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Some physical and mechanical properties of date palm trees related to cultural operations industry mechanization

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This study was conducted to find some important physical and mechanical properties of date palm trees to be applicable in mechanization of date palm cultural operations industry. To determine the tree trunk mechanical properties as tensile, compressive and shear strength, 9 tree trunk samples were selected at random from different locations within the living trunks and tested by appropriate equipments. Two special tools which had been designed and constructed in Silsoe College were used for tests on the cut trunks and on the leaf bases of living trees. The tree trunks average strengths results showed that the longitudinal tensile strength and longitudinal compressive strength are 60 and 5.34 MPa respectively. It was also indicated that the radial compressive strength is 2.96 MPa and longitudinal shear strength is 1.10 MPa. The experiment was carried out on the tree trunk leaf bases. It showed that the tree leaf base radial compressive strength is 6.38 MPa and the longitudinal leaf base shear strength is 1.00 MPa. The results showed that the safety factor of stresses exerted to the tree by a worker or a light tree climbing machine that climb a healthy producing date tree vary from 7 to 198 which are far from 1, the critical value. The results of tree trunk strengths can be used to reduce the human, tree and machine damages in the date palm cultural operations. These can help to design safe tree shakers and other date palm mechanization machinery by identification of stress limits and safety factors of different stresses exerted to the tree by human or different machines. Results showed that there were significant differences in important physical properties in tree height, spacing, yield and circumference between main cultivation areas around the world. Results can be used for determining acceptable range of sizes and values of features for a new technically acceptable date palm service machine.

Key words: date palm tree, physical and mechanical properties, date palm mechanization, cultural operations, tree and human safety

Introduction

The date palm (*Phoenix dactylifera* L.) is a mono cotyledon of the family of the Palmate. It is a feather palm, characterized by compound leaves with a series of leaflets on each side of a common petiole, originating from one

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growing point at the top of the trunk. The date palm may reach an age of over 100 years and reach up to 24 m in height to the growing point normally the age limit is less than this and consequently the height will not be more than 15-20 m maximum before it was cut down due to declining yield and the increasing difficulty (and danger) of reaching the crown during pollination, bunch management and harvesting (Seelig, 1974).

The most popular date palm cultural operations carried out in orchards are the following: pollination, dehorning, pruning, fruit thinning, bending and bagging of bunches and pesticide control. Brown (1983) showed that among cultural operations, harvesting, pollination and pruning are the most labor intensive work accounting for more than 80 percent of the total production costs.

There are two methods of date palm cultural operations, traditional and mechanical. The most difficult part of the date palm cultural operations is reaching the worker to the crown of the tree. It is because the trees are too tall and the worker is at the risk of falling out off the tree. Using the tree trunk leaf bases to climb the tree in Iran, Iraq and Libya is a traditional way of cultural operations (Nixon, 1969). Al-Kiady (2000) reported that the skilled and specialized labors were becoming rare and expensive causing a serious depression in date production industry. Mechanized cultivation methods can improve the date quality and mechanization of date palm cultural operation is essential to optimize this industry (Albozahar, 2003). There is a major interest in the mechanization of date cultural operations, because most of them are hazardous, time consuming and require skilled labor in Middle East, the origin of this fruit (Ismail & Al-Gaadi, 2006; Mazloumzadeh *et al*., 2008). Enough and comprehensive information about date palm characteristics such as physical and mechanical properties will enhance the mechanization in this sector. In most of the mechanized cultural operations, especially in the following studies that a machine moves on the tree trunk, the tree tolerates some stresses. To guarantee the tree, the machine and the worker safety it is important to know the date palm tree mechanical properties and the stresses these machines impose on the tree.

