Physical properties and image analysis of wild pistachio nut (Baneh)

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Received 22 September 2007, accepted: 10 January 2008

Abstract

Some physical properties of wild pistachio nut (Baneh) were measured by experimental method and compared with data obtained by an image processing method. The results showed a very good correlation between the results of these methods for geometrical properties of Baneh with the R^2 values ranged from 0.65 to 0.90. The aspect ratio, projected area, sphericity and roundness determined by image processing were averagely 1.164, 206.68 mm^2, 0.82 and 0.84, respectively. The geometric mean diameter, arithmetic mean diameter, aspect ratio, surface area and sphericity calculated theoretically based on micrometer data were averagely 7.4531 mm, 7.5285 mm, 1.134, 175.24 mm^2 and 0.86, respectively. The average unit mass, 1000 grain mass, volume, true density, bulk density, density ratio and porosity were measured as 0.2045 g, 194.878 g, 0.193 cm^3, 995.68 kg m^{-3}, 596.36 kg m^{-3}, 59.97% and 40.02%, respectively. The static coefficient of friction on five structural surfaces increased from 0.138 for glass, 0.180 for galvanized iron sheet and 0.266 for fiber glass to 0.436 for rubber and 0.459 for plywood. The filling and funning angles of repose were established as 16.01° and 19.92°, respectively. The terminal velocity of wild pistachio nut was 8.22 ms^{-1}.

Keywords: *Pistacia atlantica mutica*; Computer image analysis; Physical properties; Wild pistachio nut; Baneh

Introdution

Iran is the world's largest producer of pistachio (*Pistacia spp.*), with over 44% of world production (5, 12). Most of the production is from orchards that account for 53% of world planted area (12), but there are a few places, such as in the Zagros Mountains of Iran, where wild pistachio (*Pistacia atlantica mutica*) persists in natural and extensively managed (i.e., semi-natural) stands. Oak trees (*Quercus spp.*) commonly dominate forests of the Zagros Mountains (hereafter Zagros forests), but wild pistachio, known as Baneh in Iran, is the most economically important species for rural people in areas of natural forest. Cultivation of pistachio for multiple uses has been practiced in Iran for perhaps 3000–4000 years (12). The resin of wild pistachio called Saqez, is used for a variety of industrial and traditional applications, including food and medicine. The fruit of wild pistachio is an important source of food, although the fruit are smaller and not as commercially valuable as those produced in orchards (primarily from cultivars of *Pistacia vera L.*). It may require more than 200 years for trees to reach 1 m diameter and trees up to 2 m in diameter are known. Studies have confirmed the potential of *Pistacia atlantica* as a good source of oil because of high contain of oil in kernels and outer skin layers. Pistachio kernels are a good source of fat (50–60%) and contain unsaturated fatty acids (linoleic, linolenic and oleic acids), essential for human diet (6). The nuts are variable in size and color. It may be bright brown, turquoise or green in color.

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The physical properties of wild pistachio nuts, like those of other grains and seeds, are important to design the equipment for processing, transportation, sorting, separation and storing. Designing such equipments without taking these physical properties into consideration may yield poor results (6). For example, physical properties affect the conveying characteristics of solid materials by air or water. Size, shape, and physical dimensions of wild pistachio nuts are important in sizing, sorting and other separation process. Bulk and true densities are necessary to design the equipment for processing and storing such as dryers and bins. The porosity of the nuts is the most important for packing. The porosity also affects the resistance to airflow through bulk nuts. Terminal velocity is critical in designing of pneumatic conveyor. The angle of repose is essential in determination of packaging or storage structure for the material. The coefficient of static friction plays an important role in transport and storage of nuts (1, 6).

According to needs for high quality, safety standards and classification of food and agricultural products, the necessity for accurate, fast and objective quality evaluation of physical characteristics in these products is growing so fast. Image processing provides one alternative for an automated, non-destructive and cost-effective technique to accomplish these requirements by integrating an image acquisition device and a computer (4, 16 & 17). This system known as computer vision system (CVS) has proven to be successful for objective measurement parameters of various agricultural and food products such as size, color and shape. A CVS generally consists of five basic components: illumination, a camera, an image capture board (frame grabber or digitizer), computer hardware and software (3, 11). Image processing involves a series of image operations that enhance the quality of an image in order to remove defects such as geometric distortion, improper focus, repetitive noise, non-uniform lighting and camera motion. Image analysis is the process of distinguishing the objects (regions of interest) from the background and producing quantitative information, which is used in the subsequent control systems for decision making (16). Some examples of CVS application in food industry are: classification of cereal grains, evaluation of pork color, measurement and classification of corn whiteness, automated sorting of pistachio nuts, quality inspection of bakery products, inspection of golden delicious apples, detection of pinhole damage in almonds, detection of bones in fish and chicken and seed size determination (11).

