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Determining some physical properties of bergamot (*Citrus medica*)

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A b s t r a c t. Physical properties are often required for designing post harvest handling/processing equipment for agricultural products. Bergamot is a species of citrus fruit. Physical properties of bergamot are necessary for equipment used in activities such as transportation, storage, grading, packing, and in food production processes like drying, jam production and so on. In this study some physical properties of bergamot were determined. Properties which were measured included fruit dimensions, mass, volume, projected area, fruit density, shell ratio, geometric mean diameter, sphericity and surface area. Bulk density, porosity and also packing coefficient were measured for three groups of small, medium and large category of bergamots. Experiments were carried out at moisture content of 84.9% w.b. for bergamot shell and 87.34% w.b. for its meat. Result showed that average mass and volume were 291.9 g and 456.83 cm^3, respectively. Dimensions increased from 78.7 to 160 mm in length, 64.2 to 128.5 mm in width, and 64 to 125 mm in thickness. The mean projected area perpendicular to length, width, and thickness obtained 7063.61, 7933.39 and 8137.77 mm^2, respectively. The geometric mean diameter and surface area were calculated as 97.02 mm, 30412.31 mm^2, respectively, while sphericity and shell ratio (w.b.) were measured at 0.89 and 0.62%, respectively.

K e y w o r d s: bergamot, citrus, physical properties

INTRODUCTION

Iran has an annual production level of 3.5 mln t of citrus fruit and was ranked 22nd producer in the world (Khojastapour, 1996).

The Bergamot (*Citrus medica*) is a species of citrus fruit. Its tree is called citrus bergamia. Bergamia is an evergreen tree (like other trees of this family) and slow-growing. Bergamia begins to bear fruit when it is around three years old.

Bergamot is characterized by its thick rind and small sections. Its skin is thick, somewhat hard, fragrant, and covered with protuberances; the pulp is white and subacid. Bergamot fruit consists of flevedo (protuberances), albedo (pulp) and oval-shaped meat (Fig. 1).

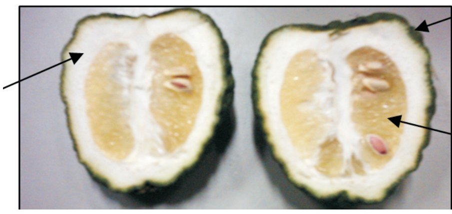

Fig. 1. Longitudinal section of bergamot.

The flevedo is initially green and, as the fruit ripens, becomes yellow. Usually before the yellow stage, the crop is harvested and the skin is dried. Dried skins are used in jam production in seasons that fresh fruit is not available. In addition, bergamot as dried fruit is exported to many countries. The albedo is white in both green and yellow stages of the flevedo. Bergamot fruit skin (flevedo) has a bitter taste but it is fragrant and should be detached in jam production.

In Iran, bergamot is used in several ways. The fruit shell is used in jam production and also in medical applications. Its meat is edible and very sour and is used in place of lemon juice or in making various pickles.

Bergamot is mostly grown near the Mediterranean, in Iran and in Central and South America. Bergamot is one of the horticultural products of Iran and usually grown in south regions like Jahrom in Fars province.

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Physical properties are often required for designing post harvest handling and processing equipment for agricultural products. Physical properties data of bergamot are necessary for harvesting and various post harvesting operations such as transportation, storage, sorting, grading, packing, food production processing like drying, jam production and so on. A thorough review of literature showed no results for bergamot product, hence, similar products are addressed due to the similar methodologies used.

Topuz *et al*. (2005) determined several properties of four orange varieties (Alanya, Finike, W.Navel, Shamouti) and made a comparison of the results. Kaleemullah and Gunasekar (2002) conducted a research to investigate some physical properties of arecanut kernels, namely, size, shape, roundness, sphericity, 100 kernel mass, bulk density, porosity, angle of repose, static coefficient of friction and kinetic coefficient of friction in the moisture range from 10.51 to 88.91% d.b.

Tabatabaeefar *et al*. (2000) determined models for predicting mass of Iranian grown oranges from their volumes, dimensions and projected areas. Tabatabaeefar (2002) determined physical properties of common varieties of Iranian grown potatoes. Relationships among physical attributes were determined and a high correlation was found between mass and volume of mixed tangerines, with a high coefficient of determination.