Davis (1977) developed a coconut tree climbing bicycle, it consisted of an angle-iron framework with wooden platform on which the operator rides. Friction rollers are passed against the trunk of the palm by the operator's weight and he is carried to the top as he turns the handle by hand. Abdalla *et al.* (1986) developed a simple walk-up elevator to suit date cultural operations. The elevator was designed where a worker can lift himself up by pedaling. Saring *et al*. (1989) in Israel developed an integrated mechanical system that could harvest the fruits by shaking the tree trunk. Shamsi (1990) designed a sprocket type climbing machine to harvest dates. The operator sits on a frame and holds on to a handle. He then drives the climber by pushing the pedals with his feet. Nicklin (1993) designed a tree climbing test rig to lift a man up to the date palm trees. Shamsi (1998) designed and developed a tree climbing date harvesting test rig in Silsoe College*. This machine climbed up the tree trunk to reach the fruit bunches. Many studies have been reported on the physical properties of date palm trees, but no detailed study concerning mechanical properties of tree trunks have been performed.

Perkins and Brown (1964) used a harvesting system which three men including a truck driver, a boom operator and a bunch cutter or shaker operate it. Al-Suhaibani *et al*. (1988) made a date service machine in Saudi Arabia which was designed at Silsoe College. They carried out a survey on 19 orchards in Saudi Arabia and measured some physical properties as tree spacing, tree height, trunk circumference, bunch spacing and ground profile. Ahmed *et al*. (1992) obtained some date palm physical properties to be applicable in date palm mechanization. They obtained tree features as age, height, trunk circumference, spacing and cutting resistance of the leaves. Abounajmi (2004) focused on the development of date fruit harvesting mechanization. He discusses the strategies for improving new method for date palm cultural operation, and factors affecting on it. Fadel (2004) designed a date palm service platform based on some date palm physical properties. Fadel (2005) also designed and developed a tractor-mounted date palm tree service machine. The machine had the capability to lift a worker and the required tools to the crown zone as high as 4.5m. Mazloumzadeh and Shamsi (2007) evaluated alternative date harvesting methods in Iran using some physical properties of date palm trees. They showed that any new harvester machine must be able to reach the lifting height of 10 m. it must be able to carry a maximum payload of around 1100-1300 N and have a length less than 3 m. Shamsi *et al.* (2005) found some physical properties as date palm visual appearance, yield, fruit quality, tree age and number of bunches to be applicable in precision agriculture. Mazloumzadeh *et al*. (2007) designed and developed a light tractor-mounted date palm service machine. Machine could reach to a maximum working height of 10 m with maximum payload of 130 kg. Mazloumzadeh *et al*. (2008) developed a fuzzy decision making technique to classify available general-purpose lifters in Iran for the date harvesting industry based on some physical properties of date palm trees.

Materials and methods

The date palm physical and mechanical properties study was carried out in Bam and Shahdad, two main date producer areas in Iran which is the second world producer. The failure stress tests were conducted on newly cut tree trunks. The trunk was cut into the small samples which were tested by

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equipment in the material physical testing laboratory of Kerman University. Two special tools which had been designed and constructed in Silsoe College were used for tests on the cut tree and on the leaf bases of living trees.

Physical parameters including tree trunk height, tree circumference at ground and crown, bunch and stalk weight, number of bunches, leaf base pitch, leaf base height, yield and tree spacing including inter row spacing, intra row spacing and distance to nearest tree were measured using different equipments. 25 random trees in 9 different orchards were selected for testing / measurements.

There are three kinds of direct stresses to which timber can be subjected; tensile, compressive and shearing. Timber is not isotopic and has three structural axes and consequently has three different sets of values for mechanical properties in the three directions (Silvester, 1967). The three structural axes of wood are longitudinal, radial and tangential. When considering the structure of wood in relation to its structural axes, it is easy to appreciate the importance of axes orientation in respect of mechanical properties.

The difference in the strength properties of wood on the radial and tangential axes, however, is not considered to be of significant importance. It is usual, therefore, in structural design to consider the strength of timber only parallel with the grain, i.e. loaded in the direction of the longitudinal axis, or perpendicular to the grain when loaded on the radial or tangential axes.
To find which stresses should be measured the behavior of human and machines on the tree were analyzed.

Machines exert a radial stress σ_r and $\tau_l = \mu \times \sigma_r$, which is a longitudinal shear stress develops on the trunk as shown in Fig. 1. μ is the coefficient of friction between the machine wheel and the tree. If a tree climbing machine is equipped with a pneumatic tire, the tire foot pint area changes with load such that σ_r stays constant and equal to the tire inflation pressure.