Other researchers have studied these properties for various grains and nuts such as pine nut (9), castor nut (8), filbert nut and kernel (10), pistachio nut and its kernel (6, 12, 13 & 14), hazel nuts (1), jatropha nut (15) and raw cashew (2). But, no data has been reported about the physical properties of wild pistachio nuts. The data obtained from this work may be of interest to people seeking information on physical properties of wild pistachio nut and also developing intelligent systems to aid in design and fabrication of processing equipment for the product. The aims of this study were (i) to measure some physical properties of wild pistachio nut such as principal dimensions, mass, volume, aspect ratio, sphericity, bulk and true densities, density ratio, 1000 nut mass, porosity, surface area, angle of repose, terminal velocity and coefficient of static friction and (ii) to develop a computer vision system (CVS) for determining the geometrical properties of wild pistachio nut including length, width, thickness, roundness, sphericity, projected area in order to compare the results obtained with the experimental measurements.

Material and Methods

The wild pistachio nuts (*Pistacia atlantica mutica*) used in this study was obtained from a local market in Shiraz province, Iran. The nuts were cleaned manually to remove all foreign matter, broken and immature nuts. The moisture content of samples was determined by air convection oven drying at 103 ± 2 °C until a constant weight was reached (6).

Determination of dimensions

To determine the average size of the nut, 100 nuts was randomly selected and their three principal dimensions namely, length, width and thickness were measured using a micrometer (model QLR digit-IP54, Qinghai, China) with an accuracy of 0.01 mm (11). The average diameter of nut was calculated by using the arithmetic mean and geometric mean of the three axial dimensions.

The arithmetic mean diameter (D_a) and geometric mean diameter (D_g) of the nuts were calculated by using the following relationships (7):

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

$$D_g = (LWT)^{0.333} \quad (2)$$

Where: L is the length, W is the width and T is the thickness in mm. The aspect ratio of a nut is the ratio of its longer dimension to its shorter dimension, was calculated by the following equation (7):

$$\text{Aspect ratio} = \frac{L}{W} \quad (3)$$

The sphericity of nuts was calculated by using the following relationship (7):

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

The surface area (S, in mm^2) of pistachio nut was found by analogy with a sphere of same geometric mean diameter, using the following relationship (7):

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

Image analysis

A Computer Vision System (CVS) was developed for determining some geometrical properties of wild pistachio nut. The system was consisted of a digital camera (Canon A550, Kuala Lampur, Malaysia), an image-capturing box and image analysis software (Clemex Vision Professional, PE4, Longueuil Canada). A sample holder was placed at the bottom of the box and it was covered with white translucent material. Two fluorescent lamps (Farhad lightening 10W, 0.09A, Mashhad, Iran) were placed behind the sample holder to eliminate the shadows and the camera was located 15 cm above it to capture standard image from samples with as good resolution as possible. The software offered the possibility of extracting the values of some parameters such as principal dimensions, projected area, sphericity, roundness, size distribution, etc.

The most important step before image processing is calibration; a correct calibration is required to obtain an accurate measurement. To perform a calibration, an image was taken of a caliper in the exact same orientation as sample images were taken. The loaded image of the caliper was adjusted in the software program to the minimum distance seen on the caliper and then introduced the width of the selected distance. After calibration, the sample's image was loaded and some picture modification has been carried out. Finally, the physical properties of wild pistachio nut such as length, width, thickness, projected area, sphericity and roundness were extracted by the image processing software. In this research, the results of the image processing were compared to the data obtained by experimental method, and then the correlation between them was determined in terms of determination coefficient (R^2).

Determination of gravimetrical properties

To obtain the mass, each nut was weighed by a digital balance (AS120, OHAUS Corporation, NJ07058, USA) reading to 0.0001 g. To evaluate one thousand grain mass, 1000 randomly selected nuts from the bulk were weighed and averaged.