Tabatabaeefar and Rajabipour (2005) recommended 11 models for predicting the mass of apples based on their geometric attributes. Lorestani and Tabatabaeefar (2006) determined some physical characteristics of kiwi fruits, including mass, volume, dimensions and projected areas perpendicular to major diameters, bulk density, geometric mean diameter, and percent sphericity. Also they determined mathematical models for predicting the mass of kiwi fruits from their dimensions and projected areas. They found that there is a very good relationship between the mass and measured volume for all of varieties of kiwi. Rafiee *et al*. (2006a) estimated the mass of date gasbi by artificial neural network. They used a multi-layer feed forward network structure with input, output and hidden layer(s). Two neural network models were constructed to predict the mass using the dimensions properties of the date. Rafiee *et al*. (2006b) investigated some physical properties of orange (Thompson) mass and proposed five equations for measuring orange mass based on dimensions and projected areas.

Also many studies have been reported on the physical properties of fruits such as plum (Ertekin *et al*., 2006) and gumbo fruit (Akar and Aydin, 2005).

Most of the processing methods employed are still traditional. There is a need to develop appropriate technologies for its processing. The development of the technologies will require knowledge of the properties of this fruit.

In this study physical properties of bergamot, such as size, mass, projected area, fruit density, solid density, bulk density, bulk porosity, packing coefficient, density ratio, geometric diameter, sphericity and surface area were determined.

MATERIALS AND METHODS

Materials

Bergamot fruits were harvested directly from a garden in Jahrom. Jahrom is one of the most important horticultural centres in the south of Iran. Approximately 300 bergamot fruit were selected randomly for the experiments.

The fruits were transported, individually, to the physics laboratory of Biosystem Faculty at the University of Tehran. The experiments were carried out in three days at laboratory temperature between 25 and 29°C.

Methods

In order to measure the moisture content the samples were split into two parts. Then the meat was detached from bergamot skin. The cut parts were weighed and dried in an oven at a temperature of about 80°C for three days. Mass loss on drying to a final constant value was recorded as moisture content (AOAC, 1984):

$$MC\,(\%) = \frac{M_0 - M_d}{M_0}\,100, \quad (1)$$

where: MC is moisture content (wet basis), M_0 is initial mass, and M_d is final mass of bergamot fruit (g). The fruit size in terms of three linear dimensions, including length, width, and thickness, was measured by means of image processing. In order to obtain dimensions and projected area, WinAreaUt_06 system (Fig. 2) with sensitivity of 0.05 mm was used (Mirasheh, 2006), where L, W and T are the major, medium and minor perpendicular dimensions of the fruit and P_a, P_b and P_c are projected area perpendicular to L, W and T, respectively (Fig. 3).

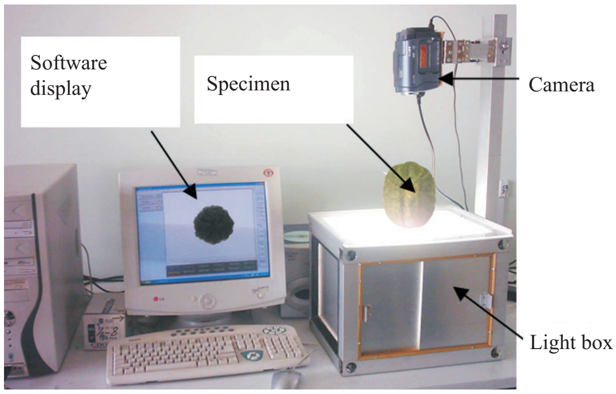

Fig. 2. WinAreaUt_06 system.

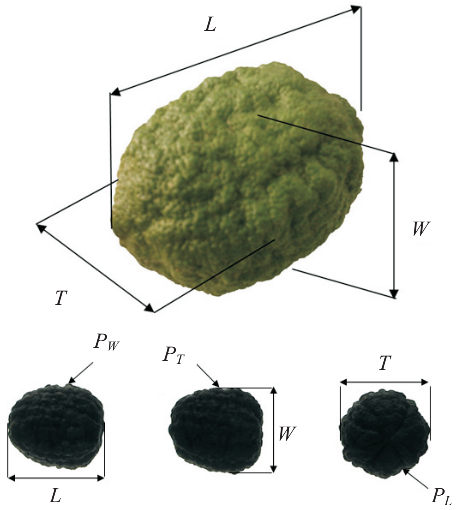

Fig. 3. Three major dimensions and projected areas of fruit.