Measurement of friction coefficient

The aim of this experiment was to establish the coefficient of friction between the wheel of a tree climbing machine and the tree trunk surface. Three leaf base samples were prepared using a hand saw. The test was done with three replications for each sample. To simulate the real condition, a piece of rubber from a tire was glued to a steel holder. The rubber sample was loaded to 20 N. The weight of the rubber holder and the rubber sample was 2.1 N. The total weight of the unit was 22.1N. One end of a plastic rope was tied to the rubber holder and the other side to a spring balance. The sample was fixed onto the table by a clamp. The rubber was placed on the sample and was pulled by the spring balance which displayed a maximum of 100 N with 1N resolution. At the point that the rubber starts to slip over the sample the amount of force was read from the spring balance. Result of the test can be seen in Table 1. The tree surface is covered with leaf bases on which the tire works; therefore, the radial compressive stress and longitudinal shear stress was measured for both the tree surface (leaf bases) and the tree trunk. The minimum stress values can be used for the design calculations of tree climbing date harvesting machines.

The human or machine applies their total weight as an eccentric load to the tree. This phenomenon produces varying stress levels on different parts of the tree. The maximum value of the stress was calculated from the principles of columns stress analysis (Beer & Johnson, 1981). According to this analysis the eccentric load of machine weight, W, on the tree which is considered as a column can be replaced with a central load of the same value and a moment equal to the product of the load and the eccentricity as is shown in Fig. 2.Then the maximum tensile and compressive longitudinal stresses, σ_t and σ_c on the tree can be calculated from the Eqns (2) and (3).

$$\sigma_t = \frac{W}{A} - \frac{My}{I} \qquad (1)$$

$$\sigma_c = \frac{W}{A} + \frac{My}{I} \qquad (2)$$

Where A is the tree cross section area in mm2 and is equal to πr^2 in which r is tree radius in mm. M is equal to W × x, maximum moment and y is farthest element distance from the neutral axes in the tree cross section which is equal to the tree radius in mm. I is moment of inertia, equal to $\pi r^4/4$ for a circular (tree) cross section.

Nine tree trunk dates samples were selected at random from different locations within the trunk for each test. Date palm trunk samples were prepared and tested. British Standard 373 (1957), "Method of testing small clear specimens of timber", was used to select the sample sizes and test methods. The tree trunk samples were tested for: Tensile strength in longitudinal direction, compressive strength in longitudinal direction, compressive strength in radial direction and shear strength in longitudinal direction. The leaf bases were also tested for: compressive strength in radial direction and shear strength in longitudinal direction.

Leaf base radial compressive strength measurements

To measure the maximum radial compression that the leaf bases on the live tree can tolerate a tool was designed and constructed for use in the field. As is shown in Fig. 3a, the tool comprises mainly of a lever in the shape of an angled beam. At one end (A) the angled beam is hinged to a plate which is attached to the tree and at the opposite end (C) weights are suspended on the tool. The weight action pushes a 4 mm diameter pin at point B to the leaf base in the radial direction. The criterion to select the pin diameter was reaching the failure stress by suspending a reasonable weight from point C.

Table 1. Horizontal force needed to pull the rubber on the leaf base sample.

Sample	**A**			**B**			**C**			**Average**	**Standard deviation**
Replication	I	II	III	I	II	III	I	II	III		
F_h, N	17	18	17	21	20	20	19	18	19	18.8	1.4

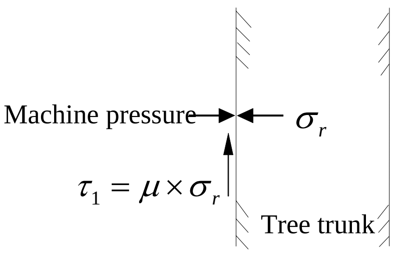


Fig. 1. Stresses on a tree trunk (The radial compressive stress(σ_r) and the longitudinal shear stress (τ_1))