The bulk density is the ratio of the mass of nuts to its total volume and it was determined with a weight per hectoliter tester which was calibrated in kg/m^3. The nuts were poured in 20×20×20 cm bucket up to the top from a height of about 15 cm and excess nuts were removed using a flat stick. The nuts were not compacted in any way.

The average true density was determined using the toluene displacement method. The volume of toluene displaced was found by immersing a weighed quantity of nuts in the toluene. Toluene was used in place of water because it is absorbed by the nuts to a lesser extent. Also, its surface tension is low, so that it fills even shallow dips in a nut and its dissolution power is low. In addition toluene has the advantages of little tendency to soak into nut; little solvent action on constituents of the nut especially fats and oils; a fairly high boiling point; not changing its specific gravity and viscosity materially on exposure to the atmosphere; and having a low specific gravity. The true volume and true density of nuts determined using the following equations (7):

$$V = \frac{M_{td}}{\rho_f} = \frac{(M_{pt} - M_p) - (M_{pts} - M_{ps})}{\rho_f} \quad (6)$$

$$\rho_t = \frac{M_{ps} - M_p}{V} \quad (7)$$

Where, V is the nuts volume in m^{-3}, M_{td} is the mass of displaced toluene in kg, ρ_f is the toluene density in kgm^{-3}, M_{pt} is the mass of pycnometer and toluene in kg, M_p is the mass of empty pycnometer in kg, M_{pts} is the mass of pycnometer filled with toluene and sample in kg, M_{ps} is the mass of pycnometer and nuts in kg, and ρ_t is the true density of nuts in kgm^{-3}.

Density ratio is defined as the ratio of bulk density (ρ_b) to true density (ρ_t) that was calculated by following relationship (7):

$$\text{Density ratio} = \frac{\rho_b}{\rho_t} \qquad (8)$$

The porosity of the bulk is the ratio of the volume of internal pores in the particle to its bulk volume and was computed from the values of true density and bulk density using the following relationship (7):

$$\varepsilon = \left(\frac{\rho_t - \rho_b}{\rho_t}\right) \times 100 \qquad (9)$$

Determination of angles of repose

To determine the filling or static angle of repose of wild pistachio nuts, a topless and bottomless tube (inner diameter 150 mm and height 250 mm) was kept vertically at the centre of a raised circular plate having a diameter of 350 mm and was filled with the sample. Tapping during filling was done to obtain uniform packing and to minimize the wall effect, if any. The tube was slowly raised above the floor so that whole material could slide and form a heap. The height of heap above the floor and the diameter of the heap at its base were measured and the angle of repose was calculated using the following relationship (9):

$$\theta_f = \tan^{-1}\left(\frac{2H}{D}\right) \qquad (10)$$

Where, θ_f is the filling angle of repose in degree; H is the height of heap above the floor in mm and D is the diameter of the heap at its base in mm.

To determine the emptying or dynamic angle of repose, a plywood box of 0.2 m × 0.2 m× 0.2 m, having a removable front panel was used. The box was filled with the nut from 150 mm height, and then the front panel quickly slid upwards allowing the samples to flow to their natural slope. The emptying angle of repose (θ_e) was obtained from measurements of height of samples at two points (h_1 and h_2) in the sloping wild pistachio nut heap and the horizontal distance between these points (x_1 and x_2) using the following equation (9):

$$\theta_e = \tan^{-1}\left(\frac{h_2 - h_1}{x_2 - x_1}\right) \qquad (11)$$

Determination of coefficient of friction

The static coefficient of friction of nuts was measured for five frictional surfaces, namely glass, fiberglass, rubber, plywood, and galvanized iron sheets. A fiberglass topless and bottomless box of 0.15 m length, 0.10 m width, and 0.04 m height was placed on an adjustable inclined plane, faced with the test surface and filled with the sample. The box was raised slightly (2 mm), so as not to touch the surface. The structural surface with the box resting on it was inclined gradually until the box just started to slide down over the surface and the angle of tilt (α) was read from a graduated scale. The static coefficient of friction (μ_s) was then calculated by the following equation (7):

$$\mu_s = \tan(\alpha) \qquad (12)$$

Determination of terminal velocity

The terminal velocities of nuts at different moisture contents were measured using an air column device. For each experiment, a sample was dropped into an air stream from the top of the air column. Then airflow rate was gradually increased until the nut became suspended in the air stream. The air velocity near the location of the nut suspension was measured using a vane anemometer having at least 0.01 m s^{-1} accuracy. Each sample consisted of 5 nuts selected randomly.

