume, length, diameter, moisture content and thickness decreased with decreasing irrigation water level, while the mean value of bulk density increased with decreasing irrigation water level from ET_1 to ET_4. The mean value of solid density increased with decreasing water level to ET_2 then decreased with decreasing irrigation water level with ET_3 and ET_4. The previous results were found with all three ripening stages; Khelaal, Rutab and Tamr; the reason for these results is due to the decreasing water of stress in the above-mentioned measurements. Data proved that the physical properties of date fruit were greatly influenced by ripening stage with all irrigation water levels.

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

3.2. Mechanical properties

The mechanical properties studied in this work were modulus of elasticity (E), firmness coefficient (FC), bio-yield stress (σb), bio-yield strain (εb), rupture stress (σr), rupture strain (εr), and rupture energy (RE) at three ripening stages of the examined date as shown in table 3. Ripening stages for date fruit showed a significant effect on mechanical properties ($P < 0.05$).

The longitudinal diameter and the lateral diameter of the date fruits were measured at three ripening stages and under four water levels. The stresses and strains were calculated from the equations (4) and (5). Elasticity, Stress, Strain in the rupture point and the bio-yield point were determined. Modulus values were calculated as the slope of the linear part of the stress – strain curve on the base of regression method.

Compression stress – strain curves of date fruit Khelaal in the lateral loading presented on the fig. 5. The modulus of elasticity in the lateral loading achieved the maximum values 727.7 kPa for ET_2 treatment at Khelaal ripening stage, 13.83 kPa and 55.8 kPa for ET_3 treatment at Rutab and Tamr ripening stages, respectively. Several stresses and strains in the bio-yield points and rupture points were created as seen at the compression curves (6) and table (3). The tissue was compressed and the corruption of the cells of different structures of date fruit was realized.

3.2.1. Stress– Strain curve

Fig. 4 shows the stress*(σ)* -strain*(ε)* curve of Khelaal variety during different ripening stages under four different water levels. For the four irrigation water level treatments, the statistical analysis (at 5% level) showed significant differences for most elasticity properties of date fruits during three stages of ripening (Khelaal, Rutab and Tamr).

Table 2. Average values of some physical properties of date for different treatments.

Treats	Stage	Fruit mass (g)	Flesh mass (g)	Fruit volume (cm^3)	Solid density (g/ cm^3)	Bulk density (g cm^{-3})	Fruit length (mm)	Fruit diameter (mm)	Flesh thickness (mm)	Fruit Moisture content (%)
ET_1 (1 ET_C)	Khelaal	7.44b	3.30c	6.20c	1.23a	0.66a	30.4a	18.7b	17.6b	66.44a
	Rutab	10.24a	4.50b	10.80a	0.95a	0.65b	36.7a	21.8a	20.3a	29.37b
	Tamr	9.53a	5.12a	9.00a	1.06a	0.69a	35.7a	20.2a	19.5a	20.13c
ET_2 (0.9 ET_C)	Khelaal	7.56b	3.25c	6.07b	1.25a	0.67a	30.5a	18.6b	15.1b	66.21a
	Rutab	10.09a	4.36b	10.37a	0.97a	0.65b	36.4a	21.3a	20a	28.36b
	Tamr	9.01a	4.73b	8.24b	1.09a	0.7a	34.9a	20.1a	19.4a	18.86c
ET_3 (0.8 ET_C)	Khelaal	6.59c	2.68d	5.90d	1.12a	0.69a	23.9c	15.0c	13.0d	62.46a
	Rutab	9.20a	3.84c	8.28b	1.11a	0.67a	27.9b	15.5c	14.9d	26.65b
	Tamr	7.59b	4.16b	6.99b	1.09a	0.72a	23.5c	14.1d	14.1d	18.06c
ET_4 (0.7 ET_C)	Khelaal	5.68c	2.50d	5.47d	1.04a	0.7a	23.9c	13.8d	10.6e	62.38a
	Rutab	7.60b	3.09c	7.53b	1.01a	0.68a	27.4b	14.9c	13.0d	25.19b
	Tamr	6.66b	3.60c	6.54b	1.02a	0.72a	23.2c	14.5c	12.5d	18.21c

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

Table 3. Average values of some mechanical properties of date for different treatments.