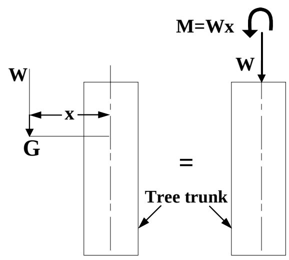
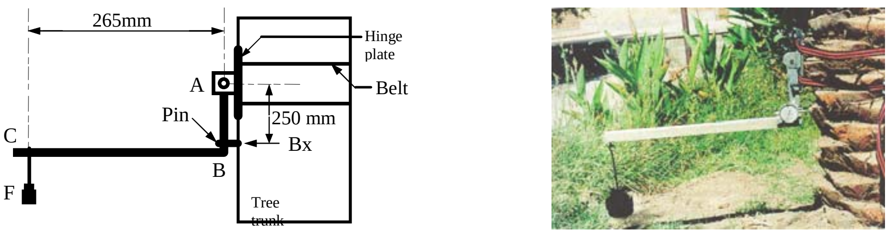


Fig. 2. Machine or human load transformation on a tree trunk



(a) (b)

Fig. 3. (a) Block diagram of the leaf base compressive strength measuring tool; (b) Date tree trunk leaf base compressive strength tool.

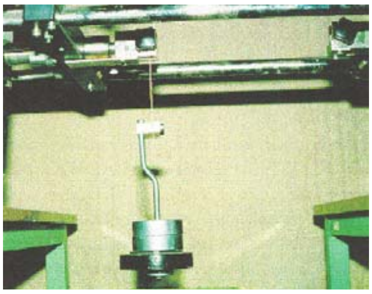


Fig. 4. Tensile strength test on a fibre.

A clock gauge connected to the tool is used to measure the depth of penetration of the pin into the leaf bases. It can be also used to draw the force, penetration diagram for the leaf bases. The pin clearly and suddenly penetrated the leaf base at a specific load. The stress at the point of failure was recorded as the maximum radial stress that can be tolerated by the leaf base. The tool is held onto the tree by two belts which are connected to the hinge plate and positioned around the tree as can be seen in Fig. 3b. After tying the belts around the tree and fastening them four adjusting bolts are used to align the plate in a vertical plane. The pin length should then be adjusted to ensure the tool lower beam is horizontal. Following these adjustments, the tool is ready to be loaded.

To convert the loading at point C to the radial compressive stress at point B the Eqns (3) and (4) was used:

σ_r = (Bx + tool weight reaction force) / (pin cross section). (3)

To find Bx a moment was taken about point A in Fig. 3a:

$\sum M_A = 0$ or 565 F - 250 Bx = 0 or Bx = 2.16 F. (4)

Using a spring scale showed that the tool weight exerts a horizontal force equal to 7.5 N at point B. Substituting this value and Bx from Eqn (4) in Eqn (3), for a pin diameter of 4 mm:

$$\sigma_r = 0.59 + 0.18\ F \quad (5)$$

Equation (5) was used to convert the loading (F) at point C to the compressive stress in radial direction (σ_r) developed on the leaf base at point B. The results of the loading F and conversion to compressive strength are shown in Table 6 with a mean value of 6.38 MPa.

In all tree loading conditions the safety factor (SF) is calculated from the Eqn (6): SF= (strength/ applied stress) (6)

Results and discussion

The interactions between tree, human and machine are summarized in the following headings:

Coefficient of friction between machine and tree trunk

The coefficient of friction (μ) could be calculated from the Eqn(7):

$$\mu = F_h / F_v \tag{7}$$

Where F_h is force reading from the spring balance and F_v is the total weight of the unit. The test was carried out based on the method explained in previous sections. Substituting 18.8 for F_h and 22.1 for F_v in Eqn (5) from Table 1, μ has an average value of 0.85.

Tree trunk tensile strength in longitudinal direction

The tree trunk and bark are composed mainly of bundled fibres which transfer water and nutrients to the leaves and fruits. An individual fibre can carry considerable load. To measure the trunk tensile strength one fibre was separated from each 20 × 20 × 300 mm sample and loaded by 1 N increment until separation (Fig. 4). The results are presented in Table 2. The tensile strength from Table 2, is equal to the average load that one fibre can carry until separation (68 N) multiplied by the average number of fibres per unit of area (0.88) which is 60 MPa.