Result and Discussion

The mean, minimum, maximum and standard deviation values of all physical properties of Baneh nut measured by experimental method are summarized in Table 1. As it is can be found, the range of geometric mean diameter, and arithmetic mean diameter calculated by equations (1) & (2) were 6.48 to 8.31 mm and 6.55 to 8.42 mm, respectively. Geometric and arithmetic mean diameters of Baneh nut were lower than values reported for different varieties of pistachio nut (6 & 12), jatropha nut (15), filbert nut (10) and raw cashew nut (2). The aspect ratio of Baneh nut varied between 1.05 and 1.49 (Table 1), which was lower than five varieties of pistachio nut (Ohadi, Kalle-ghuchi, Momtaz, Badami and Akbari) (12), jatropha nut (15), filbert nut (10), pine nut (9), castor nut (8) and raw cashew nut (2), but was higher than hazel nut (1). The surface area and sphericity of Baneh nut ranged from 131.99 to 217.23 mm^2 and 76 to 93% respectively (Table 1). The surface area of Baneh nut was lower than hazel nut (1), pine nut (9) and five varieties of pistachio nut (Ohadi, Kalle-ghuchi, Momtaz, Badami and Akbari) (12), while the sphericity and roundness of wild pistachio nut were higher than pine nut (9), different varieties of pistachio nut (6 & 12), jatropha nut (15) , and raw cashew nut (2), but were lower than filbert nut (10) and hazel nut (1).

The unit mass of Baneh nut ranged from 0.13 g to 0.32 g and the thousand grain mass of Baneh nut were between 193.58 g and 195.53 g (Table 1), which were lower than values reported for five varieties of pistachio nut (Ohadi, Kalle-ghuchi, Momtaz, Badami and Akbari) (13), jatropha nut (15), filbert nut (10), pine nut (9) and raw cashew nut (2).

Table 1 Some physical properties of wild pistachio nut (Baneh)

Physical properties	*No. of observation*	*Unit of measurement*	*Mean value*	*Min value*	*Max value*	*Standard deviation*
Moisture content	3	% (w.b.)	4.26	4.00	4.60	0.30
Length	100	mm	8.69	7.27	10.04	0.66
Width	100	mm	7.67	6.72	8.73	0.54
Thickness	100	mm	6.22	5.13	7.32	0.49
Geometric mean dimension	100	mm	7.45	6.48	8.31	0.48
Arithmetic mean dimension	100	mm	7.52	6.55	8.42	0.49
Surface area	100	mm^2	175.23	131.99	217.23	22.93
Aspect ratio	100		1.134	1.016	1.303	0.074
Sphericity	100	%	85	76	93	3
Unit mass	100	g	0.20	0.13	0.32	0.03
1000 grain mass	5	g	194.87	193.58	195.93	0.75
Volume	15	cm^3	0.19	0.13	0.31	0.05
True density	15	kg/m^3	995	956	1030	20
Bulk density	15	kg/m^3	596	584	603	6
Porosity	15	%	40.02	36.90	42.05	1.62
Density ratio	15	%	59.97	57.94	63.09	1.62
Terminal velocity	10	m/s	8.21	8.10	8.40	0.12
Coefficient of static friction						
galvanized steel	5	-	0.18	0.17	0.19	0.005
glass	5	-	0.13	0.12	0.15	0.013
plywood	5	-	0.45	0.44	0.46	0.009
rubber	5	-	0.43	0.40	0.46	0.024
Fiberglass	5	-	0.26	0.24	0.27	0.010
Filling angle of repose	5	degree	16.00	14.49	17.73	1.23
Emptying angle of repose	5	degree	19.92	18.76	21.84	1.28

