International Food Research Journal 24(3): 1286-1291 (June 2017)
Journal homepage: *http://www.ifrj.upm.edu.my*

Physical and frictional properties of pomegranate arils as a function of fruit maturity

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Article history

Received: 1 February 2016
Received in revised form: 9 June 2016
Accepted: 11 June 2016

Keywords

Physical properties
Friction coefficients
Pomegranate arils
Maturity

Abstract

In this study, some physical properties (three axial dimensions, geometric mean diameter, sphericity, volume, surface area, unit mass, true and bulk density) and frictional characteristics (angles of repose and static and dynamic coefficients of friction against four structural surfaces namely aluminium, plywood, galvanized iron and rubber) as a function of maturity indices for Ashraf variety of pomegranate arils were investigated. All physical properties of pomegranate arils were significantly ($P<0.05$) affected by changing maturity in the studied stages. The obtained results showed that studied physical properties (except sphericity and true density) and frictional characteristics increased with an increase in maturity. The highest static coefficient of friction for pomegranate arils was against the rubber surface, followed by plywood, galvanized iron, and finally aluminium surfaces. In addition, static coefficient of friction values were higher than the dynamic coefficient of friction at similar maturity stages of the samples and on the same surfaces. The emptying angle of repose found to be higher than the filling angle of repose for pomegranate arils at all maturity stages. Static and dynamic coefficient of friction as well as empting angle of repose increased linearly with advancement of maturity.

Introduction

Pomegranate, (*Punica granatum* L.), is a major member of the Punicaceae family and it is in high demand due to its high nutritional value, delicious taste and excellent flavour and low calories (Holland *et al*., 2009). It is consumed both as fresh fruit as well as used after separation of the seeds for the preparation of fruit juice, jams, jellies, canned beverages and for flavoring and coloring drinks. Because of this market demand it has become increasingly important to characterize its properties to obtain a high quality product with economic interests.

Analyzing and modeling of various processing operations of agricultural products such as agricultural seeds and grains needs a comprehensive understanding of physical properties (namely dimensions, shape, mass, bulk and true density) and frictional characteristics (angles of repose and static and dynamic coefficients of friction). The knowledge of these properties is essential for the design of handling, sorting, sizing, drying, dehulling, storage and other processing equipment (Kingsley *et al*., 2006; Riyahi *et al*., 2011; Dak *et al*., 2014; Szychowski *et al*., 2015). For example, knowledge on friction coefficients of grains is an important data used for designing of equipment such as hoppers, storage and handling systems. Also sizing grain hoppers and storage facilities can be improved by knowing bulk density, true density and porosity which affect the rate of heat and mass transfer of moisture during aeration and drying operation (Jouki, and Khazaei, 2012). The dimensions and shape of bulk materials such as pomegranate arils are important for either their electrostatic separation from undesirable materials or an analytical prediction of their drying behavior (Dak *et al*., 2014; Szychowski *et al*., 2015).

An analysis of published papers (Mohsenin, 1986; Cangi *et al*., 2011; Altuntas *et al*., 2013; Altuntas *et al*., 2015) specifies that physical characteristics of agricultural materials are affected by maturity and ripeness. Some physical properties of pomegranate arils are reported in literature (Kingsley *et al*., 2006; Riyahi *et al*., 2011; Martinez *et al*., 2012; Dak *et al*., 2014; Szychowski *et al*., 2015), however frictional properties and their relationship with maturity was scarce.

The current study was therefore conducted to determine physical and frictional characteristics as a function of maturity for Ashraf variety of pomegranate arils. These properties were correlated with the maturity stages between 88 and 143 days after full bloom (DAFB).

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Materials and Methods

Sample collection and preparation

A total of 20 pomegranate fruit (ASHRAF variety) of the same size and without physical defects were obtained at each maturity stages from a commercial orchard in Shahidabad Village, Mazandaran Province, Iran (36°41′32″N 53°33′09″E). Test samples were from the 2014 growing season. Four different maturity stages of the samples were considered in this study (At 88, 109, 124 and 143 days after full bloom (DAFB)). Then pomegranate arils were extracted and cleaned manually to remove all foreign materials and broken arils. Finally, the samples transferred to the lab to prepare samples and to measure studied characteristics.

The moisture content of arils samples (in d.b.%) at each studied stage was determined using the standard hot air oven method with a temperature setting of 105±1°C for 24 h (Mohsenin, 1986). Samples were kept in a double layered low density polyethylene bags of 90 µm thickness and inside a fridge (5°C). Before starting the tests, the samples were taken out of the refrigerator and allowed to warm up to room temperature for approximately 2 h (Mohsenin, 1986).

