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Physical and engineering properties of pomegranate fruit and arils

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ABSTRACT

Several physical properties such as porosity, geometric mean diameter, surface area, fruit mass and dimensions, fruit volume, coefficient of static friction, projected area, skin colour, aril colour, aril dimensions and aril ratio which are imperative to characterize the fruits of pomegranate with a view to understand the properties that may affect the design of machines to handle their processing were determined. The average fruit mass, length, width and thickness of pomegranates were determined as 208.06 g, 58.04 mm,72.06 mm and 70.08 mm respectively. On three different surfaces static friction coefficient values were between 0.76 (galvanized steel sheet) and 0.46 (plywood) and 0.84 (glass). The aril ratio and 1000-arils mass were 72 per cent and 278 g respectively.

Keywords: Pomegranate; physical properties; sphericity index; coefficient of friction; surface area; bulk density

INTRODUCTION

The pomegranate, *Punica granatum* L fruit a native of Iran is extensively cultivated in Spain, Egypt, Russia, France, Argentina, China, Japan, USA and India (Patil and Karade 1996). In India pomegranate also known as Anar has been grown since ancient period. The versatile adaptability, table and therapeutic values and better keeping quality are the features responsible for its cultivation on a wide scale (Dhandar and Singh 2002). Pomegranate is commercially grown for its sweet and acidic taste of the arils. In addition to dessert (sweet type) purpose pomegranate is also found in its wild form in the dense forests of Himachal Pradesh, Jammu and Kashmir and Uttaranchal of India and in Mt Carmel (Parmar 1981, Saxena et al 1987).

The determination of physical properties of agricultural materials is important to design machines and processes for harvesting, handling and storage of these materials and requires understanding for converting these materials into food and feed. For horticultural materials (fruits, vegetables),

dimensions (length, diameter, thickness) are widely used properties to describe them. Fruit physical dimensions particularly shape are very important in sorting, sizing and determining how many fruits can be placed in shipping containers or plastic bags of a given size (Keramat Jahromi et al 2008). Fruit skin colour is an attribute that determines consumer's behaviour and it is accepted as one of the most important external quality parameters (Ercisli et al 2007). Fruit volume, shape and density are important to design fluid velocities for transportation (Mohsenin 1986). Fruits being a solid material surface areas must be known for accurate modelling of heat and mass transfer during cooling and drying. Porosity which is the percentage of air space in particulate solids affects the resistance to air flow through bulk solids (Keramat Jahromi et al 2008). On the other hand knowledge of frictional properties of fruits is needed for design of handling equipment (Mohsenin 1986).

The physical properties of pomegranate can be important to design equipment for processing, transportation, sorting, separating and also packing. Currently used system has been designed without taking these criteria into consideration; and the resulting designs lead to inadequate applications.

This results in a reduction in work efficiency and an increase in product loss. Therefore determination and consideration of these criteria have an important role in designing of this equipment. There is not enough published work relating to physical properties of pomegranate. The objective of this study was to determine the physical properties of pomegranate fruits and arils so that the knowledge is gained used to design and develop equipments for cleaning, grading, dehydration, storage and handling.

MATERIAL and METHODS

Twenty kg of fresh pomegranate fruits from the Koyambed market of Chennai was purchased to determine the engineering properties. The physical properties determined for pomegranate fruits and arils were size, shape, bulk density, true density, porosity, angle of repose, surface area and coefficient of friction.