The volume of Baneh nut ranged from 0.13 to 0.31 cm^3 (Table 1), which was lower than values obtained for different varieties of pistachio (Ohadi, Kalle-ghuchi, Momtaz, Badami and Akbari) (6 & 13), jatropha nut (15), filbert nut (10), pine nut (9) and raw cashew nut (2). The bulk density of Baneh nut varied between 584 kg m^{-3} and 603 kg m^{-3}, which was higher than pistachio nut (6 & 13), jatropha nut (15), filbert nut (10), castor nut (8) and hazel nut (1), but lower than pine nut (9) and raw cashew nut (2). The Baneh nut had averagely a true density of 995 kgm^{-3}, which was higher than values of hazel nut (1), pine nut (9), pistachio nut (13), and filbert nut (10), but was lower than true density of raw cashew nut (2), and jatropha nut (15). The density ratio of Baneh nut varied between 57.94 and 63.09 (Table 1), which was similar to values were obtained for pine nut (9), filbert nut (10) and Kalle-ghuchi variety of pistachio (13). This was lower than the value reported for other four varieties of pistachio (Ohadi, Momtaz, Badami and Akbari) (6, 13), but higher than hazel nut (1), jatropha nut (15) and raw cashew nut (2). The porosity of Baneh nut ranged from 36.90 to 42.05%. This was lower than the value reported for jatropha nut (15), raw cashew nut (2), pistachio nut (6), and hazel nut (1), but higher than the values reported for pine nut (9) and pistachio nut (13).

The static coefficient of friction of Baneh nut obtained experimentally on five surfaces namely plywood, galvanized iron, rubber, fiberglass and glass. Plywood and rubber surface had the highest coefficient of friction and it is found that the static coefficient of friction is lowest against glass (Table 1). This is owing to the smoother and polished surface of glass sheet compared other sheets used. The coefficient of friction of wild pistachio nut was lower than different varieties of pistachio nut (14), jatropha nut (15), filbert nut (10), pine nut (9), raw cashew nut (2) and castor nut (8). The round shape of this nut may cause sliding more easily than other grains.

The filling angle of repose of Baneh nut ranged from 14.49 to 17.73 with the mean value as 16.00 ± 1.23 (Table 1), which was lower than those reported for jatropha nut (15), and similar to Momtaz variety pistachio nut (14). The emptying angle of repose varied between 18.76 and 21.84, with the mean value as 19.92±1.28 (Table 1). This is lower than values obtained for castor nut (8), jatropha nut (15) and five varieties of pistachio nut (14).

The terminal velocity of Baneh nut ranged from 8.1 to 8.4 ms^{-1} with the mean value as 8.21 ± 0.12 (Table 1), which was almost similar to the values obtained for pine nut (9), but higher than pistachio nut (6) and hazel nut (1). This characteristic can be used to design separating, cleaning and handling process for nuts.

The frequencies of geometrical properties of Baneh nut determined by CVS method are shown in Figs. 1-7. It was found that the length of wild pistachio nut ranged from 8.413 to 11.471 mm with the mean value as 9.780±0.789 mm (Fig. 1), the width ranged from 6.471 to 9.961 mm with the mean value as 8.424±0.713 mm (Fig. 2) and the thickness ranged from 5.110 to 7.643 mm with the mean value as 6.434±0.522 mm (Fig. 3), while the range of length, width and thickness measured by micrometer were between 7.271 to 10.049 mm with the mean value as 8.690 mm, 6.721 to 8.733 mm with the mean value as 7.674 mm and 5.130 to 7.323 mm with the mean value as 6.220 mm, respectively (Table 1). The correlation (R^2 values) between the results of CVS and experimental methods for length, width and thickness were 0.90, 0.88 and 0.69, respectively. As it can be concluded the results of length and width measurement that obtained by these methods have an excellent correlation, therefore we can use this system instead of micrometer method for measurement of nut dimensions. In this research, about 88% of the nuts had a length ranging from 9 to 11 mm; about 77% of width was from 7 to 9 mm and about 87% of thickness ranged from 6 to 8 mm (Figs. 1-3).

