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Some Physical and Mechanical Properties of Jujube Fruit

D. Zare, H. Safiyari, F. Salmanizade

Abstract**—**In this study, some physical and mechanical properties of jujube fruits, were measured and compared at constant moisture content of 15.5% w.b. The results showed that the mean length, width and thickness of jujube fruits were 18.88, 16.79 and 15.9 mm, respectively. The mean projected areas of jujube perpendicular to length, width, and thickness were 147.01, 224.08 and 274.60 mm^2, respectively. The mean mass and volume were 1.51 g and 2672.80 mm^3, respectively. The arithmetic mean diameter, geometric mean diameter and equivalent diameter varied from 14.53 to 20 mm, 14.5 to 19.94 mm, and 14.52 to 19.97 mm, respectively. The sphericity, aspect ratio and surface area of jujube fruits were 0.91, 0.89 and 926.28 mm^2, respectively. Whole fruit density, bulk density and porosity of jujube fruits were measured and found to be 1.52 g/cm^3, 0.3 g/cm^3 and 79.3%, respectively. The angle of repose of jujube fruit was 14.66° (±0.58°). The static coefficient of friction on galvanized iron steel was higher than that on plywood and lower than that on glass surface. The values of rupture force, deformation, hardness and energy absorbed were found to be between 11.13-19.91N, 2.53-4.82mm, 3.06-5.81N mm and 20.13-39.08 N/mm, respectively.

Keywords**—**Mechanical and Physical properties, Jujube fruits, friction coefficient

I. INTRODUCTION

TO properly design machines for harvesting, handling, processing and storage one should be aware of material physical properties. These properties include size, shape, mass, volume, sphericity, bulk density, true density, porosity, geometric mean diameter, projected area, surface area, radius of curvature, etc. The study of size of fruits is essential for uniformity and packing in standard cartons or storage in container. Shape and physical dimensions, such as major, intermediate and minor diameters, unit mass, volume and sphericity, are important in screening solids to separate foreign materials and in sorting out various sizes of fruits and vegetables [1]. In addition, knowledge of frictional properties is necessary in designing of handing equipment and storage structures [2]. These engineering properties are useful to the engineers as well as food scientist and processors.

Jujube is a species of Ziziphus in the buckthorn family Rhamnaceae, used primarily as a fruiting shade tree. The jujube is a little known fruit, but is gaining momentum in Western cultures for its high amount of vitamins and minerals.

D. Zare is with Department of Agricultural Engineering, Shiraz University, Shiraz, Iran (P. O. Box: 7144165186, e-mail: dzare@shirazu.ac.ir).

H. Safiyari, is graduate student in Department of Agricultural Engineering, Shiraz University, Shiraz, Iran (e-mail: safiyari.hasan@gmail.com).

F. Salmanizade is graduate student in Department of Agricultural Engineering, Shiraz University, Shiraz, Iran.

It has been used for thousands of years in Asian countries by medicine men and herbalists alike. Jujube contains the potassium, phosphorus, manganese and calcium as the major minerals. There are also high amounts of sodium, zinc, iron and copper. Jujube also contains vitamin C, riboflavin and thiamine. It contains 20 times the amount of vitamin C as citrus fruits. The vitamin and mineral content of the fruit helps to soothe the stomach, ease sore throats, suppress the appetite, support cardiovascular health, enhance metabolism and cleanse the blood vessels.

In recent years many researches have been worked to measure the physical and mechanical properties of agricultural products. Koocheki *et al* evaluated some physical properties of watermelon seed as a function of moisture content and variety [3]. Keramat Jahromi *et al* determined some physical properties for data fruit at a moisture content of 10.45% (dry basis) [4]. Ozturk ***et al.*** evaluated some physical properties of olive cultivars [2]. Davies determined some physical properties of arigo seeds at a moisture content of 10.3% (wet basis) [5]. Altuntas *et al* determined physical and chemical properties of persimmon fruit (cv. Fuyu) [6]. Also, Ercisli *et al* determined physical and mechanical properties of nuts and kernels of 12 common hazelnut genotypes to optimize hazelnut mechanization and processing [7]. To design the dehulling machine, mechanical properties such as rupture force, hardness and energy used for rupturing fruits are useful information. The rupture force indicates the minimum force required for dehulling the fruit. The deformation at rupture point can be used for the determination of the gap size between the surfaces to compress the fruit for dehulling [8]. As far as we know, no study has been reported on physical and mechanical properties of jujube fruits. Therefore the aims of this study were to investigate the principle dimensions (Length, Width, and Thickness), arithmetic mean diameter, geometric mean diameter, equivalent diameter, sphericity, aspect ratio, surface area, fruit mass, volume, true and bulk densities, porosity, angle of repose, coefficient of static friction on different surfaces, and rupture force, deformation, energy absorbed and hardness of jujube fruits.

