Int. Agrophysics, 2008, 22, 125-131

INTERNATIONAL
Agrophysics
www.international-agrophysics.org

Some postharvest physical properties of Iranian apricot (*Prunus armeniaca* L.) fruit

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Received October 29, 2007; accepted April 14, 2008

A b s t r a c t. Some of the postharvest physical properties of six cultivars of Iranian apricot fruits are presented in this study. Information about these properties is very important for understanding the behaviour of the product during the postharvest operations, such as harvesting, transporting, sorting, grading, packaging and storage processes. This research was undertaken to study some physical properties of six Iranian apricot cultivars (Shams, Nakhjavan, Djahangiri, Sefide Damavand, Shahroud-8, and Gheysi-2). These properties include: linear dimensions, geometric mean diameter, projected area, criteria projected area, surface area, sphericity, volume, mass, bulk and average fruit density, packaging coefficient, coefficient of static friction, and ratio of length to width (L/W), length to thickness (L/T), and length to mass (L/M).

K e y w o r d s: apricot, *Prunus armeniaca* L., fruit, physical properties, Iranian cultivars

INTRODUCTION

Apricot (*Prunus armeniaca* L.) is classified under the *Prunus* species of Prunodae sub-family of the Rosaceae family of the Rosales group. This type of fruit is a cultivated type of zerdali (wild apricot) which is produced by inoculation. Apricot has an important place in human nutrition, and can be used as fresh, dried or processed fruit. As known, the fruit of apricot is not only consumed fresh but also used to produce dried apricot, frozen apricot, jam, jelly, marmalade, pulp, juice, nectar, extrusion products, *etc*. Moreover, apricot kernels are used in the production of oils, benzaldehyde, cosmetics, active carbon, and aroma perfume (Yildiz, 1994). Apricot is rich in minerals such as potassium, and vitamins such as β-carotene which is the pioneer substance of mineral A, is necessary for ephithelia tissues covering our bodies and organs, eye-health, bone and teeth development and working of endocrine glades (Haciseferogullari *et al*., 2005).

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Apricot trees can grow over the five continents of the world and production level exceeds 2 million tons. Australia, France, Hungary, Iran, Italy, Morocco, Spain, Tunisia, Turkey can be regarded as important apricot producer countries. While some of the countries such as Hungary, Morocco, Iran and Tunisia are important fresh apricot exporters, the others, such as Australia and Turkey, are major and famous dried apricot producers and exporters. Dried apricots which are in extensive demand in several parts of the world *ie* USA, UK, Germany, Australia, *etc*., occupy an important place in the world trade. In 2005, Turkey and Iran (having cultivated area with 20000 hectares and with average annual production of 275 580 t) were the largest producers of apricot in the world (USDA, 2005).

Agricultural crops and food products have several unique characteristics which set them apart from engineering materials. These properties determine the quality of the fruit and identification of correlations between changes in these properties makes quality control easier. Proper design of machines and processes to harvest, handle and store agricultural materials and to convert these materials into food and feed requires an understanding of their physical properties (Stroshine and Hamann, 1994). Information regarding dimensional attributes is used in describing fruit shape which is often necessary in horticultural research for a range of differing purposes, including cultivar descriptions in applications for plant variety rights or cultivar registers (Beyer *et al*., 2002), evaluation of consumer preference, investigation of heritability of fruit shape traits (White *et al*., 2002), or analysis of stress distribution in the fruit skin (Considine and Brown, 1981). Knowledge of the shape and physical dimensions are important in screening solids to separate foreign materials and in sorting and sizing of apricot fruit. Quality differences in apricot fruits can often be detected by differences in density. When apricot fruits are transported hydraulically, the design of fluid velocities is related to both density and shape. Volumes and projected area of apricots must be known for accurate modelling of heat and mass transfer during cooling and drying. The porosity of apricots can be used for controlling the temperature of stored apricot fruits. An awareness of fruit surface area would be useful in determination of mass of the cuticular membrane per unit fruit surface area, as emphasized by Peschel *et al*. (2007). The cuticular membrane (CM) covers fruit and forms the interface between the plant and its environment. The CM serves as a protective barrier against water loss, nutrient leaching, mechanical damage, and invasion by pathogens (Jeffree, 1996).