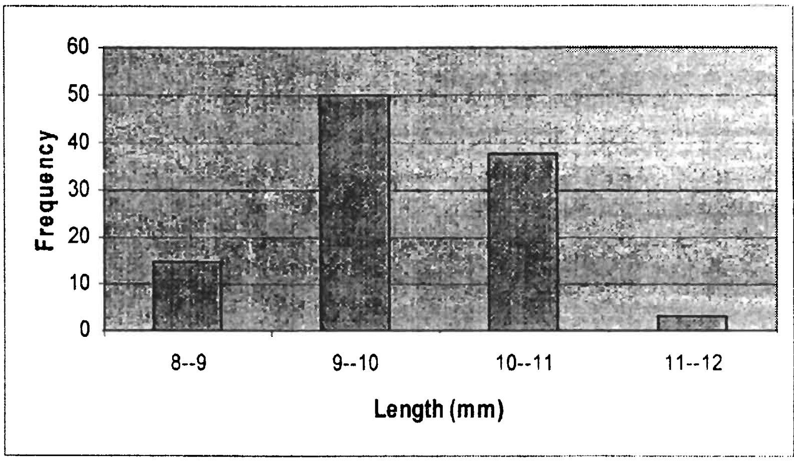

Figure 1. Length distribution of wild pistachio nuts (Baneh) determined by image processing technique.

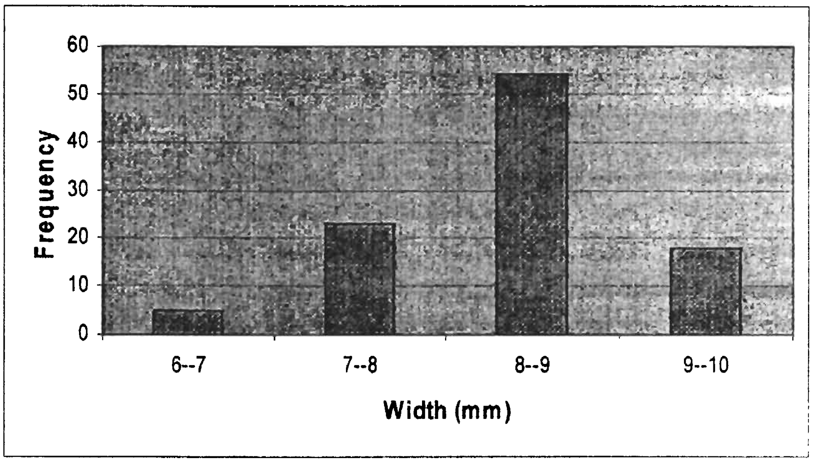

Figure 2. Width distribution of wild pistachio nuts determined by image processing technique.

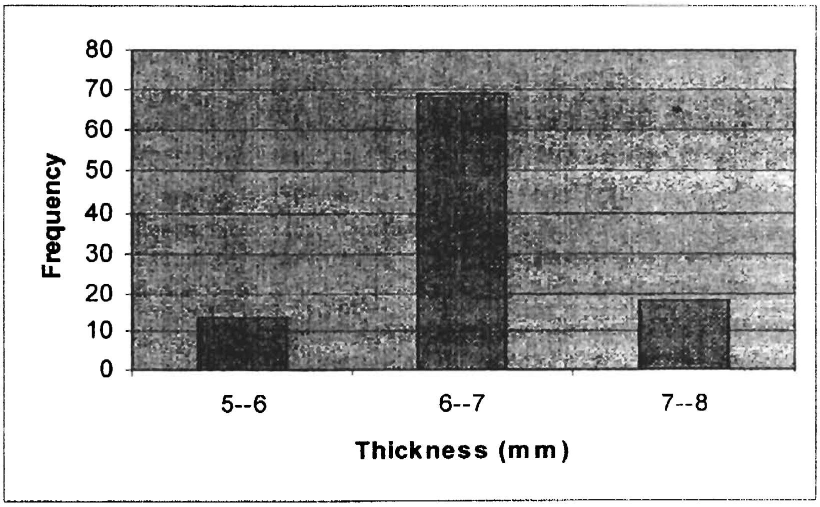

Figure 3. Thickness distribution of wild pistachio nuts determined by image processing technique.

The sphericity of Baneh nut which was determined by CVS method ranged from 70 to 88% with the mean value as 82±3.9% (Fig. 4), which was lower than the values obtained by experimental method (Table 1). The correlation (R^2 values) between the results of CVS and experimental methods for sphericity was 0.65. The result of image processing showed that the range of roundness was between 67 and 92% with the mean value as 83±5.7% (Fig. 5). Results of sphericity and roundness showed that the mean values for these two characteristic of Baneh nut were above of 80%, therefore the Baneh nut is more likely to roll than to slide. This is important information for hopper, separation and conveying equipment design.

