Comparison of Physical and Hydrodynamic Properties of Two Iranian Commercial Pomegranates

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Astract: The aim of this study was to determine and compare several physical and hydrodynamic properties of two commercial pomegranate cultivars in Iran (Poost sefid and Malas-Yazd). Values of geometric diameter (74.61-82.45 mm), volume (176-503 mm^3), true density (970.25-1028.30 kg/m^3) and packing coefficient (0.48-0.55) showed statistically significant difference at the 1% level. Besides, projected area and face surface area of cv. Poost sefid were 15 and 18 percent more than cv. Malas-Yazd, respectively ($P<0.01$). Terminal velocity, coming up time and drag force were 0.17 m/s, 3.42 s and 17 N for cv. Poost sefid and 0.18 m/s, 3.38 s and 1.94 N for cv. Malas-Yazd ($P>0.05$), respectively. Further, buoyancy force levels of cv. Poost sefid (3.25 N) and cv. Malas-Yazd (2.41 N) had statistically significant difference at the level 5%. The rupture force values of Iranian pomegranate varieties had significant differences at Y and Z-axes loading ($P<0.05$), while this factor was not significant at X-axes loading. The values of rupture energy for pomegranate varieties at all of the loading directions were also significant at 5% probability level. Determining these properties is of high importance in design

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and construction of conveying, sorting and processing machines and equipment for pomegranate cultivars.

Keywords: pomegranate (Punica granatum L.), cv. Poost sefid, cv. Malas-Yazd, hydrodynamic properties

1 Introduction

Pomegranate (scientific name: Punica granatum L.) is mostly native to Iran. It is raised in many areas of Iran which have dry weather and has the most cultivars variety in the world. However, pomegranate is widely cultivated in Spain, Egypt, Russia, France, China, Japan, U.S.A and India too. The total pomegranate production of Iran amounts to around 650,000-680,000 tons and the area under cultivation of this orchard crop in Iran is estimated around 56,000 hectares. This fruit contains many valuable compounds including carotenoids, dietary fibers, unsaturated fatty acids, flavonoids, anthocyanins and glucose using which may reduce the risk of cancer, boost body immune system and prevent heart and veins diseases, diabetes and osteoporosis (Mousavinejad et al.,2009).

However, exporting this valuable commercial crop of Iran, as exports of many other agricultural commodities, still faces many challenges regarding storage, conveying, sorting, grading according to quality and size and also processing, which may cause irreparable harms to pomegranate export industry. Hence, in order to design processing and storage equipment for this fruit, it's very important to investigate its physical and hydrodynamic properties. Basically, designing agricultural machinery ignoring these parameters is imperfect and will lead to weak

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results. Thus, these properties including mass, volume, projected area and gravity center are absolutely necessary in defining proper standards in designing grading, conveying, processing and packing systems (Gharibzahedi et al., 2010). In modeling mass and heat transmission during cooling and drying processes, it's necessary to know volume and projected area of fruit. Moreover, because of the importance of face surface area in determining mass of the cuticular membrane per unit fruit surface area, building a relationship between mass, dimensions and projected area is useful in determining weight (Tabatabaeefar, 2003).Defining fluid velocity in hydraulic conveying of fruits depends on their density and shape, and therefore, difference in fruits qualities can be determined by difference in their densities (Tabatabaeefar and Rajabipour ,2005). Jordan and Clark (2004) stated that an approach of quality sorting of fruits is to use the terminal velocity of fruit moving in a fluid that has a density above or below the target fruit density. Fruits with different terminal velocities will reach different depths at fixed time durations and may be separated by suitably placed dividers. As far as we know, any report of measuring physical and hydrodynamic properties of two pomegranate cultivars, cv. Malas-Yazd and cv. Poost sefid has not been reported yet. Hence, our goal was to determine and compare some physical and hydrodynamic properties of these commercial cultivars to assess their post-harvest process.