Due to the lack of information about the physical properties of Iranian apricot cultivars, which are very important for understanding the behaviour of the product during the postharvesting operations such as harvesting, transporting, sorting, grading, packaging and storage processes, and also in processing operations such as cooling, drying and all heat and mass transfer processes, the main objective of this work was to study some physical properties to form an important database for six apricot cultivars in Iran (Shams, Nakhjavan, Djahangiri, Sefide Damavand, Shahroud-8, and Gheysi-2). These properties include: linear dimensions, geometric mean diameter, surface area, projected area, fruit volume, packing coefficient, mass, bulk and average fruit density, and static friction coefficient.

MATERIALS AND METHODS

The Iranian apricot fruits used in this study consisted of Shams, Nakhjavan, Djahangiri, Sefide Damavand, Shahroud-8, and Gheysi-2 cultivars which were obtained from agricultural research centre of Shahroud, Iran (distance of which from the Semnan province is 170 km). The samples of the fruits were weighed and dried in an oven at a temperature of 78°C for 48 h, then weight loss on drying to a final content weight was recorded as moisture content (AOAC, 1984).

For each apricot fruit, three linear dimensions were measured, that are length, width, and thickness. Also, cross sectional areas (CSAs) in three perpendicular directions of the fruit, using area measurement system Delta-T, England, were determined (Fig. 1). Dimensional characteristics obtained from this device are based on image processing. Captured images from a camera are transmitted to a computer card which works as an analogue to digital converter. Digital images are then processed in the software and the desired user needs are determined. Through three normal images of the apricot fruit, this device is capable of determining the length, width and thickness diameters as well as projected areas perpendicular to these dimensions. Total error for these objects is less than 2%. This method has been used and reported by Mirasheh (2006).

The geometric mean diameter, sphericity, criteria projected area and surface area were calculated (Mohsenin, 1986):

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

where: D_g – geometric mean diameter (mm), L – length of apricot fruit (mm), W – width of apricot fruit (mm), T – thickness of apricot fruit (mm), and:

$$\Phi = D_g / L, \quad (2)$$

where: Φ – sphericity (%),

$$CPA = \frac{PA_1 + PA_2 + PA_3}{3}, \quad (3)$$

where: CPA – criteria projected area (mm^2); PA_1 – first, PA_2 – second, PA_3 – third projected areas (mm^2), they are perpendicular to length, width and thickness, respectively:

$$S = \pi D_g^2, \quad (4)$$

where: S – surface area (mm^2). The above experiments were performed in 40 replicates.

Fruit density was determined by the water displacement method (Dutta *et al*., 1988). Randomly selected apricot fruits were weighed on a digital balance with 0.01 g accuracy. The fruits were lowered with a metal sponge sinker into a measuring cylinder containing water such that the fruits did not float during immersion in water; weight of water displaced by the fruit was recorded.

The volume and, in aftermath, average fruit density (average fruit density other than fruit density because of different density of tissue, kernels, skin, *etc.*) were calculated by the following equations (Mohsenin, 1986):

$$V_w = \frac{m_w}{\rho_w}, \quad (5)$$

where: V_w – volume of displaced water (cm^3), m_w – mass of displaced water (g), ρ_w – density of water (kg m^{-3}), and

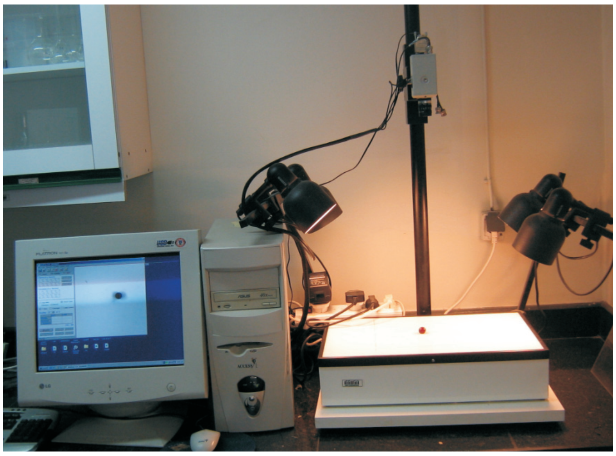

Fig. 1. Apparatus for measuring dimensional characteristics (areameter Delta T, England).

$$\rho_t = \frac{m}{V_w}, \quad (6)$$

where: ρ_t – true density (kg m^{-3}), m – mass of apricot fruit (g).