Treats	Stage	Modulus of Elasticity (kPa)	Firmness Coefficient (N/mm)	Bio-yield point		Rupture point	
				stress (kPa)	strain	stress (kPa)	strain
ET_1 (1 ET_C)	Khelal	707.04a	0.62a	169.69a	0.24c	272.09a	0.55c
	Rutab	13.26c	0.22b	2.652	0.20d	5.61c	0.75a
	Tamr	54.84b	0.13d	24.13b	0.44b	30b	0.7a
ET_2 (0.9 ET_C)	Khelal	727.70a	0.62a	179.36a	0.25c	278.23a	0.57b
	Rutab	13.52c	0.23b	2.75c	0.20d	5.81c	0.76a
	Tamr	55.38b	0.15c	24.92b	0.45a	30.50b	0.73a
ET_3 (0.8 ET_C)	Khelal	707.86a	0.65a	196.63a	0.28c	280.25a	0.60b
	Rutab	13.83c	0.26b	3.14c	0.23c	5.93c	0.78a
	Tamr	55.80b	0.17c	27.44b	0.49a	31.94b	0.75a
ET_4 (0.7 ET_C)	Khelal	712.07a	0.66a	205.11a	0.29c	294.98a	0.61b
	Rutab	13.64c	0.28b	3.16c	0.23c	6.16c	0.79a
	Tamr	55.63b	0.18c	28.79b	0.52a	33.82b	0.77a