2 Materials and methods

Two Iranian commercial pomegranate cultivars (Poost sefid and Malas-Yazd) were selected from the orchard of pomegranate research center of Yazd. The cv. Poost sefid is bone color and bigger, while Malas-Yazd is dark red and average size. From each cultivar, 40-50 fruits were picked randomly and transported to laboratory in polyethylene bags to reduce moisture loss during

transportation. All samples were kept in a 4°C store room until the tests were finished. All analyzes were performed at room temperature and in physical properties laboratory of Food science Department and in mechanical properties laboratory of Agricultural Machinery Department of University of Tehran.

2.1 Physical properties

The fruit mass was measured using a digital balance with 0.001 g accuracy. The fruit dimensions (length (L), width (W) and thickness (T)) of 100 fruits were measured randomly using a caliper with 0.01 mm accuracy. Then according to equations 1-4, mean arithmetical diameter (D_a), geometric diameter (D_g) and equivalent diameter (D_e) (all in mm), and also sphericity (ϕ)(%) as the surface area of a sphere (with the same volume as the given fruit) to the surface area of the fruit were determined for them (Mohsenin, 1986)

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

$$D_g = (LWT)^{1/3} \qquad (2)$$

$$D_e = \left(\frac{L(W+T)^2}{4} \right)^{1/3} \qquad (3)$$

All parameters are in (mm).

$$\phi = \frac{(LWT)^{1/3}}{L} \qquad (4)$$

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Fruit face surface area (S) was measured in mm^2 using equation 5 (Mohsenin, 1986) and aspect ratio (R_a) was obtained from the equation 6 (Gharibzahedi et al, 2009):

$$S = \pi D_g^2 \qquad (5)$$

$$R_a = \frac{W}{L} \qquad (6)$$

To measure fruit volume and density, water displacement method was used. Using a long metal bar, the randomly selected fruits were placed inside a graduated water column which was filled with water to a specified volume. Volume (V) was calculated using the equation below (Mohsenin, 1986):

$$V = \frac{w}{\gamma} \qquad (7)$$

Where:

w= displaced water weight

γ= water density

Projected areas including PA1 (the area perpendicular to axial diameter L), PA2 (the area perpendicular to axial diameter W) and PA3 (the area perpendicular to axial diameter T) of each pomegranate were measured and recorded using the "Area measurement system-Delta Tengland" apparatus with 0.05 mm^2 accuracy (Figure 1) .

Figure 1 Fruit projected area measurement system

Then, the criteria projected area (CPA) was defined as:

$$CPA = \frac{PA1 + PA2 + PA3}{3} \quad (8)$$

Packing coefficient, as the inherent volume of packed fruits to total volume of the box containing them, was obtained using the equation 9 below (Topuz et al.,2004):

$$\lambda = \frac{V}{V_0} \quad (9)$$

Where:

λ= packing coefficient

V= inherent volume of fruits

V_0= volume of the box containing fruits

To determine hydrodynamic properties of pomegranates, a graduated polexy glass column with 1200 mm height and 400×400 mm cross section was used (Figure 2). This column is optimum sized according to fruit diameter which is almost 20 percent of column diameter (Mirzaee et al., 2009). The column was filled with tap water to the height of 1100 mm. The pomegranates were placed at the bottom of the column, with the tail upwards, means the biggest projected area of fruit was facing upward. A digital camera, JVC, capable of shooting at 25 frames per second, recorded the fruit displacement from where it was released to top of water column (Figure 2).

Figure 2 Water column and camera setting to the side

Each fruit was tested 3 or 4 times. Using a video to frame software, the pomegranate movement video from the start point (bottom of the column) to end (top of the water column) was converted to image. The fruit coming up time and its terminal velocity were calculated according to the fact that every image is taken in 0.04 s.