The bulk density was determined using the mass and volume relationship by filling an empty plastic container of predetermined volume and weight. The fruits were left to fall from a constant height, striking off the top level and weighting. The average fruit density value is the ratio of mass to volume values, while porosity was computed (Jain and Bal, 1997) as:

$$\varepsilon = \frac{\rho_t - \rho_b}{\rho_t} 100, \quad (7)$$

where: ε – porosity (%), ρ_b – bulk density (kg m^{-3}).

Packing coefficient (λ) was defined by the ratio of the volume of fruit (V) packed to the total volume (V_0) and calculated by the following equation:

$$\lambda = \frac{V}{V_0}, \quad (8)$$

where: λ – packaging coefficient, V – volume of apricot fruit (cm^3).

The coefficient of static friction of the fruit was found with respect to three structural materials, namely iron, rubber and galvanized iron sheet, using the inclined plane apparatus as described by Dutta *et al*. (1988). The table was gently raised and the angle of inclination to the horizontal at which the sample, arranged in a box of 15x15 cm (avoiding fruit rolling phenomenon), started sliding was read off the protractor attached to the apparatus. The tangent of the angle was reported as the coefficient of static friction (Dutta *et al*., 1988). Each of above stated parameters were obtained from average of five experimental data.

RESULTS AND DISCUSSION

Some physical properties of the six apricot cultivars are given in Table 1. These properties were found at specific fruit moisture contents of cultivars (Shams, Nakhjavan, Djahangiri, Sefide Damavand, Shahroud-8, and Gheysi-2) at 84.87, 87.88, 81.73, 81.75, 85.04, and 87.27 % d.b., respectively. Knowing these moisture content values is helpful in analysing the convective dehydration of apricot as suggested by Ochoa *et al*. (2007) who reported that during convective dehydration of whole apricots, both volume and surface area changes are independent of operating conditions in the tested range, and are related only to the moisture content of the partially dehydrated fruit. Considering water, which is an important component in most fruits and determines their perishability, knowledge of fruit moisture content and water activity is very useful to forecast the stability conditions in apricot fruits in order to select formulations and storage conditions in new products and to improve drying processes and equipments (Vulliod *et al*., 2004).

As seen in Table 1, all properties considered in the current study were found to be statistically significant at 1% probability level. The greatest dimensional characteristics were found for Djahangiri cultivar, varying from 41.70 to 53.10, 39.80 to 50.40, and 38.70 to 49.10 mm, related to length, width and thickness, respectively. Nakhjavan had the lowest values of length, width and thickness among the studied cultivars. The corresponding values were obtained with means of 40.97, 36.23, and 35.26 mm, respectively. To design a mechanism for mechanical harvesting of apricot (*Hacthaliloglu* L.), Erdogan *et al*. (2003) reported length, width, and thickness of the fruit as 38.94, 40.92, and 35.21 mm, respectively. The axial dimensions are important in determining aperture size of machines, particularly in separation of materials, and these dimensions may be useful in estimating the size of machine components. For example, they may be useful in estimating the number of fruits to be engaged at a time, the spacing of slicing discs, and number of slices expected from an average fruit. The major axis has been found to be useful by indicating the natural rest position of the material and hence in the application of compressive force to induce mechanical rupture.