The following symbols have been used in the article:

L	major diameter with calyx (mm)
Vm	measured volume (cm^3)
W	intermediate diameter (mm)
Vosp	volume of oblate spheroid (cm^3)
T	minor diameter (mm)
ρ_b	bulk density(g/cm^3)
CPA	criteria projected area (mm^2)
$^{\rho}t$	true density(g/cm^3)
$_L{}^*$	major diameter without calyx (mm)
E	Porosity
$^D g$	geometric mean diameter (mm)

Φ	spheiricity
M	mass (g)
φ	angle of repose (degree)
PA1	first projected area (mm^2)
$^{\theta}f$	filling angle of repose (degree)
PA2	second projected area (mm^2)
PA3	third projected area (mm^2)
θ_e	emptying angle of repose (degree)
R^2	coefficient of determination repose(degree)
V	volume (cm^3)
$^{\mu}s$	static coefficient of friction
Vsp	volume of ellipsoid (cm^3)
W_{1000}	thousand seeds mass (g)

Dimensions of pomegranate

Pomegranates were randomly chosen for measuring dimensions. Length, width and thickness of each fruit were measured using vernier caliper (least count 0.01 cm). Hundred observations were made to get average values for length, width and thickness of the fruits.

Geometric mean diameter (GMD): The geometric mean diameter for 100 fruits was determined using the measured geometric dimensions of length (L), width (W) and thickness (T) through the following equation:

$$GMD = (LWT)^{\frac{1}{3}}$$

Sphericity: Sphericity (S) is defined as the ratio of the surface area of a sphere having the same volume as the fruit to the surface area of the fruit. The shape of a food material is usually expressed in terms of its sphericity. It is an important property used in fluid flow and heat and mass transfer calculations. Sphericity was determined using the measured geometric dimensions in the following formula;

$$S = \frac{(LWT)^{\frac{1}{3}}}{L}$$

In order to gather more information about the shape of the fruit aspect ratio (R) of the fruit was determined from the following relationship:

$$\text{Aspect ratio, } R = \frac{W}{L} \times 100$$

1000-kernel weight (TKW): The 100 fruits were weighed on a top loading electronic balance (EK 5350) with a resolution of 0.01 g and the resultant weight was multiplied by 10 to get the 1000-kernel weight. This was also applied by Tavakoli et al (2009) for barley grains and Gharibzahedi et al (2010) for pine nut.

Surface area and volume: The surface area and volume of pomegranate fruits were calculated based on the geometric mean diameter (GMD) through the following equations:

$$S = \pi (GMD)^2$$

$$V = \frac{\pi}{6} (GMD)^3$$

Radius of curvature: This is an important property needed for the design of conveyors and chutes. It determines the rollability of objects. The minimum radius of curvature (R_{min}) and maximum radius of curvature (R_{max}) were calculated using the following equations:

$$R_{min} = \frac{H}{2}$$

$$R_{max} = \frac{H^2 + \frac{L^2}{4}}{2}$$

where H is the average of thickness and length (mm).

Angle of repose: Angle of repose is an important physical property for the design of processing, storage, and conveying systems of particulate materials. When the materials are smooth and rounded the angle of repose is low. For sticky and fine materials the angle of repose is high. Angle of repose therefore indicates the cohesion amongst the individual units of the materials. It was determined using a bottomless cylinder (10 cm diameter, 15 cm height) which was also applied by Taser et al (2005). The cylinder was placed over a smooth surface and fruits were filled in the cylinder that was raised slowly permitting the sample to flow down and form a natural slope. The height (H) and diameter (D) of the heap were measured and the dynamic angle of repose calculated as follows.

$$\theta = \tan^{-1}\frac{2H}{D}$$

Bulk density: Bulk density which is defined as the ratio of the mass of the sample to its container volume was evaluated by weighing an pomegranate fruit filled beaker of known weight and volume and calculated as per Baryeh (2000).

$$\rho_b = \frac{\text{Mass}}{\text{Volume}} = \frac{m}{v}$$

where ρb (g/cm^3) is bulk density and mass m (g) of sample.