Mass (g) of individual fruit was determined by using an electronic balance (Mettler Toledo GmbH, Greifensee, Switzerland) with a sensitivity of 0.01 g. Fruit volumes (cm^3) and fruit density (g cm^{-3}) were measured by water displacement method (Dutta *et al*., 1988; Oje and Ugbor, 1991; Oje, 1994; Aviara *et al*., 1999). Fruits were weighed and allowed to float in water. The fruits were lowered with a metal sponge sinker into water. Mass of water displaced by the fruit was recorded. Finally fruit densities (g cm^{-3}) were calculated by using the following equation:

$$\rho_f = \frac{M}{M - M_w}\rho_w, \tag{2}$$

where: ρ_f is the fruit density (g cm^{-3}), ρ_w is the water density (1.05 g cm^{-3} at laboratory temperature); M_a and M_w are mass of bergamot in air and water, respectively.

Bulk density was determined using the AOAC (1984) recommended method. The bulk density (g cm^{-3}) of bergamot was measured based on the volume occupied by the bulk. Bulk density was determined measuring bergamot fruit mass per volume by using a balance and box (Suthar and Das, 1996a; Singh *et al*., 1996).

$$\rho_b = \frac{M}{V}, \tag{3}$$

where: ρ_b is the bulk density (g cm^{-3}), M and V are mass of fruit and box volume, respectively.

The bulk density was determined using the mass volume relationship (Fraser *et al*., 1978) by filling an empty plastic container of predetermined volume and mass. The fruits were poured from a constant height, striking off the top level and weighing. Porosity was calculated as the ratio of the difference in the fruit and bulk density to the fruit density value and expressed in percentage. The porosity was calculated from the following relationship (Mohsenin, 1978; Vursavus *et al*., 2006):

$$\varepsilon = \left(\frac{\rho_f - \rho_b}{\rho_f}\right)100, \tag{4}$$

where: ρ_b is the bulk density (g cm^{-3}), and ρ_f is the fruit density (g cm^{-3}).

Packing coefficient was defined by the ratio of the volume of fruit packed to the total volume and calculated by the following equation:

$$\lambda = V/V_o, \tag{5}$$

where: λ, V_0 and V are packing coefficient, box volume and total volume of bergamots in the box, respectively.

Shell ratio was defined by dividing the shell mass to the fruit mass and calculated by the following equation:

$$R_s = (M_s / M_f)100, \tag{6}$$

where: R_s, M_s and M_f are shell ratio, peel mass and fruit mass, respectively. Shell ratio was measured based on wet and dry bases. Packing coefficient and shell ratio equations were presented in the report by Topuz *et al*. (2005).

Geometric mean diameter (D_g), sphericity (Φ) and surface areas (S) were calculated by using the following equations:

$$D_g = (LWT)^{1/3}, \tag{7}$$

$$\Phi = D_g / L, \tag{8}$$

$$S = \pi D_g{}^2. \tag{9}$$

The equations used for calculating the geometric mean diameter, sphericity and surface area were presented in the Baryeh (2001), Demir *et al*. (2002), Mohsenin (1978), and Sitkei (1986) reports, Kabas *et al*. (2005) and Karababa (2006), respectively.

The results of experiments of physical properties are presented as follows.

RESULTS AND DISCUSSION

Experiments were carried out at moisture content of 84.9 w.b. for bergamot shell and 87.34 w.b. for its meat. The results showed that mass varied from 98.69 to 572.05 g and its mean was 291.9 g, while volume varied from 116.1 to 994.29 cm^3 and its mean was 456.83 cm^3. The results showed that the fruit dimensions increased from 78.7 to 160 mm in length, 64.2 to 128.5 mm in width, and 64 to 125 mm in thickness, with average values of 109.56, 93.05 and 89.76 mm, respectively. The importance of dimensions is in determining the aperture size of machines, particularly in separation of materials, as discussed by Mohsenin (1978) and Omobuwajo *et al*. (1999). These dimensions may be useful in estimating the size of machine components. For example, it 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 for drying and jam production. 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 forces to induce mechanical rupture. This dimension will be useful in applying shearing force during slicing.