The highest geometric mean diameter values were found for Djahangiri and Shams cultivars, with means of 45.27 and 44.06 mm, respectively, but the lowest ones were for Sefide Damavand and Nakhjavan cultivars, with average of 38.83 and 37.35 mm, respectively. In a study conducted by Lorestani and Tabatabaeefar (2006), the highest geometric mean diameter for kiwifruit was obtained as 55.3 mm. Sphericity values differed significantly among the tested cultivars. The latter property values were 0.971, 0.917, 0.973, 0.925, 0.923, and 0.875 for Shams, Nakhjavan, Djahangiri, Sefide damavand, Shahroud-8, and Gheysi-2 cultivars, respectively. The knowledge related to geometric mean diameter would be valuable in designing the grading process. According to the results, the highest PA_1, PA_2, and PA_3 values were fore Djahangiri, with mean of 1571.46, 1654.72, and 1705.27 mm^2, respectively. Nakhjavan had the lowest projected areas, so that values of PA_1, PA_2, and PA_3 were found within 792.10-1128.90, 877.20-1269.80, 904.90 -1980.60 mm^2, respectively. The results for the projected area are due to the differences in values of dimensional characteristics, because Djahangiri and Nakhjavan had the highest and the lowest dimensional characteristics and projected areas, respectively.

The criteria projected area of each apricot cultivar resulted in different means, varying from 1117.34 to 1643.81 mm^2. The volume of the Djahangiri cultivar (49.99 cm^3) was significantly greater than that of the other ones. The volume values of the Shams and Shahroud-8 fruits were 48.22 and 43.31 cm^3, respectively, followed by the Sefide Damavand (36.74 cm^3), Gheysi-2 (36.04 cm^3), and Nakhjavan (27.39 cm^3) cultivars. Considering the latter result, it is clear that a large number of Nakhjavan fruits could be packed in the predetermined volume compared

Table 1. Some physical properties of six Iranian apricot fruits

Properties	Varieties					
	Shams	Nakhjavan	Djahangiri	Sefide Damavand	Shahroud-8	Gheysi-2
Fruit length (mm)	45.37 ± 2.42	40.97 ± 5.19	46.54 ± 2.5	41.98 ± 3.1	46.63 ± 2.77	46.51 ± 1.95
Fruit width (mm)	43.96 ± 2.23	36.23 ± 1.81	45.37 ± 2.46	38.42 ±2.25	43.95 ± 2.57	39.93 ± 2.03
Fruit thickness (mm)	42.9 ± 2.54	35.26 ± 1.42	43.97 ± 2.52	36.33 ± 2.78	38.93 ± 1.83	36.36 ± 2.29
Geometric mean diameter (mm)	44.06 ± 2.32	37.35 ± 1.87	45.27 ± 2.41	38.83 ± 2.55	43.04 ± 2.20	40.71 ± 1.85
Fruit mass (g)	49.01 ± 2.67	27.55 ± 2.22	49.69 ± 2.81	35.82 ± 2.59	42.97 ± 2.31	33.29 ± 1.55
Fruit volume (cm^3)	48.22 ± 2.59	27.39 ± 1.8	49.99 ± 2.86	36.74 ± 1.62	43.31 ± 2.4	36.04 ± 2.54
Sphericity	0.971 ± 0.002	0.917 ± 0.003	0.973 ± 0.003	0.925 ± 0.002	0.923 ± 0.001	0.875 ± 0.002
Surface area (mm^2)	6115.36 ± 43.34	4395.25 ± 338.8	6458.35 ± 313.1	4757.96 ± 312	5835.89 ± 249.9	5217.7 ± 298.45
PA_1 (mm^2)	1545.69 ± 21.32	1009.08 ± 79.96	1571.46 ± 85.23	1134.64 ± 104.12	1353.36 ± 94.71	1192.46 ± 121.33
PA_2 (mm^2)	1598.06 ± 132.6	1145.89 ± 96.94	1654.72 ± 126.37	1306.14 ± 108	1489.79 ± 133.58	1384.83 ± 122.99
PA_3 (mm^2)	1653.84 ± 134.47	1197.06 ± 97	1705.27 ± 127.65	1383.73 ± 92.14	1668.18 ± 135.65	1523.86 ± 125.05
CPA (mm^2)	1599.20 ± 131.06	1117.34 ± 89.80	1643.81 ± 125.38	1274.84 ± 101.27	1503.78 ± 132.2	1367.05 ± 128.58
Bulk density (kg m^{-3})	453.61 ± 17.53	463 ± 23.41	457.47 ± 25.65	444.75 ± 18.65	431.57 ± 12.35	455.27 ± 0.004
Average fruit density (kg m^{-3})	1017.6 ± 25.06	1000.5 ± 68.17	994.6 ± 25.73	982.5 ± 10.23	992.7 ± 28.83	924.1 ± 13.07
Porosity (%)	55.42 ± 0.4	53.7 ± 0.94	54 ± 0.26	54.7 ± 0.95	56.52 ± 1.2	50.7 ± 0.44
Packaging coefficient	0.4458 ± 0.004	0.463 ± 0.009	0.46 ± 0.002	0.543 ± 0.009	0.434 ± 0.012	0.493 ± 0.004
Static friction coefficient						
Iron sheet	0.206 ± 0.011	0.294 ± 0.013	0.284 ± 0.020	0.376 ± 0.011	0.173 ± 0.017	0.404 ± 0.015
Galvanized iron sheet	0.186 ± 0.009	0.261 ± 0.023	0.247 ± 0.021	0.291 ± 0.022	0.141 ± 0.007	0.308 ± 0.015
Rubber	0.286 ± 0.010	0.344 ± 0.013	0.333 ± 0.017	0.407 ± 0.020	0.246 ± 0.020	0.434 ± 0.015