II. MATERIALS AND METHODS

In this study, about 15 kg jujube fruits were prepared from Birjand region in Iran. Before each experiment, foreign matters were removed manually from rest of fruits. The initial moisture content determined through an oven method at 105 ± 3 ^{0}C during 24 hours [9]. The principle dimensions (Length (L), width (W), thickness (T)) of selected randomly 50 jujube fruits were measured using a digital micrometer having the accuracy of 0.001mm and P_L, P_W and P_T are the projected areas taken along these three mutually perpendicular axes [10-11].

Projected areas were determined by image processing method. To avoid the shades, an illumination chamber was made to produce indirect uniform lighting on samples (Fig 1). A CCD camera (Canon IXUS 960IS; a 12 megapixel camera with 3.7x optical zoom) was mounted on top of the chamber at a distance of 30 cm above the drying samples. All sample photos taken with a resolution of 1600*1200. M.C. [10-11]. Sample images were analyzed in the image processing toolbox of MATHLAB software (version 7.10, publish; 2010). Image analyze consists of image segmentation or binarization as well as data extraction. The main goal of any image processing algorithm is to extract useful information from processed image. The extracted information then can be analyzed and used for several operations depended on the aim of project. The area of the particle is calculated multiplying the area occupied by a single pixel by the number of pixels corresponding to the particle.

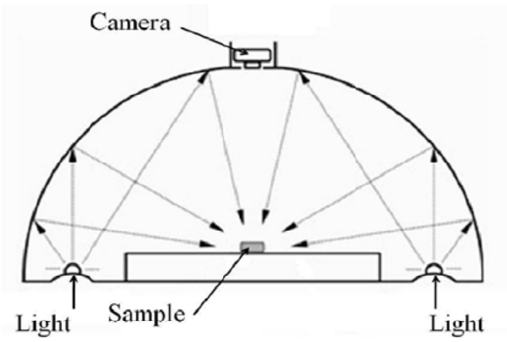

Fig. 1 Illumination chamber

The arithmetic mean diameter, D_a, and geometric mean diameter, D_g, of the fruits were calculated by using the following relationships [11]:

$$D_a = \frac{L + W + T}{3} \quad (1)$$

$$D_g = (L W T)^{\frac{1}{3}} \quad (2)$$

The equivalent diameter (D_p) for a fruit, was calculated by Mohsenin [11]:

$$D_p = \left(\frac{L(W+T)^2}{4}\right)^{\frac{1}{3}} \quad (3)$$

Surface area, aspect ratio of the shape and sphericity were determined according to the Mohsenin's method [11]. The porosity of Russian olive fruit was computed from the values of true density and bulk density of the fruits [11]:

$$\varepsilon = \frac{\rho_t - \rho_b}{\rho_t} \times 100 \quad (4)$$

Where: ε is the porosity (%); ρ_b is the bulk density (kg/m^3); and ρ_t is the true density (kg/m^3). Reported values of all density characteristics are means of 20 replications.

The angle of repose was determined by using an open-ended cylinder of 15 cm diameter and 50 cm height. The cylinder was placed at the center of a circular plate having a diameter of 70 cm and filled with fruit or kernel. The cylinder was raised slowly until it formed a cone on the circular plate. The height of the cone was recorded by using a movable pointer fixed on a stand having a scale of 0-1 cm precision. The angle of repose, θ, was calculated using the formula:

$$\theta = \tan^{-1}\left(\frac{2H}{d}\right) \quad (5)$$

Where: H is the height of the cone (cm) and d is the diameter of cone (cm). Other researchers have used this method [12]. The reported value is mean of 20 replications.

The static coefficient of friction was measured using the instrument shown in Fig.2 consisting of two fixed and adjustable plates. The static coefficient of friction for jujube fruits was determined with respect to three test surfaces, plywood, glass, and the galvanized iron sheet. For this purpose a cylinder with diameter and depth of 75mm and 50mm was filled with grains. The cylinder was mounted on the surface and the slope of the surface was increased gradually. When the cylinder started sliding down, the angle (α) was measured. The value of static friction coefficient (μ_s) was calculated using equation below [10-11].