Drag force (F_d) and buoyancy force (F_b) are forces acting against the fruit moving in water and defined by equations below, respectively:

$$F_d = C_d A_p \frac{\rho_f v^2}{2} \quad (10)$$

Where:

F_d= drag force (N)

A_p=projected area (cm^2)

ρ_f= true density of fruit (kgm^{-3})

C_d=drag coefficient

v=velocity of the fruit (ms^{-1})

Equation 10 is a function of fruit velocity, which at low velocities can be modeled according to stock law (Crowe et al., 2008)

$$C_d = \frac{24}{N_R} \quad N_R < 1 \quad (11)$$

$$N_R = \frac{v.D_e}{\mu} \quad (12)$$

$$F_b = \rho_f vg \quad (13)$$

Where:

N_R=Reynolds' number

D_e=fruit diameter (mm)

F_b= buoyancy force (N)

μ=dynamic viscosity of water (Pa·s)

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g= acceleration of gravity (ms^{-2})

2.2 Mechanical properties

Mechanical properties of pomegranate fruits were performed using a Testometric Machine M350-10CT (Testometric Co. Ltd., Rochdale, Lancashire, England) equipped with a 50N load cell and integrator. The measurement accuracy was ±0.001N in force and 0.001mm in deformation (Fathollahzadeh and Rajabipour, 2008). Twenty fruits from each variety were loaded between two parallel plates of the machine and compressed along the three major dimensions (x-axis, y-axis and z-axis) at loading rate of 50mm·min^{-1}, giving a total of 120 fruits tested. The selected loading rate for fruits was determined after primary experiments based on the best product quality and time and energy saving items.

The rupture point is a point on the force–deformation curve at which the loaded specimen shows a visible or invisible failure in the form of breaks or cracks. This point is detected by a continuous decrease of the load in the force-deformation diagram. While the rupture point was detected, the loading was stopped. The values of the force and deformation for the initial rupture of fruits were obtained from each compression curve. Energy absorbed by the sample at rupture was determined by calculating the area under the force-deformation curve by means of a digital planimeter (Numonics Corp., Lansdale, PA, Model 1250-1).

3 Results and discussion

3.1 Physical properties

Some physical properties of two pomegranate cultivars, cv. Poost sefid and cv. Malas-Yazd are given in Table 1. According to the results, the fruit mean length, width and thickness of cv. Poost sefid were 82.62 mm, 83.45 mm and 81.31 mm, respectively. While same dimensions for cv. Malas-Yazd were 71.65 mm, 75.35 mm and 75.70 mm. The difference between these values for two cultivars was statistically significant at the 1% level which means cv. Poost sefid is bigger in size than cv. Malas-Yazd. The mean values of geometric, equivalent and arithmetic diameters were different for two cultivars. They were 82.45 mm, 82.47 mm and 82.51 mm for cv. Poost sefid and 74.61 mm, 74.63 mm and 74.64 mm for cv. Malas-Yazd ($P< 0.01$). Also, the projected area on three axes and fruit face surface area were determined for both cultivars. Results showed that projected area and face surface area of cv. Poost sefid were respectively 15 and 18 percent more than that of cv. Malas-Yazd ($P<0.01$). Mean true density of cv. Poost sefid and cv. Malas-Yazd were 1028.3 kg/m^3 and 970.25 kg/m^3, respectively. Packing coefficient for cv. Poost sefid and cv. Malas-Yazd varied from 0.48 to 0.55; showing that while fruit volume decreases, the packing coefficient increases. Salah and ahmad (2002) in their study of physical properties of pomegranates cultivated in Saudi Arabia showed that other than weight and density, there is not a significant difference between other parameters including length, diameter and volume and obtained values of 6.55 cm, 3.67 cm, 156.74 cm^3 and 1.38 grcm^{-3} for length, diameter, volume and density, respectively. The difference between the results presented by these researchers and the findings in this study can be related to difference in cultivar type, environmental conditions

like cultivating area, weather and treatments as amount of fertilizers used during growth stages (Gharibzahedi et al., 2009).