with the other cultivars. The surface area of the Djahangiri fruit (6458.35 mm^2) was significantly greater than those of the other studied cultivars. The surface area of the Shams cultivar was found to be 6115.36 mm^2, followed by the Shahruod-8, Gheysi-2, Sefide damavand and Nakhjavan cultivars, which had mean values of 5835.89, 5217.70, 4757.96, and 4395.25 mm^2, respectively. Hacisefrogullari *et al*. (2007), in their study on Turkish apricot cultivars, reported the highest and the lowest surface area values for Hasanbey and Zerdali cultivars, respectively, with means of 5351.69 and 2646.27 mm^2. These properties could be beneficial in proper prediction of apricot drying rates and hence drying times in the dryer. If in the drying equipment simulation models for apricot, such as the changes of volume (that contains a characteristic dimension as the fruit radius) and the surface area to volume ratio of the individual fruit, are not considered, the estimates could lead to important errors. Therefore, this requires the knowledge of the relation between the volume and surface area changes, on the operation conditions of the dryer, and the average water content of the apricot fruits. These volume and area changes also modify transport properties of individual fruits, as well as the thickness and porosity of the packed bed (Ochoa *et al*., 2002).

According to the obtained results, the mean porosity values for Shams, Nakhjavan, Djahangiri, Shahroud-8, Sefide Damavand, and Gheysi-2 fruits were found to be 55.42, 53.7, 54, 56.52, 54.7, and 50.7%, respectively. The Nakhjavan cultivar had a 463 kg m^{-3} bulk density, followed by the Djahangiri and Gheysi-2 cultivars with means of 457.47 and 455.27 kg m^{-3}, respectively. Shams, Sefide Damavand and Shahroud-8 ranked at the next places with means of 453.61, 444.75, and 431.57 kg m^{-3}, respectively. Also, the average fruit density of both Shams and Nakhjavan cultivars was significantly greater than that of the other cultivars, varying from 8504.33 to 1280.35, and from 9534.57 to 1043.51 kg m^{-3}, respectively. A similar study was conducted by Sharifi *et al*. (2007) on physical properties of orange (Var. Tompson) fruit, based on which those authors reported that the average fruit density varied from 1.01 to 1.04 g cm^{-3}. The sample mass of apricots was found to have different means, and these values varied from 27.55 to 49.69 g. Also, Djahangiri had more weight than other cultivars. The variation in those parameters was found to be significant at 5% probability level. Corresponding value was found to be 28.8 g for apricot (*Hacthaliloglu* L.), reported by Erdogan *et al*. (2003), and 21.33 g for Alyanak cultivar found by Betul Akin *et al*. (2008). This property may be useful in the separation and transportation of the fruit by hydrodynamic means in water canals.

The packaging coefficient of the apricot fruits resulted in different means, varying from 0.434 (Shahroud-8) to 0.543 (Sefide Damavand). Postharvest treatment with low O_2 and/or high CO_2 concentrations is an attractive alternative for controlling fungal decay, maintaining fruit quality and extending post-harvest life of fruits (Tian *et al*., 2004). Considering this fact, having any information on packaging coefficient of apricot could result in efficient control of fruit quality during storage.