$$\mu_s = \tan \alpha \quad (6)$$

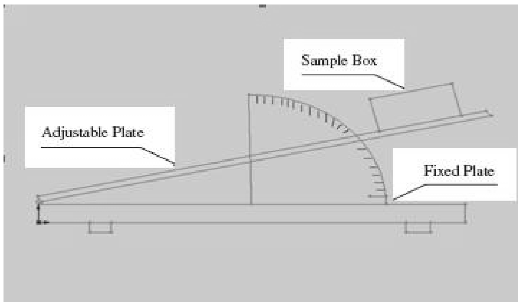

Fig. 2 Schematic of instrument for measuring static coefficient of friction

The mechanical properties for one compression axis (in line with the longitudinal) of jujube fruits was determined by a quasi-static loading device that performed with an Instron Universal Testing Machine (Model Santam SMT-20). The device consists of a lower plate that a single fruit was placed on this plate and upper plate moved up with a fixed speed of 3mm min^{-1} and initial distance of 10 mm from the surface of sample compressing the jujube between two parallel plates until it ruptured. A load cell connected to a stationary upper plate and sensed the force applied to the sample which increased with time and transmitted the data to a computer (Fig. 3). The test was repeated fifty times. The individual jujube was loaded between two parallel plates of the machine and compressed at preset force condition until rupture occurred as is denoted by bio-yield point in the force-deformation curve (Fig. 4). The bio-yield point was detected by a break in the force deformation curve. Once the bio-yield was detected, the loading was stopped. Rupture force and deformation measured at rupture point [6]. The area under the load-deformation curve given the energy absorbed during the loading up to rupture [11], and hardness, Q, was calculated by dividing the rupture force by the deformation at rupture [1].

Fig. 3 Universal testing machine used in experiments (Model Santam SMT-20)

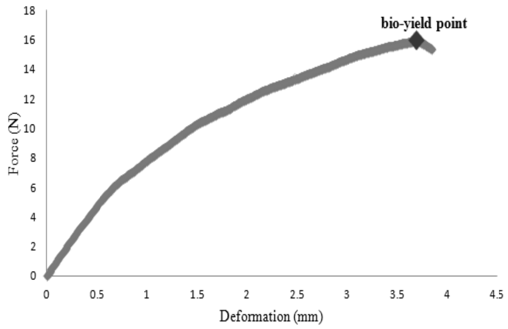

Fig. 4 Typical force-deformation curve for jujube fruit

III. Results and Discussion

The moisture content of jujube fruit samples was measured 15.5 (w.b. %). Results showed that mass varied from 1.04 to 2.33 g. Dimensions varied from 15.29 to 21.69 mm in length, 13.14 to 20.45 mm in width, and 13.11 to 18.76 mm in thickness, respectively. The dimensions of materials are the important parameters in separation as discussed by Mohsenin [11]. These dimensions can be later used in designing and optimizing elements and parameters. For instant, they could be useful in estimating the number of fruits to be engaged at a time and indicating the natural rest position of the fruit. The average fruit projected areas perpendicular to length, width, and thickness were 147.01, 224.08 and 274.60 mm^2, and their values varied from: 146.43 to 147.61, 242.84 to 245.28, and 273.36 to 275.53 mm^2, respectively. The projected areas were compared to each other. It appeared that the projected area perpendicular to thickness (T) was greater than both other dimensions (Fig. 5).

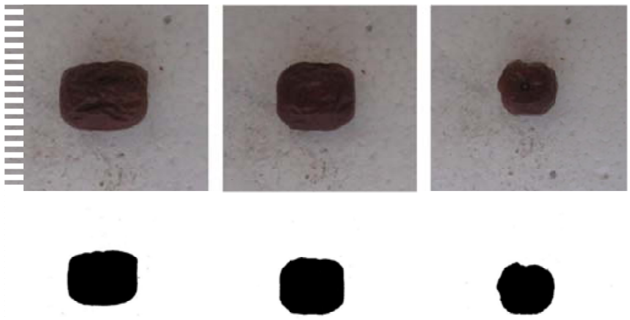

Fig. 5 Several steps of image analysis: Top row: original colour image of sample; Bottom row: image after thresholding (binary image)

The arithmetic mean diameter, geometric mean diameter and equivalent diameter varied from 14.53 to 20 mm, 14.5 to 19.94, and 14.52 to 19.97 mm, while mean values were 17.19 mm, 17.13, and 17.14 mm, respectively. The knowledge related to arithmetic mean diameter, geometric mean diameter and equivalent diameter would be valuable in designing the grading process machines specially for irregular solids. The fruit shape is evaluated based on its sphericity and aspect ratio. The average sphericity of jujube fruits was 0.91 which is in the range of 0.32-1 reported by Mohsenin [11]. The mean aspect ratio was obtained as 0.89, with variation of 0.7 to 0.99. The volume and surface area varied from 1594.29 to 4147.91 mm^3, and 659.87 to 1248.24 mm^2, while mean values were 2672.80 mm^3, and 926.28 mm^2, respectively.

Whole fruit density, bulk density and porosity of jujube fruits were measured and found to be 1.52 g/cm^3, 0.3 g/cm^3 and 79.3%, respectively.