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

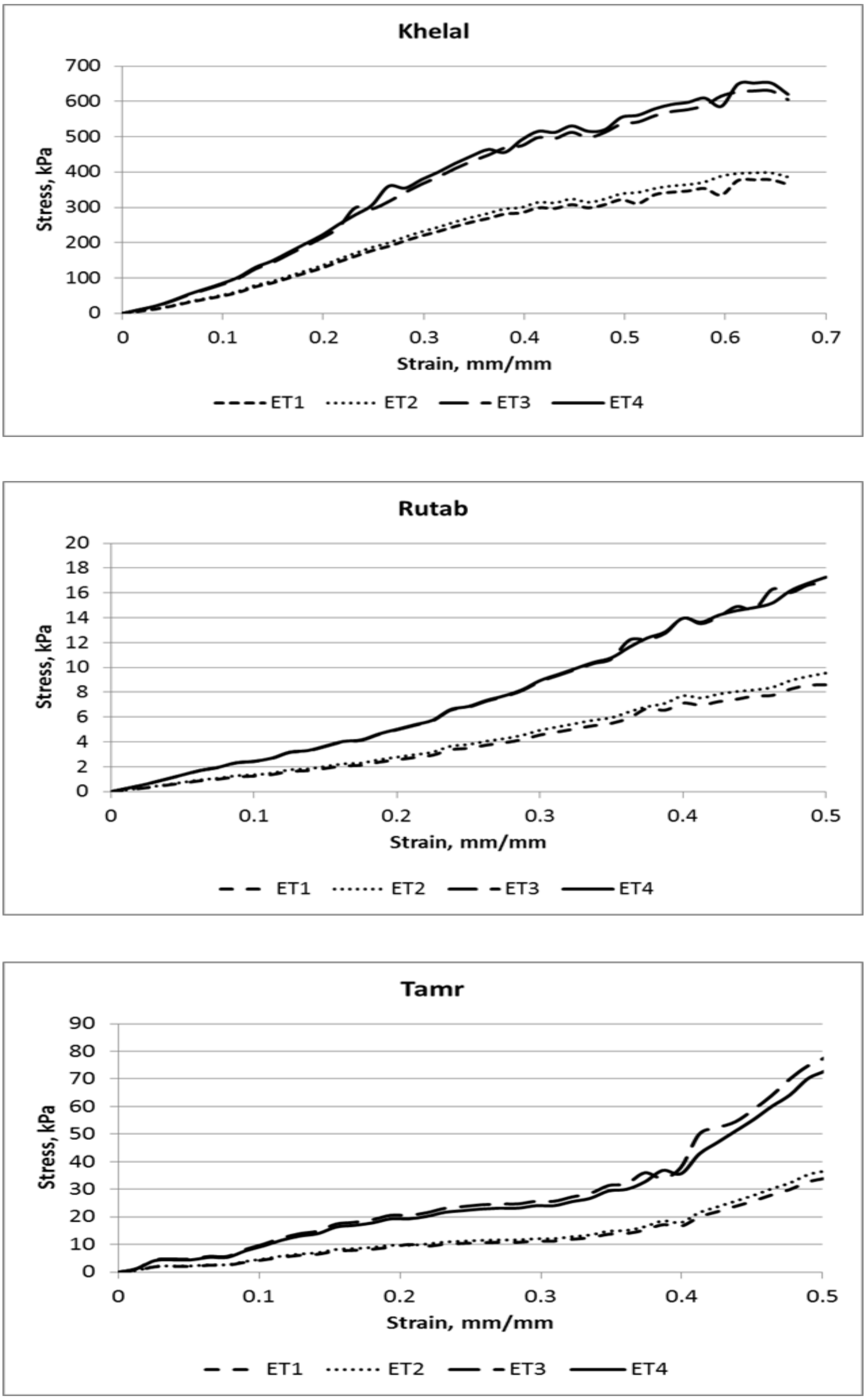


Fig. 4. Stress- strain curves of date fruit (Khelaal) at different ripening stages.

The elastic limits as shown in fig. 5 and table 3 of three ripening stages, Khelal, Rutab and Tamr, were (707.04, 13.26 and 54.84 kPa), (727.7, 13.25, and 55.38 kPa), (707.86, 13.83 and 55.8 kPa) and (712.07, 13.64, and 55.63 kPa) for ET_1, ET_2, ET_3 and ET_4 treatments, respectively. The results showed that the elastic limit decreased from Khelaal 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 on-going maturation process and change from Khelaal 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 Khelaal stage despite the reduction in moisture content at the Rutab stage (Rastegar et al., 2012).

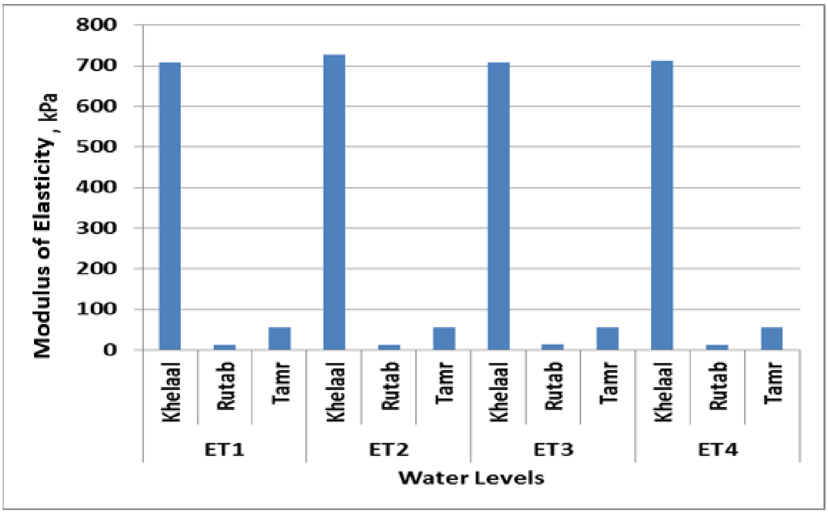


Fig. 5. Modulus of elasticity for different irrigation water levels at different ripening stages of date fruit.

3.2.2. Firmness Coefficient

The average values of firmness coefficient (*FC*) for date fruits at different ripening stages and water levels are shown in table 3 and fig. 6. It is clear that the firmness coefficient (*FC*) decreased from Khelaal to Tamr stage, for all different water levels. Also, the results showed that the values of *FC* increased with decreasing water level. For ET_1 treatment, the values of *FC* were 0.62, 0.22, and 0.13 N/mm for Khelaal, Rutab and Tamr stages, respectively. For ET_2 treatment, the values of *FC* were 0.62, 0.23, and 0.15 N/mm for Khelaal, Rutab and Tamr stages respectively. For ET_3 treatment, the values of *FC* were 0.65, 0.26, and 0.17 N/mm for Khelaal, Rutab and Tamr stages respectively. For ET_4 treatment, the values of *FC* were 0.66, 0.28, and 0.18 N/mm for Khelaal, Rutab and Tamr stages respectively.