True density: This is the ratio of mass of sample to its pure volume. For fruit true density was determined by the water displacement method (Abdullah 2011). The true density was then calculated as:

$$\rho_t = \frac{\text{Mass of individual fruit (kg)}}{\text{Volume of individual seed (m}^3\text{)}}$$

Porosity: Porosity is a vital physical property that characterizes the amount of air spaces in a bulk. It is needed in modeling and design of various heat and mass transfer processes. It is defined as the volume fraction of air in the bulk sample and is calculated as:

$$\text{Porosity, } P = \frac{\rho_t - \rho_b}{\rho_t} \times 100$$

Coefficient of static friction: This is the ratio of force needed to start sliding the

sample over a surface by the weight of the sample. The coefficient of static friction was determined on four different structural surfaces namely plywood, galvanized steel sheet, rubber and glass. Each fruit was placed on the surface and raised gradually by screw until the fruit began to slide. The angle that the inclined surface marked with the horizontal when sliding began was measured. The coefficient of static friction (μs) was calculated using the following expression:

$$\text{Coefficient of static friction, } \mu_s = \tan\theta$$

where θ= Angle that the incline makes with the horizontal when sliding begins

RESULTS and DISCUSSION

Dimensional and frictional attributes of pomegranate fruits

The physical properties such as major, minor and intermediate diameter, mass, volume, bulk density, true density, geometric mean, porosity, sphericity and rolling frictional properties of pomegranate fruit are given in Table 1.

The maximum, minimum and mean values of each property with its standard deviation were determined. Length of fruit was measured in two states. In the first state calyx over the fruit was considered and in the second it was not considered. Length in first state was changed from 51.6 to 72.0 mm with mean value 58.04 mm. Other dimensional properties such as width, thickness, mass, mean geometric diameter, volume, criteria project area, surface, sphericity and porosity showed the mean values of 72.06 mm, 70.08 mm, 208.06 g, 64.01 mm, 208.07 cm^3, 0.94 cm^2, 219.90 cm^2, 94 per cent and 30.04 per cent respectively.

In a study conducted by Jannatizadeh et al (2008) stated that sphericity values of Iranian pomegranate differed significantly among the tested cultivars and mean values were 0.971, 0.917, 0.973, 0.925, 0.923 and 0.875 for Shams, Nakhjavan, Djahangiri, Sefidedamavand, Shahroud-8 and Gheysi-2 cultivars respectively. Kheiralipour et al (2003) also reported length, width and thickness of apple fruit (cv Red Spur) as 57.13, 66.98 and 62.60 mm respectively.

Among the frictional properties coefficient of friction on glass surface gave the highest values with 0.82 and wood surface had lowest valve with 0.46. Sessiz et al (2007) reported the static and dynamic coefficients of friction on four different surfaces namely galvanized steel, plywood, rubber and metal steel for caper fruit. On the all of mentioned surfaces the values of the static coefficient of friction obtained were more than dynamic coefficient of friction.

The importance of dimensions is in determining the aperture size of machines particularly in separation of materials as discussed by Mohsenin (1986). These

Table 1. Physical properties of pomegranate fruit

Property	Value			
	Min	Max	Mean	SD
Fruit parameter				
Fruit length, *L* (mm)	51.6	72.0	58.4	6.1
Fruit width, *W* (mm)	66.4	82.9	72.6	4.3
Fruit thickness, *T* (mm)	62.4	84.6	70.8	3.4
Geometric mean diameter, D_g (mm)	60.8	74.0	64.1	3.2
Surface area, *S* (mm^2)	13.804	18.582	15.423	7.1
Fruit mass, M_f (g)	158.4	286.5	208.6	38.0
Fruit volume, *V* (cm^3)	152.9	292.8	208.7	38.4
Fruit firmness (N cm^{-2})	108.3	142.8	126.1	0.9
Bulk density (kg/m^3)	614.46	764.14	684.76	42.32
True density P_t (kg/m^3)	895.03	1135.37	974.32	74.38
Sphericity	0.84	0.98	0.94	0.03
Porosity e (%)	28.76	34.44	30.44	3.08
Coefficient of static friction				
Wood	0.46	0.47	0.46	0.01
Galvanized iron	0.74	0.75	0.76	0.02
Glass	0.85	0.79	0.84	0.02

dimensions can be used in designing machine components and parameters. For example they may be useful in estimating the number of fruits to be engaged at a time.