Physical characteristics measurement

To measure the size and shape of pomegranate arils, totally 25 arils were randomly selected (After extracting from 20 fruits by hand) and labeled for easy identifications. The following physical characteristics and indexes were studied:

Three main dimensions of arils namely length (L), width (W) and thickness (T), expressed in mm using a digital caliper (Mitutoyo, Japan) with an accuracy of ±0.01 mm.

Geometric mean diameter, D_g (mm); sphericity, φ; surface area, S (mm^2) and volume, V (mm^3) of arils were computed using the following formulas, respectively (Mohsenin, 1986; Fawole and Opara, 2013):

$$D_g = (LWT)^{1/3} \quad (1)$$

$$\phi = D_g / L \quad (2)$$

$$S = \pi D_g^2 \quad (3)$$

$$V = 0.25[(\frac{\pi}{6})L(W+T)^2] \quad (4)$$

Aril mass, m, expressed in g, was measured by counting and weighing 100 arils using a precision weighting device (PX-200, Phantom Scales LLC), with an accuracy of 0.0001 g and then divided by 100 to obtain the average unit mass of aril.

Bulk density of aril, ρ_b (g/mm^3). This parameter was determined by filling a cylindrical container of 500000 mm3 volume with arils to a height of 150 mm at a constant rate and then weighting the contents (Mohsenin, 1986).

True density of arils, ρ_t, (g/mm^3), was calculated by dividing the unit of mass of aril to its volume.

Static coefficient of friction

Static coefficient of friction for pomegranate arils was measured against aluminium, plywood, galvanized iron and rubber, which are common useable materials for handling and processing of grains, construction of storage and drying bins (Riyahi *et al*., 2011, Immanvel *et al*., 2014). A galvanized iron cylinder of 100 mm diameter and 50 mm height without base and lid was filled with the sample of the desired maturity stages and was placed on the adjustable tilting surface so that the cylinder does not touch the surface (Figure 1). The tilting surface with the cylinder resting on it was raised gradually with a screw device until the cylinder just started to slide down. Then the angle of tilt (α) was read from a graduated scale. The coefficient of friction (μ_s) was calculated from the following relationship (Mohsenin, 1986):

$$\mu_s = \tan\alpha \quad (5)$$

Dynamic coefficient of friction

The dynamic coefficient of friction (μ_k), also called the kinetic or sliding coefficient of friction, is defined as the ratio of friction force (F) to the normal force (N) acting on the contact surface

$$\mu_k = F/N \quad (6)$$

To measure the dynamic coefficient of friction of pomegranate arils, tests were carried out using the friction test. A wooden box with the dimensions of 300×150×25 mm with 5 mm thickness was used and filled with samples. The bottom surface of wooden box placed on the plate of driving unit of setup and a friction surface was placed on the top of wooden box. A dead load of 1 kg was applied to the top of friction surface and the friction surface was connected to the 5000 N load cell with an accuracy of 0.01 N. The driving unit moved horizontally at a fixed velocity of 24 mm/min. The data were recorded through a data acquisition system.

Static angle of repose

The static angle of repose (β) was determined using an open-ended cylinder of 150 mm diameter and 250 mm height. The cylinder was placed at the

Figure 1. Apparatus for measuring static coefficient of friction (a) dynamic coefficient of friction (b)

center of a circular plate with diameter of 350 mm. It was filled with the samples until a cone formed on the circular plate. The diameter (D) and height (H) of the cone were recorded. The filling angle of repose was calculated using the following formula (Mohsenin, 1986):

$$\beta = Arctan(2H/D) \tag{7}$$

Dynamic angle of repose

A plywood box of 300×300×300 mm^3 with a removable front panel was used to measure the dynamic angle of repose (θ). The box was filled with the samples, and then the front panel was quickly removed, allowing the samples to flow out and assume a natural slope. The empting angle of repose was computed using the vertical depth and radius of spread values (Ozarslan, 2002; Razavi *et al*., 2007).

Statistical analysis

The experiments were done at least in 25 replications for each stage of maturity, then the mean (±S.E.) values reported. SPSS 16.0 software package for windows was used.