The relational statistics, such as L/W, L/T, and L/M, with respect to dimensional properties of all apricot fruit types were found to be meaningful at 1% probability level. As given in Table 2, the highest and the lowest of L/W value were found for Gheysi-2 and Djahangiri cultivars with means of 1.166 and 1.026, respectively. In the case of L/T value, the Gheysi-2 cultivar had a 1.281 ratio, followed by the Shahroud-8 and Nakhjavan with means of 1.198 and 1.162, respectively. Sefide Damavand, Djahangiri, and Shams ranked at the next places with means 1.156, 1.059, and 1.058, respectively. Nakhjavan cultivar showed the greatest L/M among the other cultivars with mean of 1.503, but Shams had the minimum ratio at 0.941. The coefficient of static friction on the examined surfaces was found to be

T a b l e 2. Some dimensional characteristics ratios of the studied apricot cultivars

Varieties	Particulars	Ratio
Shams	*L/W*	1.032
	L/T	1.058
	L/M	0.941
Nakhjavan	*L/W*	1.132
	L/T	1.162
	L/M	1.503
Djahangiri	*L/W*	1.026
	L/T	1.059
	L/M	0.951
Sefide Damavand	*L/W*	1.092
	L/T	1.156
	L/M	1.182
Shahroud-8	*L/W*	1.061
	L/T	1.198
	L/M	1.100
Gheysi-2	*L/W*	1.166
	L/T	1.281
	L/M	1.416

statistically significant at 1% probability level. On the iron sheet surface, the static friction coefficient values of the Shahroud-8 and Gheysi-2 cultivars were found to be the lowest and the highest coefficients with means of 0.173 and 0.404, respectively. On the rubber surface, the coefficient of static friction of the Gheysi-2 fruit, with mean of 0.434, was significantly greater than those of the other cultivars. This value for the Sefide Damavand, Nakhjavan, and Djahangiri was found to be 0.407, 0.333, and 0.344, respectively, and was followed by the Shams and Shahroud-8, with a mean of 0.286 and 0.246, respectively. Similar to the surfaces mentioned above, on the galvanized iron sheet the highest coefficient of static friction was obtained for Gheysi-2 fruit with a mean of 0.308, while the corresponding value was 0.141 for Shahroud-8 as the lowest coefficient. In a study, the static friction coefficient on sheet iron, galvanized sheet iron, and rubber surfaces were reported as 0.201, 0.181, 0.281 for Zerdali cultivar (Hacisefrogullari *et al*., 2007).

Data obtained in this research are the first ones for the apricot fruits grown in Iran. These data will have a potential usage in harvest, transportation, classification, processing, storing, packaging and other processes related to apricot fruits (Khanali *et al*., 2007). At the end, it is recommended that other properties of apricot fruit, such as thermal, rheological, mechanical, and nutritional characteristics should be studied and changes of these properties be examined as a function of moisture content and ripening phases.

CONCLUSIONS

1. The length of apricot fruit varied from 35.6 to 70.8 mm with CV (coefficient of variation) of 8.68%.

2. The fruit width and thickness ranged from 32.2 to 50.4, from 28.9 to 49.1 with CV of 9.69% and 10.48%, respectively.

3. The geometric mean diameter ranged from 32.98 to 50.84 with CV of 8.64%.

4. The criteria projected area of each apricot cultivar resulted in different means, varying from 1117.34 to 1643.81 mm^2.

5. The highest and the lowest volume and mass were found for Djahangiri and Nakhjavan cultivars, with means of 49.99 cm^3, 49.69 g and 27.39 cm^3, 27.55 g, respectively.

6. The greatest values of *L/W, L/T* were obtained for Gheysi-2 cultivar, whereas the highest *L/M* value was found for Nakhjavan cultivar.

7. Three surfaces of iron, rubber, and galvanized iron sheets were selected for measuring the static friction coefficient. Among the six Iranian apricot cultivars; Gheysi-2 showed the greatest friction coefficients on all surfaces.

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