Table 1 Some physical and hydrodynamic properties of two pomegranate cultivars

Physical properties	Varieties						Significant level
	Malas-Yazd			Poost sefid			
	max	min	mean	max	min	mean	
length (mm)	85.87	61.19	71.65 ± 5.62	99.6	68.77	82.62 ± 6.54	**
width (mm)	87.88	67.31	75.35 ± 5.53	100.85	73.29	83.45 ± 5.61	**
thickness (mm)	86.67	67.32	75.70 ± 4.91	96.42	70.27	81.31 ± 6.27	**
arithmetic diameter mm)	83.96	66.7	74.64 ± 3.23	95.58	73.61	82.51 ± 5.2	**
Geometric iameter(mm)	83.93	66.61	74.61 ± 5.22	95.59	73.61	82.45 ± 5.203	**
mean diameter(mm)	83.95	66.62	74.63 ± 5.22	95.51	73.61	82.47 ± 6.29	**
mass (g)	319	166.37	245.54 ± 10.81	502.68	227.93	331.67 ± 32.89	**
Volume (cm^3)	332	176	244.00 ± 51.3	503	217	326.5 ± 32.58	**
Sphericity (%)	1.11	0.97	1.04 ± .035	1.1	0.91	1.0139 ± 0.04	**
Area (mm^2)	2218.7	13933.3	17479.23 ± 248.8	28629.0	17014.97	21348.90 ± 264.48	**
PA1(mm^2)	88877	5563.4	7103.3 ± 161.07	11610.9	6180.1	8385.4 ± 130.39	**
PA2(mm^2)	9063.9	5685.9	7320.03 ± 045.51	11981.5	6479.8	8491.8 ± 1256.66	**
PA3(mm^2)	9057.8	5323.1	7154.4 ± 100.92	11918	6374.2	8577.95 ± 122.93	**
CPA(mm^2)	11738	6344.7	7172.55±229.34	11738.1	6344.12	8720.33±189.3	**
Packing coefficient	53.9	44.78	48.89±7.09	62.43	47.54	55.55 ± 5.4	**
True density ρ_t (kgm^{-3})	1021.3	882.44	970.25 ± 22.31	1340.4	958.13	1028.3 ± 31.29	**
Aspect ratio	1.02	0.84	0.94 ± 0.04	1.22	0.9	1.03 ± 0.09	**
Terminal velocity (ms^{-1})	0.32	0.09	0.18 ± 0.05	0.27	0.1	-0.17 ± 0.06	ns
T_d (s)	6.4	1.88	3.38 ± 1.3	8.64	2.16	3.42 ± 1.2	ns

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Buoyancy force (N)	3.13	1.63	2.41 ± 0.45	4.93	2.24	3.25 ± 0.61	**
Drag force (N)	3.43	0.89	1.94 ± 0.15	3.47	1.05	2.17 ± 0.12	ns

** significant level at 1%. ns: not significant.

3.2 Hydrodynamic properties

The investigated hydrodynamic properties of two pomegranate cultivars, cv. Poost sefid and cv. Malas-Yazd, are given in Table 2. The terminal velocity of cv. Poost sefid and cv. Malas-Yazd were respectively 0.18 ms-1 and -0.17 ms-1, which comparing the absolute value of them, no significant difference was seen. However, because the density of cv. Poost sefid was higher than water, it moved downwards in water, while cv. Malas-Yazd floated on water as a result of lower density compared to water. These results agreed the findings on apple reported by Dewey et al. (1966). Therefore, it is absolutely possible to sort and separate these two cultivars by nondestructive hydraulic means. Studying other parameters showed that the terminal velocity of two pomegranate cultivars was mostly affected by fruit true density, so that by increasing true density, the terminal velocity of fruit increased too. Taheri et al. (2010), in a study on hydrodynamic properties of tomato, by plotting curves of density difference, fruit volume and shape factor against terminal velocity showed that density has the strongest influence on terminal velocity. Kheiralipour (2006) studied the terminal velocity and coming up time of two apple cultivars cv. Redspar and cv. Delbarstival. Results showed that apples reach their terminal velocity 0.5 seconds after being released in water and while moving, they have a little tendency to rotate and displace horizontally. They also showed that a decrease in true density and an increase in mean geometric diameter would increase the terminal velocity.