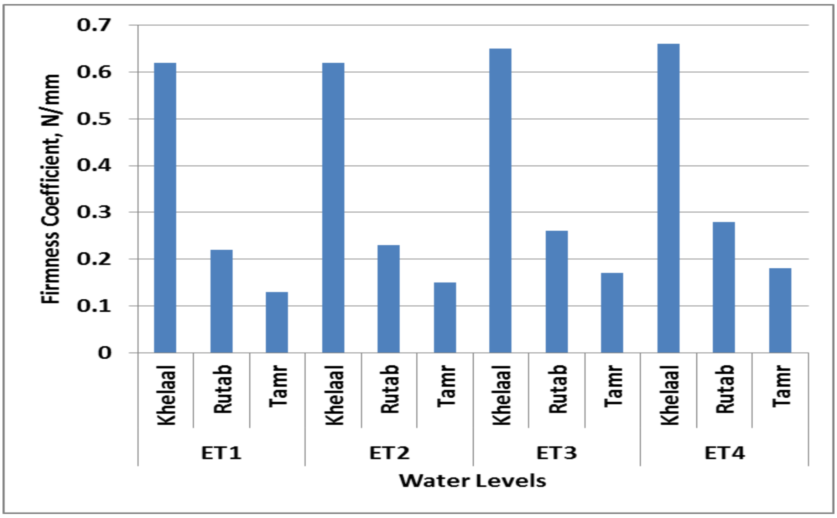


Fig. 6. Firmness coefficient for different irrigation water levels at different ripening stages of date fruit.

3.2.3. Bio-yield stress:

The average values of bio-yield stress *(σb)* for date fruits at different ripening stages and water levels are shown in table 3 and fig. 7. It is clear that the bio-yield stress *(σb)* decreased from Khelaal to Rutab stage, while increased from Rutab to Tamr, with all water levels. In case of ET_1 treatment, the values of *(σb)* were 169.69, 2.65, and 24.13 kPa for Khelaal, Rutab and Tamr stages respectively. In case of ET_2 treatment, the values of *(σb)* were 179.36, 2.75, and 24.92 kPa for Khelaal, Rutab and Tamr stage respectively. In the case of ET_3 treatment, the values of *(σb)* were 196.63, 3.14, and 27.44 kPa for Khelaal, Rutab and Tamr stages respectively. In the case of ET_4 treatment, the values of *(σb)* were 205.11, 3.16, and 28.79 kPa for Khelaal, Rutab and Tamr stages respectively.

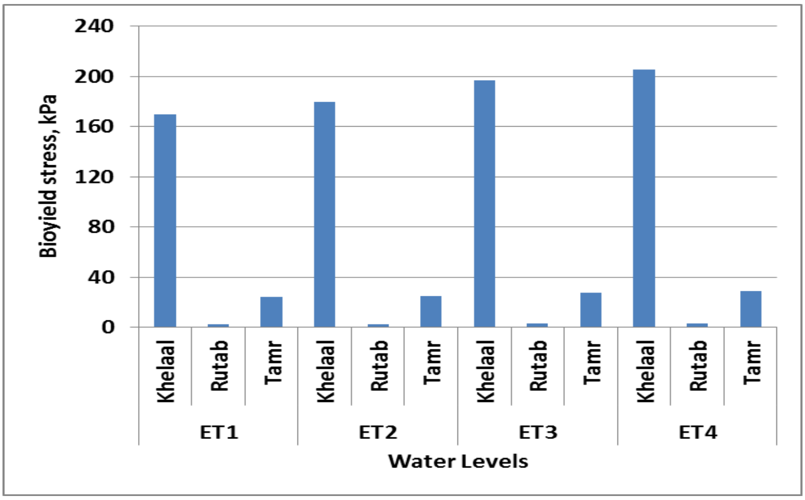


Fig. 7. Bio-yield stress for different irrigation water levels at different ripening stages of date fruit.