Table 2. Tree trunk longitudinal tensile strength.

No.	1	2	3	4	5	6	7	8	9	Average	Standard deviation
Force, N	72	77	62	57	59	72	81	65	69	68	8
Fibres per mm^2	0.92	0.83	0.95	0.90	0.89	0.92	0.85	0.80	0.87	0.88	5
Strength, MPa	66.24	63.9	58.9	51.3	52.51	66.24	68.85	52	60.03	60	

Tree trunk longitudinal compressive strength

The tree trunk test samples of 50 × 50 × 50 mm were prepared and loaded in longitudinal direction with a hydraulic press until sample starts to deform and release water. The results are shown in Table 3 with an average strength of 5.34 MPa.

Table 3. Tree trunk longitudinal compressive strength.

No.	1	2	3	4	5	6	7	8	9	Average	Standard deviation
Load, N	13000	13300	13400	13300	13500	13200	13800	13500	13400		
Area, mm^2	2601	2525	2500	2500	2450	2575	2401	2500	2525		
Strength,MPa	5.00	5.27	5.36	5.32	5.51	5.13	5.75	5.40	5.31	5.34	0.21

Tree trunk radial compressive strength

The tree trunk compressive test was carried out by applying a force in the radial direction, the samples of 50 × 50 × 50 mm failed due to shear force which developed in the 45° plane relative to the compressive force direction. The results show that the average radial compressive strength is 2.96 MPa. (Table 4).

Table 4. Tree trunk radial compressive strength.

No.	1	2	3	4	5	6	7	8	9	Average	Standard deviation
Force, N	7800	6800	7200	7300	7400	7300	7700	7500	7400		
Area, mm^2	2500	2425	2474	2500	2523	2475	2525	2601	2425		
Strength, MPa	3.12	2.80	2.90	2.92	2.93	2.95	3.05	2.88	3.05	2.96	0.10

Tree trunk longitudinal shear strength

The hydraulic and mechanical press could not measure the shear strength directly. A shear tool was designed in order to convert the compressive force of the press to shear force. The principle involves, a moving jaw with an opposing stationary jaw; each jaw holds half of the sample. Loading the moving jaw creates a shear force equal to the compressive load on the sample in a vertical plane. Shear strength measurements were conducted using this tool. Longitudinal samples of 20 × 20 × 20 mm were cut from the trunk fixed in the shear tool which was loaded gradually up to the breaking point where in there is complete shear occurs in the sample. The results are shown in Table 5 with a mean value of 1.1 MPa.

Leaf base radial compressive and longitudinal shear strengths

The leaf bases were tested for compressive and shear strengths. The compressive test was done by the special tool designed and showed in Fig. 3a.

The results of the loading, F, and conversion to compressive strength are shown in Table 6 with a mean value of 6.38 MPa.

The shear strength testing of the leaf bases was conducted employing the same method and tool used for the tree trunk shear test. Sample sizes of 20 × 20 × 20 mm were used for the test. The results are shown in Table 7 with a mean strength value of 1.00 MPa.

To show the typical use this study, the results were measured the safety factors for a human and a machine. To calculate the working stresses, Eqns (1) and (2) and data of Tables 1 to 7 were used. The SF was calculated from Eqn (6). The critical condition of stresses is when the human or machine with full equipments are climbed and worked on a minimum diameter tree. Data of field measurements show that the minimum diameter of a producing date tree is 280 mm (Al-Suhaibani *et al.*, 1988). The expert man who climbed the tree plus his tools, at an eccentric distance of 500 mm, exerts maximum 1300 N force to the tree. Calculated FS for this condition was calculated which varies from 11.5 to 198.

An experimental tree climbing date harvesting machine inserts 1880 N load at an eccentric distance of 300 mm to the tree (Shamsi, 1998). The results show that the minimum SF when this machine climbs the tree is 7. It is far from 1, the critical SF. The complete results are tabulated in Table 8.