Furthermore, the obtained buoyancy force was 3.25 N and 2.41 N for cv. Poost sefid and cv. Malas-Yazd, respectively and the values of drag force for these two cultivars were 2.17 N and 1.94 N, respectively. These parameters can be used to model terminal velocity and coming up or dropping time of fruit in a fluid, because in order to obtain terminal velocity, indexes as buoyancy force, drag force and fruit weight must be in balance.

3.3 Mechanical properties

Table 2 shows the mean comparison of data in correlation with the rupture force, maximum deformation and rupture energy of two studied pomegranate varieties. The rupture force values of Iranian pomegranate varieties had significant differences at Y and Z-axes loading ($P<0.05$), while this factor was not significant at X-axes loading. The values of rupture energy for pomegranate varieties at all of the loading directions were also significant at 5% probability level.

Table 2 Mean comparison of rupture force, deformation and energy pomegranate fruit considering interaction effect of variety and loading orientation

Variety	Loading orientation								
	Rupture force (N)			Maximum deformation (mm)			Rupture energy (mJ)		
	X-axes	Y-axes	Z-axes	X-axes	Y-axes	Z-axes	X-axes	Y-axes	Z-axes
Pust sefid	52.54±3.1	52.1±2.3	198±5.11	2.3±0.3	1.89±0.2	6.4±0.7	58.3±4.4	48.67±4.8	619.56±27.1
Malas	85±6.7	140±8.4	307.5±11.3	4.5±0.5	5.8±0.4	6.76±0.7	188.5±8	400.8±23.5	1020.3±87.9
Significant level	n.s	*	*	n.s	*	n.s	*	*	*

* significant level at 5%. ns: not significant.

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However, the deformation values were not significant for both loading directions of X and Y-axes. The lowest value of rupture force (52.1N) and energy (48.67mJ) was observed at Y-axes orientation for Poost sefid variety, while the highest rupture force (307.5N) and energy (1020.3mJ) values were for Malas variety under compression loading at Z-axis direction. Braga et al. (1999) also reported that rupture force increased as nut size increased for macadamia nut under compression loading. Therefore, it was observed that the rupture force and energy used to indicate pomegranate mechanical behavior were dependent on deformation rate and size for compression along the X-, Y-, and Z-axis. Also, the Pust sefid variety at Y-axes orientation had the lowest deformation value. These data will have a potential usage in harvest, transportation, classification, packaging and also providing useful knowledge for industrial processing.

4 Conclusions

1) Length, width and thickness of cv. Poost sefid and cv. Malas-Yazd were 82.62 mm, 83.45 mm and 81.31 mm and 35.65 mm, 75.71 mm and 75.7 mm, respectively. Results showed that overall, cv. Poost sefid is bigger in size than cv. Malas-Yazd.
2) The criteria projected area (CPA) of cv. Poost sefid was 21.5% bigger than that of cv. Malas-Yazd, while true density of cv. Poost sefid was 5.97% more than that of cv. Malas-Yazd. Packing coefficient was also higher for cv. Poost sefid compared with cv. Malas-Yazd.
3) The absolute values of terminal velocities of two pomegranate cultivars studied here were equal.
4) Two hydrodynamic parameters, buoyancy force and drag force were bigger for cv. Poost sefid compared with cv. Malas-Yazd.

5) It was observed that the deformation rate effect on rupture force and energy to indicate pomegranate mechanical behavior.

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