The average fruit projected areas perpendicular to length, width, and thickness were 7063.61, 7933.39 and 8137.77 mm^2, and their values varied from: 3476 to 12733, 4131 to 15176, and 4233 to 15712 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.

The geometric diameter and surface area varied from 70.17 to 136.98 and from 15471.03 to 58947.76 mm^2, with mean values of 97.02 mm and 30412.31 mm^2, respectively, while sphericity and shell ratio (w.b.) varied from 81 to 98 and 53 to 65%, with mean values of 89 and 62%. The values sphericity indicate a strong tendency of bergamots shape towards a sphere.

The average bulk density, porosity and packing coefficient were measured at 0.38 g cm^{-3}, 48.65 and 55.16% for small, 0.31 g cm^{-3}, 53.03 and 50.52% for medium, and 0.19 g cm^{-3}, 69.35 and 32.68% for large group of bergamots. It appears that fruit density, bulk density and packing coefficient decrease, and porosity increases with regard to increasing size.

Comparing bergamots with oranges, Topuz *et al*., 2005 and Rafiee *et al*., 2006b showed that dimensions, mass, volume and surface area of bergamots were bigger than those of oranges (all varieties). Density, bulk density and packing coefficient of bergamots (all categories) were lower than those for oranges, while porosity and shell ratio of bergamots (all categories) were higher than those for oranges. These properties may be useful in the separation and transportation of the fruits. A summary of the results of the determined physical parameters is shown in Table 1 and Table 2. The physical properties of the bergamots described herein can be helpful for better design of specific machines for harvesting and post-harvesting operation.

T a b l e 1. Some physical properties of bergamot fruits

Properties	Number of observation	Standard deviation	Mean value	Max. value	Min. value
Moisture content of shell (w.b.)	5	0.63	84.90	85.59	84.41
Moisture content of fruit meat (w.b.)	5	0.42	77.34	87.97	86.95
Fruit mass (g)	250	103.07	291.90	572.05	98.69
Fruit volume (cm^3)	250	191.12	456.83	994.29	116.10
Length, L (cm)	100	19.40	109.56	160.00	78.80
Width, W (cm)	100	16.11	93.05	128.50	64.20
Thickness, T (cm)	100	15.16	89.76	125.00	64.00
PL* (cm^2)	100	408.79	7063.61	12733.00	3476.00
PW* (cm^2)	100	2716.80	7933.39	15176.00	4131.00
PT* (cm^2)	100	2763.41	8137.77	15176.00	4233.00
Geometric mean diameter (mm)	100	16.40	97.02	136.98	70.17
Sphericity (%)	100	0.04	0.89	0.98	0.81
Surface area (cm^2)	100	10305.84	30412.31	58947.76	15471.03
Shell ratio (w.b.)	5	0.05	0.62	0.65	0.53
Shell ratio (d.b.)	5	0.06	0.66	0.70	0.56

*PL, PW, PT – projected areas perpendicular to L, W, T.

T a b l e 2. Properties of different categories of bergamot

Properties	Number of observation	Average value		
		small	medium	large
Fruit density (g cm^{-3})	30	0.74	0.66	0.62
Bulk density (g cm^{-3})	3	0.39	0.32	0.18
Porosity (%)	3	48.65	53.03	69.35
Packaging coefficient	3	55.16	50.52	32.68

CONCLUSIONS

1. The average mass and volume of bergamot were 291.90 g and 456.83 g cm^{-3}, respectively.

2. The dimensions of bergamot increased from 78.70 to 160 mm in length, 64.2 to 128.5 mm in width, and 64 to 125 mm in thickness.

3. The mean projected areas of bergamot perpendicular to length, width, and thickness were 7063.61, 7933.39 and 8137.77 mm^2, respectively.

4. The geometric mean diameter and surface area of bergamot were calculated as 97.02 mm and 30412.31 mm^2, respectively.

5. The sphericity and shell ratio (w.b.) of bergamot were measured as 0.89 and 0.62%, respectively.

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