Summary of some physical properties and tree spacing of date palm trees are tabulated in Table 9. Tree height is a key factor for lifting height of any machine to lift a worker to the date palm crown for cultural operations. Results showed that the producing trees height in studied area was varies from 6.5-17 m with average of 10.3 m. Al-Suhaibani *et al.* (1988) recorded tree height average of 7.4 m for 6 varieties of date palms in Saudi Arabia with minimum and maximum values of 1.00 and 17.43 m. Ahmed *et al.* (1992) measured height of date palm trees in different locations in range of 1.1-10.2 m. Fadl (2004) recorded the average height of 4.9 m for nine different varieties of producing date palm trees with minimum and maximum values of 2.5 and 6.8 m in UAE. Fadl (2005) also reported the average height of 2.9 m in three UAE date palm cultivars. Kerama *et al.* (2007) found the average height of 5.3 m for Shahani variety of date palms in Iran that was in range of 10-45 years old. Mazloumzadeh *et al.* (2007) recorded the average height of 6.4 m for most important variety of dates in Iran (Mozafati) with minimum and maximum values of 1.9 and 10.7 m.

Tree yield is an important factor for determining payload capacity of any date harvesting machine. Table 9 shows that the average and maximum tree yield were about 67 and 128 kg respectively. Shamsi *et al.* (2005) found the average production of 85 kg for Mozafati variety of dates. Considering average production of 20 kg per tree in the Iran (Anon, 2003), there is a significant different between these data.

The tree bunch and stalk weight and number of bunches are also important factors for determining machine payload capacity in bunch cutting method is used where all fruits on a bunch ripen simultaneously. The results were shown in Table 9. The average trees inter and intra rows spacing were 5.8 and 4.6 m respectively and the average distance to nearest tree was 3.66 m. Al-Suhaibani *et al*. (1988) recorded the average distance between trees about 5.71 m in range of 5-6.8 m. They also showed average distance between neighboring trees about 3.89 m. Mazloumzadeh *et al*. (2007) found the average Mozafati cultivar tree spacing about 5.5 m.

Table 5. Tree trunk longitudinal shear strength.

No.	1	2	3	4	5	6	7	8	9	Average	Standard deviation
Force, N	425	390	410	450	405	455	430	415	470		
Area, mm^2	380	400	370	410	400	409	370	409	400		
Strength, MPa	1.12	1.08	1.11	1.10	1.02	1.11	1.16	1.01	1.18	1.10	0.06

Table 6. Leaf base radial compressive strength.

No.	1	2	3	4	5	6	7	8	9	Average	Standard deviation
Force, N	27	40	32	31	29	39	37	28	30		
Strength, MPa	5.45	7.79	6.35	6.17	5.81	7.61	7.25	5.63	5.99	6.38	0.96

Table 7. Leaf base longitudinal shear strength.

No.	1	2	3	4	5	6	7	8	9	Average	Standard deviation
Force, N	450	380	415	420	410	455	290	355	430		
Area, mm^2	400	390	400	400	390	380	410	430	410		
Strength, MPa	1.13	0.97	1.04	1.05	1.05	1.20	0.71	0.82	1.05	1.00	0.15

Based on the analysis tree spacing showed significantly differences between inter row, intra row and distance to nearest tree spacing. It showed that the tree spacing is not standardized, so available machines may not achieve required turning circle. It also indicated that most of date palm trees are randomly planted and often inter cropped with forage and vegetable crops and sometimes inter cropped with other fruit trees such as citrus.With respect to traditional cultivation methods and the valuable idea of cultivation of fruit trees such as oranges under the shadow of palm trees, the available machines have some limitation in length, width and height.

Table 8. Safety factor of stresses applied to the tree by human or machine.

Type	Equation	Human stress, MPa	Machine stress, MPa	SF, human	SF, machine	
				Tree trunk	Tree trunk	Leaf base
σ_r	σ_r = Machine pressure		0.17		17	38
τ_l	$\tau_l = \mu \times \sigma_r$		0.14		8	7
σ_t	Equation 1	0.302	0.406	198	148	
σ_c	Equation 2	0.323	0.467	16.5	11.5	

Table 9. Summary of some physical properties and tree spacing of date palm trees.