Results and Discussion

Changes in physical characteristics

Physical characteristics of studied pomegranate arils changed significantly with maturity (Table 1). However Salah and Dilshad (2002) did not report any significant change in physical properties of pomegranate fruit. Riyahi *et al.* (2011) found significant change in dimensions, sphericity, geometric mean diameter and unit mass of pomegranate arils with moisture content. As it can be found from Table 1, aril size increased with advancing fruit maturity. The main dimensions (length, width, thickness) of pomegranate arils were 8.74 (0.81), 5.83 (0.97), and 4.09 (0.35) mm, respectively at 88 DAFB and reached 12 (0.41), 7.7 (0.36) and 6 (0.28) mm, respectively at full-ripe stage. Similarly, surface area, volume and shape parameters of studied variety of aril such as geometric mean diameter increased while sphericity decreased (shape index) with advancing fruit maturity (Table 1). Also as it can be seen from Table 1, aril mass increased from 0.184 g at stage 1 (S1) to 0.407 g at stage 4 (S4). Similarly, there was a significant increase in bulk density of aril (696-865 g/mm^3), throughout the developmental stages investigated (Table 1). However, in these maturity stages the true density of arils (1196-1040 g/mm^3) decreased.

Changes in static and dynamic coefficient of frictions

The static and dynamic coefficients of friction for studied variety of pomegranate arils against four structural surfaces including aluminium, plywood, galvanized iron and rubber at four maturity stages are presented in Table 2.

Aluminium

Table 2 shows the change patterns of static and dynamic coefficients of friction for Ashraf variety of pomegranate arils on aluminium surface during studied different stages of fruit maturation. As it can be seen, static and dynamic coefficients of friction increased linearly during maturity. Also the lowest value were 0.23 and 0.11, respectively. In addition, the values of static coefficient of friction were higher than dynamic coefficient of friction in each maturity stage for pomegranate arils. Similar behaviour is reported for juniper berries (Altuntas, 2015).

Plywood

Same as the obtained results on aluminium surface, the static and dynamic coefficient of friction of pomegranate aril on plywood surface increased linearly with advancing fruit maturity. Also, it can be seen that the values of static are higher than those dynamic ones for all runs. Also the lowest values were 0.24 and 0.12, respectively. The values of friction on plywood surface were higher than those for aluminium. The reason may attributes to rough surface of plywood compared with aluminium. Riyahi *et al.* (2011) have reported that the range of friction coefficient of pomegranate arils on wood was 0.53-0.54.

Galvanized iron

The static and dynamic coefficient of friction of pomegranate arils on galvanized iron sheet were obtained in the range of 0.21-0.24 and 0.11-0.32, respectively (Table 2). The results on galvanized iron sheet showed an increase in static and dynamic coefficient of friction with increase of fruit growth. The values of friction coefficient of pomegranate

Table 1. Influence of maturity stages on physical characteristics of 'Ashraf' pomegranate arils during 2014 growing season

Geometrical attributes	Fruit maturity stages (DAFB)			
	S_1(88)	S_2(109)	S_3(124)	S_4(143)
L (mm)	8.74^a (0.81)	10.71^b (0.29)	11.15^{bc} (0.34)	12.01^c (0.41)
W (mm)	5.82^a (0.97)	6.47^{ab} (0.35)	7.14^{bc} (0.28)	7.71^c (0.36)
T (mm)	4.09^a (0.56)	5.72^b (0.06)	5.25^c (0.41)	6.14^c (0.28)
D_g (mm)	5.92^a (0.71)	7.34^b (0.21)	7.39^b (0.35)	8.21^c (0.45)
ϕ	0.69^a (0.01)	0.68^a (0.05)	0.67^a (0.02)	0.67^a (0.01)
S (mm^2)	111.26^a (27.43)	169.58^b (9.54)	171.57^b (15.23)	211.75^c (10.92)
V (mm^3)	213^a (0.21)	291^b (0.18)	330^c (0.22)	390^d (0.12)
Arils mass (g)	0.184^a (0.02)	0.324^b (0.01)	0.351^c (0.02)	0.407^d (0.02)
True density (g/mm^3)	1196^a (0.01)	117^{0a} (0.04)	1090^b (0.03)	1040^c (0.02)
Bulk density (g/mm^3)	696^a (0.04)	810^b (0.01)	835^{bc} (0.02)	865^c (0.01)

Different superscript(s) in a row indicate statistically significant differences ($p<0.05$) according to Duncan's multiple range test

arils on galvanized iron was reported by Riyahi *et al*. (2011) in the range of 0.49-0.51. Similar to the obtained results on aluminium and plywood surfaces, the values of static coefficient of friction were higher than those on dynamic coefficient of friction in each maturity stage. As it can be seen from Table 2, the values of static and dynamic coefficient of friction on galvanized iron sheet were higher than those on aluminium surface but were lower than the values on plywood surface. The reason may be attributed to the different roughness degree of applied surfaces.