3.2.4. Bio-yield strain

The average values of bio-yield strain (*εb)* for date fruits at different ripening stages and water levels are shown in table 3 and fig. 9. It is clear that the bio-yield strain (*εb)* decreased from Khelaal to Tamr stage, with all different water level treatments.

In case of ET_1 treatment, the values of *εb* were 0.24, 0.20, and 0.44 mm/mm for Khalaal, Rutab and Tamr stages, respectively. In case of ET_2 treatment, the values of *εb* were 0.25, 0.20, and 0.45 mm/mm for Khelaal, Rutab and Tamr stages, respectively. In case of ET_3 treatment, the values of *εb* were 0.28, 0.23, and 0.49 mm/mm for Khelaal, Rutab and Tamr stages, respectively. In case of ET_4 treatment, the values of *εb* were 0.29, 0.23, and 0.52 mm/mm for Khelaal, Rutab and Tamr stages, respectively.

The results also showed that the values of bio-yield strain (*εb)* increased with decreasing water level.

3.2.5. Rupture stress

The average values of rupture stress (*σr*) for date fruits at different ripening stages for the different water levels are shown in table 3 and fig. 9. It is clear that the rupture stress (*σr*) decreased from Khelaal to Rutab stage, while increased from Rutab to Tamr, with all different water level.

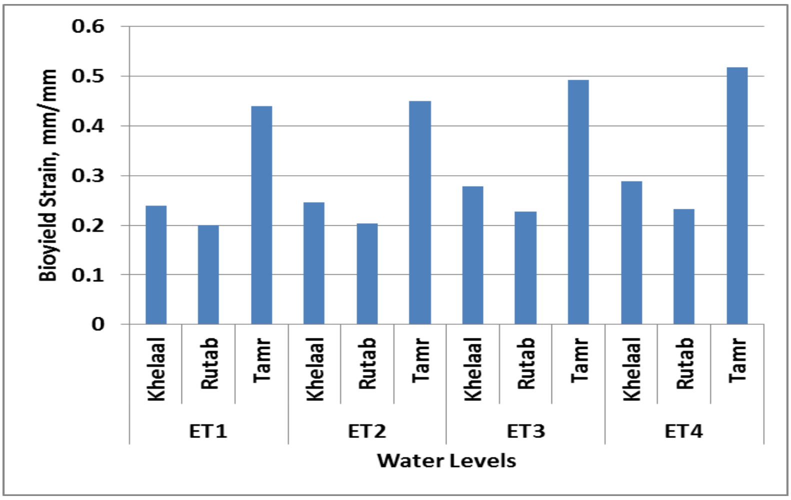


Fig. 8. Bio-yield strain for different irrigation water levels at different ripening stages of date fruit.

In case of ET_1 treatment, the values of σr were 272.01, 5.61, and 30 kPa for Khelaal, Rutab and Tamr stages, respectively. In case of ET_2 treatment, the values of σr were 278.23, 5.81, and 30.51 kPa for Khelaal, Rutab and Tamr stages, respectively. In case of ET_3 treatment, the values of σr were 280.25, 5.93, and 31.94 kPa for Khelaal, Rutab and Tamr stages, respectively.

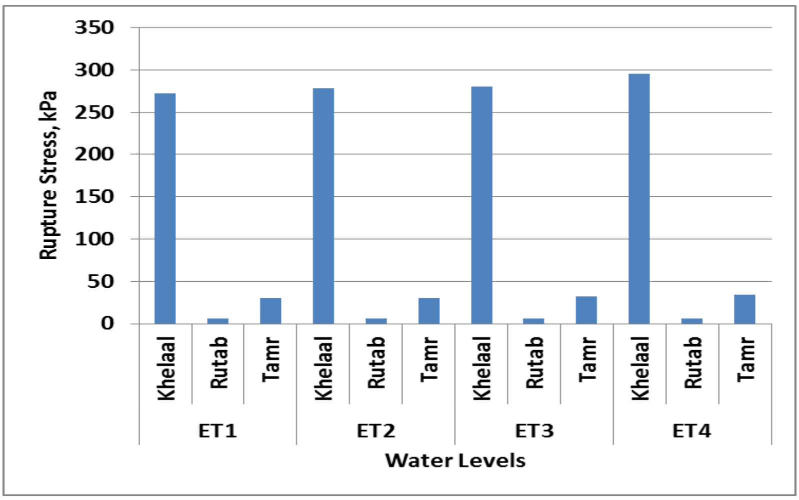


Fig. 9. Rupture stress for different irrigation water levels at different ripening stages of date fruit.