Producing trees features	Min	Max	Mean	Standard deviation
Tree trunk height, m	6.5	17	10.3	3.6
Yield, kg	34.1	127.6	66.9	28.2
Tree circumference at ground, cm	157	267	200.7	32.7
Tree circumference at crown, cm	94.2	201.6	138.5	29.2
Inter row spacing, m	4.1	7.3	5.8	0.96
Intra row spacing, m	3.5	5.7	4.6	0.69
Distance to nearest tree, m	2.5	5.2	3.66	0.74
Bunch and stalk weight, kg	6	14.5	9.67	2.66
Number of bunches	7	11	8	2
Bunch circumference, cm	125.7	204.2	160.2	41.5
Bunch height, cm	42	111	77.2	28.3
Leaf base pitch, cm	6	11.5	9.4	1.99
Leaf base height, cm	4.1	7.5	6	1
Worker climbing speed, m/sec	0.18	0.41	0.31	0.08
City	Bam, Shahdad			
Grove name	Dehghan, Istghah, Sabzevary, Shahrdadi, Baghe rig, Kohestani, Rahmani, Char farsahk, Saheb dadi			
Variety	Mozafati, Karoot, Ghasab, Porkoo, Bazmani			

Tree circumference is an important criterion for designing U shape platforms for any date palm service machine. Results showed that tree circumference at the ground vary from 157-267 cm with average value of 200.7 cm, while average circumference at crown was measured as 138.5 cm in range of 94.2-201.6 cm. Al-Suhaibani *et al.* (1988) found that the averages of date palm tree circumference vary from 130 to 180cm with maximum and minimum values of 256 and 90 cm in different location. Ahmed *et al*. (1992) found the tree circumference in ranges of 116-172cm. Fadel (2004) reported the average tree circumference of 155cm in range of 140-140 cm in nine UAE date palm cultivars. Fadl (2005) also reported the average tree circumference of 193 cm in range of 170-210 cm in three UAE date palm cultivars. Mazloumzadeh *et al*. (2007) recorded the Mozafati date tree circumference in range of 150-226 cm with average of 190 cm.

Leaf base pitch and Leaf base height parameters were very important factors for designing any new date palm climbing machine structure and dimensions. Results are shown in Table 9.

The physical and mechanical properties of the date palm trees are necessary for the design of appropriate equipments for date palm cultural operations. This study was conducted to find some important physical and mechanical properties of date palm trees. The strength test results are summarized in Table 10. These are the strength limits at which damage to the tree occurs. To satisfy the tree safety any machine or human should exert forces and stresses lower than these values. It is important to know that the fibres are positioned in longitudinal direction and mostly parallel to each other for the whole length of the tree trunk. They exhibit poor resistance to longitudinal shear stress. It is also obvious from the test results.

It is also important to consider that the leaf bases can tolerate greater radial compressive stresses than the tree trunk; therefore, the lower strength value which is belong to the tree trunk must be adopted as the design criterion for any tree climbing machine. Test results in Table 8 show, high SF for different loadings on the tree by human and light tree climbing machines. It gives self confidence to a worker who climbs the tree and afraid of the tree trunk breakage. In the date palm cultural operations industry, occasionally two or three workers climb the tree together, it reduce the FS for them. In some date palm trees, disease decreases the tree trunk circumference and it also strongly reduces the SF for workers. The Mechanical properties findings can be used as a based knowledge for wide range of applications such as furniture and composites industries.

Comparison between of the results, date palm physical properties showed that there were significant differences in tree height, spacing, yield and circumference between most important cultivation areas around the world. It clears that any new date palm service machine must be adopted with local cultivation conditions and any date palm cultivation in the area needs different mechanization equipments from others.

Table 10. Stress test results.

	Tree trunk	Leaf base
Average compressive strength in radial direction (σ_r), Mpa	2.96	6.38
Average shear strength in longitudinal direction (τ_l), Mpa	1.10	1.00
Average tensile strength in longitudinal direction (σ_t), Mpa	60	
Average compressive strength in longitudinal direction (σ_c), Mpa	5.34	

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