Some dimensional and frictional attributes of pomegranate arils

Selected properties of pomegranate arils the maximum, minimum and mean values of each property with its standard deviation are reported in Table 2. These properties were found at specific fruit moisture content of 76.70 per cent wb. About arils thousand weight gave more importance respect to weight of each arils, thousand weights and weight of each aril gave mean values of 0.36 g and 278.00 g respectively. The bulk density, true density and porosity were changed as 673.05-681.12 kg/m^3, 1083.88-1096.81 kg/m^3 and 36.14-37.66 respectively.

The range of friction coefficient on wood, galvanized iron and glass surface were 0.08-0.36, 0.14-0.32 and 0.15-0.37 respectively. Aydin (2003) investigated

Table 2. Physical properties of pomegranate aril

Properties	Values			
	Min	Max	Mean	SD
Aril parameter				
Numbers of arils/fruit	370	622	504	76
Total aril mass/fruit (g)	110	184	140	21
Aril length (mm)	7.4	12.4	8.0	0.8
Aril width (mm)	4.3	8.4	8.3	0.7
Aril thickness (mm)	3.7	6.6	5.4	0.4
Aril geometric mean diameter (mm)	5.8	7.9	7.2	0.6
1000-aril mass (g)	232	324	278	27
Aril ratio (%)	53	72	65	4
Sphericity	0.49	0.95	0.79	0.50
Bulk density P_b (kg/m^3)	673.05	681.12	678.87	3.21
True density P_t (kg/m^3)	1083.88	1096.81	1088.93	3.14
Porosity	36.14	38.24	37.66	1.27
Filling repose angle (degree)	44	54	44.63	1.02
Emptying repose angle (degree)	32.36	34.79	33.67	2.1
Coefficient of static friction, m_s				
Galvanized steel sheet	0.14	0.32	0.24	0.03
Glass	0.15	0.37	0.26	0.05
Plywood	0.08	0.36	0.28	0.04
Aril colour				
L*	14.6	23.7	19.2	2.5
a*	11.7	20.5	15.8	2.7
b*	3.5	7.9	5.8	1.2

some physical properties of almond nut and kernel as functions of moisture content. The average length, width, thickness, the geometric mean diameter, unit mass and volume of nuts were 25.49, 17.03, 13.12, 18.13 mm, 2.64 g and 2.61 cm^3 respectively. Corresponding values for kernel were 21.19, 14.34, 6.38, 11.42 mm, 0.69 g and 0.71 cm^3 respectively.

The results showed that pomegranate fruits were a free flowing material. It required force to convey the material. The results and observations are

comparable with the results reported by Owolarafe and Shotonde (2004) for the physical properties of okro fruit. The results on the average length, width, thickness, the geometric mean diameter, unit mass and volume of gumbo fruits of Sultani and Amasya variety reported by Akar and Aydin (2005) are comparable with the methods adopted in the present study.

CONCLUSION

For post-harvest technology such as grading, transporting, packaging, sorting etc knowing physical properties and mechanical behavior of agricultural products are necessary. In the present study physical properties of pomegranate fruits and aril such as mass, dimensions (big, medium and small diameter), geometric mean diameter, projected area (big, medium and small area), criteria area, surface area, arithmetic mean diameter, sphericity, moisture which fruit can be supported, work which performed to this force and hardness under compression loading in two directions were determined.

Highest coefficient of friction was on glass surface and lowest value was on wood surface for pomegranate fruit. Results indicated that filling repose angle had value greater than emptying repose angle for pomegranate seed and aril. Highest coefficient of friction was on wood surface and lowest value was on glass surface for pomegranate aril. These data will facilitate to design equipment and machinery for this production and damage to products will be less than before.

The physical properties of any food material and its derived products are very essential for designing and development of process machineries, feed hoppers, storage structures, material handling equipment and packaging purpose.

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