Rubber

The values of static and dynamic coefficients of friction increased as maturity increased, like the results of the pervious studied surfaces. Also, static coefficient of friction revealed higher values in comparison with the dynamic coefficient of friction. Table 3 shows the regression models and coefficients of determination *(R^2)* obtained by fitting the experimental data of static and dynamic coefficient of friction for pomegranate arils as a function of maturity. The relationship between static and dynamic coefficient of friction and maturity for the studied variety was a positive linear relation. Similar trends have been reported by Riyahi *et al.* (2011) for pomegranate arils. However, several researchers observed a nonlinear relationship (Konak *et al.*, 2002; Kalimullah and Gunasekar, 2002).

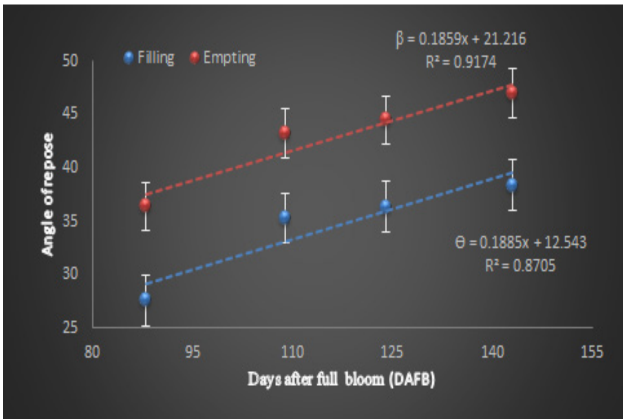

Figure 2. Filling and empting angle of repose of Ashraf pomegranate arils as a function of maturity

Changes in filling and empting angle of repose

The empting angle of repose revealed higher values in comparison with the filling angle of repose. Also, there were positive linear relationships with very high correlation *(R^2)* between filling and empting angle of repose with maturity (Figure 2). Riyahi *et al.* (2011) found that the emptying angle of repose increased non-linearly with increase in moisture content for pomegranate fruit, arils and seeds.

Table 2. Influence of maturity stages on frictional properties of 'Ashraf' pomegranate arils during 2014 growing season

Frictional attributes	Surface	Fruit maturity stages (DAFB)			
		S_1(88)	S_2(109)	S_3(124)	S_4(143)
Static coefficient of friction	Aluminium	0.227	0.238	0.245	0.253
	Plywood	0.24	0.25	0.261	0.272
	Galvanized iron	0.215	0.223	0.23	0.241
	Rubber	0.26	0.27	0.282	0.29
Dynamic coefficient of friction	Aluminium	0.116	0.12	0.135	0.142
	Plywood	0.12	0.13	0.14	0.15
	Galvanized iron	0.111	0.115	0.122	0.132
	Rubber	0.135	0.148	0.152	0.165

Table 3. Regression models and coefficients of determination obtained for static and dynamic coefficient of friction of studied variety of pomegranate arils as a function of maturity

Surface	Static coefficient of friction	R^2	Dynamic coefficient of friction	R^2
Aluminium	$\mu_s = 0.0005x + 0.1859$	0.99	$\mu_k = 0.0005x + 0.0693$	0.93
Plywood	$\mu_s = 0.0006x + 0.1871$	0.99	$\mu_k = 0.0006x + 0.0708$	0.99
Galvanized iron	$\mu_s = 0.0005x + 0.1726$	0.98	$\mu_k = 0.0004x + 0.0753$	0.95
Rubber	$\mu_s = 0.0006x + 0.2102$	0.98	$\mu_k = 0.0005x + 0.089$	0.98

x= days after full bloom

Conclusion

Physical and frictional characteristics of pomegranate arils were investigated as a function of maturity. The main dimensions (length, width, thickness) of pomegranate arils increased with advancing fruit maturity. During maturity stages the true density of arils (1196-1040 g/cm^3) decreased. Static and dynamic coefficients of friction for pomegranate arils on four studied surfaces increased linearly as maturity increased. The highest static coefficient of friction for pomegranate arils was on the rubber surface, followed by plywood, galvanized iron, and finally aluminium surfaces. In addition, static coefficient of friction revealed higher values in comparison with the dynamic coefficient of friction at similar maturity stages of the samples and on the same surfaces. The filling angle of repose increased linearly as maturity increased. The empting angle of repose increased linearly with an increase in maturity stage. The emptying angle of repose assumed higher values than the filling angle of repose for pomegranate arils at all maturity stages.

Acknowledgment

The authors would like to thank the Ferdowsi University of Mashhad for providing the laboratory facilities and financial support through the project No. of 28580.

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