Also, values of mean coefficient of static friction on plywood, galvanized iron steel, and glass surfaces were obtained as 0.33, 0.35 and 0.38, respectively. Results of analysis showed that static coefficient of friction on glass surfaces has a significant difference ($p<0.05$) compared to the static coefficient of friction with surfaces of wood and galvanized iron steel. The static coefficient of friction on galvanized iron steel was higher than that on plywood and lower than on glass surface. This is due to the frictional properties between fruits and surface materials. These properties are essential in separation process and handling of the fruits. A summary of physical parameters is given in Table I & II.

TABLE I
SOME PHYSICAL PROPERTIES OF JUJUBE

Properties	No. sample	Mean	Max	Min	SD
Mass(g)	50	1.51	2.33	1.04	0.33
Length(mm)	50	18.88	21.69	15.29	1.58
Width(mm)	50	16.79	20.45	13.14	1.39
Thickness(mm)	50	15.9	18.76	13.11	1.33
First Projected area (P_L) (mm^2)	50	147.01	147.61	146.43	0.31
Second Projected area (P_W) (mm^2)	50	224.08	245.28	242.84	0.58
Third Projected area (P_T) (mm^2)	50	274.60	275.53	273.36	0.53
Arithmetic mean diameter(mm)	50	17.19	20	14.53	1.27
Geometric mean diameter(mm)	50	17.13	19.94	14.5	1.27
Equivalent diameter(mm)	50	17.14	19.97	14.52	1.27
Sphericity	50	0.91	0.98	0.79	0.04
Aspect ratio	50	0.89	0.99	0.7	0.06
Volume(mm^3)	50	2672.80	4147.91	1594.29	588.23
Surface area(mm^2)	50	926.28	1248.24	659.87	136.76
Glass		**0.38**	**0.51**	**0.19**	**0.07**

TABLE II
CHOSEN PROPERTIES OF JUJUBE FRUIT AT 15.5% (W.B)

Properties	Values	Max	Min	SD
Bulk density(kg/m³)	0.3	0.39	0.27	0.03
True density(kg/m³)	1.52	2.18	1.14	0.3
Porosity (%)	79.32	86.32	71.1	4.46
Angle of repose(deg)	14.66	15	14	0.58
Static coefficient of friction:				
Plywood	0.33	0.51	0.16	0.09
Galvanized iron	0.35	0.46	0.18	0.06

The values of rupture force, deformation, hardness and energy absorbed were found to be between 11.13-19.91 N, 2.53-4.82 mm, 3.06-5.81 N mm and 20.13-39.08 N/mm. A summary of results of the mechanical properties of jujube fruits at longitudinal axis is presented in Table III.

TABLE III
SOME MECHANICAL PROPERTIES OF JUJUBE AT LONGITUDINAL AXIS

	Rupture force (N)	Deformation (mm)	Hardness (N/mm)	Energy absorbed (N mm)
No. of sample	50	50	50	50
Mean	15.68	3.69	4.31	28.29
Max	19.91	4.82	5.81	39.08
Min	11.13	2.53	3.06	20.13
SD	2.6	0.58	0.72	5.78

IV. CONCLUSIONS

1. Dimensions varied from 15.29 to 21.69 mm in length, 13.14 to 20.45 mm in width, and 13.11 to 18.76 mm in thickness, while the arithmetic mean diameter, geometric mean diameter and equivalent diameter varied from 14.53 to 20 mm, 14.5 to 19.94, and 14.52 to 19.97 mm, at moisture content of 15.5% (w.b.).
2. The mean projected areas of jujube perpendicular to length, width, and thickness were 147.01, 224.08 and 274.60 mm^2, respectively.
3. The average sphericity of jujube fruits was 0.91 and mean aspect ratio was obtained as 0.89, with variation of 0.7 to 0.99. The volume and surface area varied from 1594.29 to 4147.91 mm^3, and 659.87 to 1248.24 mm^2, while mean values were 2672.80 mm^3, and 926.28 mm^2, respectively.
4. The mean mass of jujube fruits was 1.51 g. Whole fruit density, bulk density and porosity of jujube fruits were measured and found to be 1.52 g/cm^3, 0.3 g/cm^3 and 79.3%, respectively.
5. The angle of repose of jujube fruit was 14.66° (±0.58°).
6. Values of mean coefficient of static friction on plywood, galvanized iron steel, and glass surfaces were obtained as 0.33, 0.35 and 0.38, respectively.
7. The values of rupture force, deformation, hardness and energy absorbed were found to be between 11.13-19.91 N, 2.53-4.82 mm, 3.06-5.81 N mm and 20.13-39.08 N/mm^1.

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