In case of ET_4 treatment, the values of *σr* were 294.98, 6.16, and 33.82 kPa for Khelaal, Rutab and Tamr stages, respectively. The results also showed that the values of rupture stress (*σr)* increased with decreasing water level.

3.2.6. Rupture strain

From the calculated results of rupture strain (*εr)* for date fruits at different ripening stages with different water levels, as shown in table 3 and fig. 10, it found that the rupture strain increased from Khelaal to Tamr stages, and the increased values were obtained from Rutab for all water levels.

In case of ET_1 treatment, the values of rupture strain were 0.56, 0.40, and 0.21 mm/mm for Khelaal, Rutab and Tamr stages, respectively. In case of ET_2 treatment, the values of rupture strain were 0.59, 0.39, and 0.21 mm/mm for Khelaal, Rutab and Tamr stages, respectively. In case of ET_3 treatment, the values of rupture strain were 0.58, 0.41, and 0.22 mm/mm for Khelaal, Rutab and Tamr stages, respectively. In case of ET_4 treatment, the values of rupture strain were 0.61, 0.43, and 0.24 mm/mm for Khelaal, Rutab and Tamr stages, respectively.

The results also showed that the values of rupture strain (*εr)* increased with decreasing irrigation water level. For the different irrigation water levels.

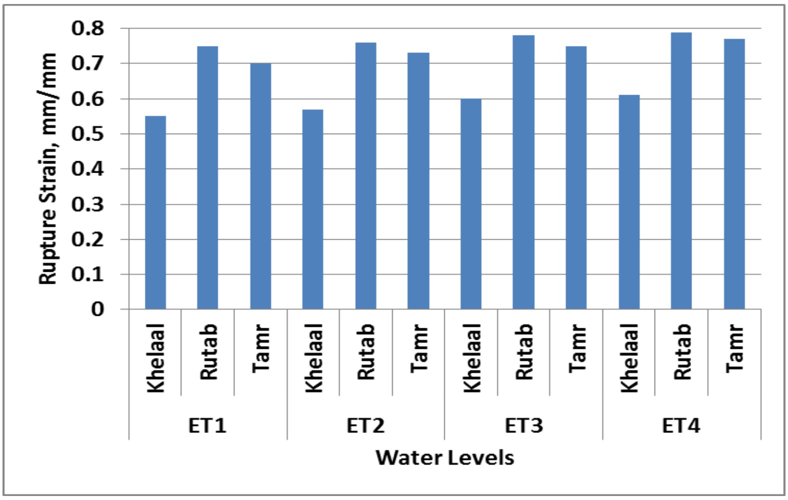


Fig. 10. Rupture strain for different irrigation water levels at different ripening stages of date fruit.

The statistical analysis showed significant differences for all previous mechanical properties (*FC, σb, εb, σr* and *εr*) of date fruits during the three stages of ripening (Khelaal, Rutab and Tamr). These results due to decrease water content in date flesh, which shows some resistance to deformation caused by stress.

3.3. Predicting the height of packing box

In order to get 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 $\approx$ 0.4 .

l = Fruit length.

P_{max} = Bio-yield stress of date fruit.

Substitute equation (10) in equation (11) used to calculate the maximum allowable force (F_{max}) for the three stages (the bio-yield stress in Rutab stage is less than other stages), the values of F, H_{th}, and H_{act} can be calculated as shown in fig.11.

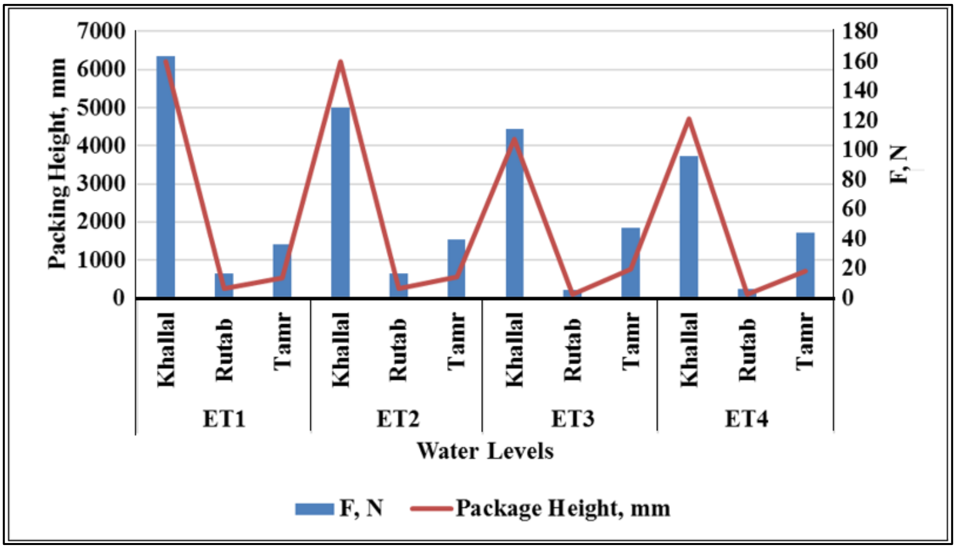


Fig. 11. The maximum force acting and packing height.

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الملخص العربي

خواص المرونة لثمار البلح تحت النقص المائي للتنبؤ بارتفاع العبوة

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يهدف هذا البحث إلى تقدير بعض الخواص الطبيعية والميكانيكية لثمار التمر (صنف خضري) المنزرعة في مزرعة خاصة بمدينة سبها -الجمهورية العربية الليبية (عامى ٢٠١٤-٢٠١٥) أثناء مراحل النضج المختلفة (خلال، رطب، تمر) تحت أربعة مستويات من الإحتياجات المائية ، 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 ثمار التمر خلال عملية النقل والتخزين والتنبؤ بإرتفاع العبوات التى تحافظ على الثمار من هذه الأضرار.

وقد تم تقدير كل من الخواص البعدية للثمرة، سمك اللحم، المحتوى الرطوبى للثمرة، الكثافة الظاهرية للثمار، كتلة وحجم البذرة، وخواص المرونة للثمرة ومنها معامل "يانج" للمرونة، معامل الصلابة، وإجهاد الخضوع الحيوي، إنفعال الخضوع الحيوي، إجهاد التحطم،إنفعال التحطم.

و قد بينت نتائج الدراسة ما يلي:

١. توجد فروق معنوية بين مراحل نضح المختلفة للثمرة في معظم الخصائص الطبيعية لمستويات الرى المختلفة.
٢. توجد فروق معنوية بين مراحل نضح الثمرة في الخصائص الميكانيكية لصنف خضري لمستويات المياه المختلفة: معامل يانج للمرونة ومعامل الصلابة وإجهاد الخضوع الحيوي وانفعال الخضوع الحيوي وإجهاد التحطم وانفعال التحطم والطاقة اللازمة للتحطيم.
٣. تقل قيم الخواص الميكانيكية من مرحلة الخلال إلى مرحلة الرطب ثم بعد ذلك تزيد من مرحلة الرطب إلى مرحلة التمر وذلك مع مستويات الرى المختلفة.
٤. أقصى إرتفاع مأمون للعبوات لمراحل النضج الثلاثة (خلال ورطب وتمر) كانت ٦٣٦٠,٥١ و ٦٥٤,٢ و ١٨٥٠ مم مع المعاملات ET_1، ET_2، ET_3 على الترتيب. بينما كان أقل ارتفاع مأمون للعبوات لمراحل النضج الثلاثة (خلال ورطب وتمر) كانت ٣٧٣٨ و ٢٦٠,٦ و ١٤١١ مم مع المعاملات ET_4، ET_3، ET_1 على الترتيب.

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