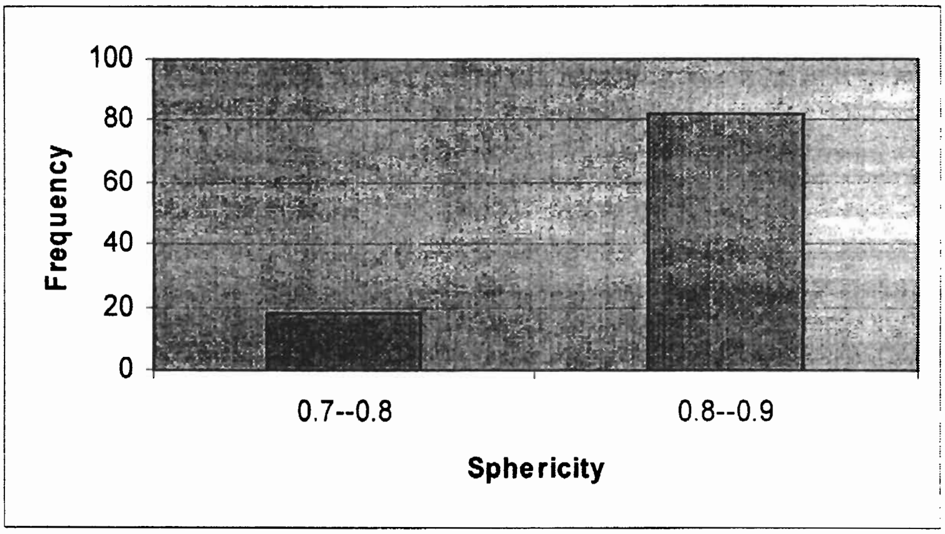

Figure 4. Sphericity distribution of wild pistachio nuts (Baneh) determined by image processing technique.

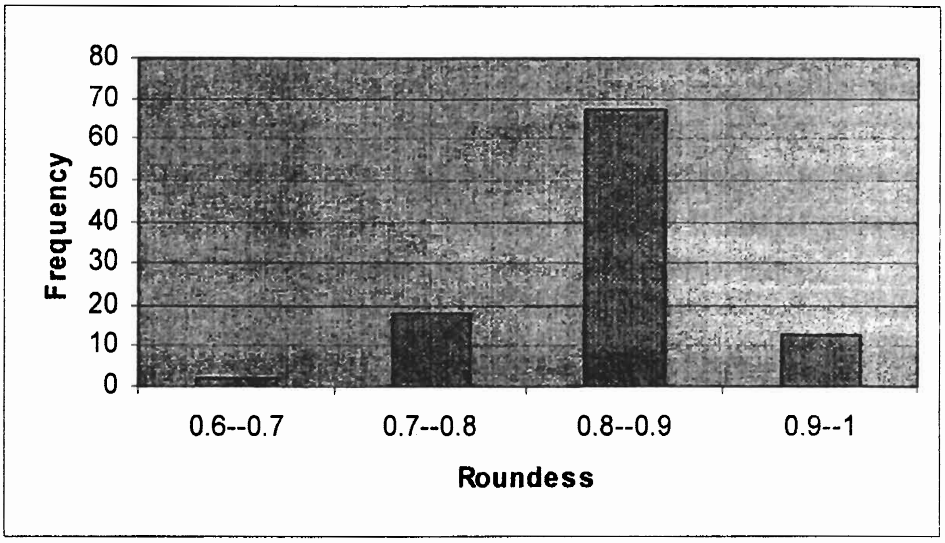

Figure 5. Roundness distribution of wild pistachio nuts (Baneh) determined by image processing technique.

The projected area of Baneh which was determined by CVS method varied between 147.23 and 277.83 mm^2 with the mean value as 206.68±31.13 mm^2 (Fig. 6). Furthermore, the range of aspect ratio for Baneh nut calculated by image processing was in the range of 1.059 to 1.499 with the mean value as 1.164±0.094 (Fig. 7), which was higher than values obtained by experimental method (Table 1). The correlation between the results of CVS and experimental methods for aspect ratio was 0.72.

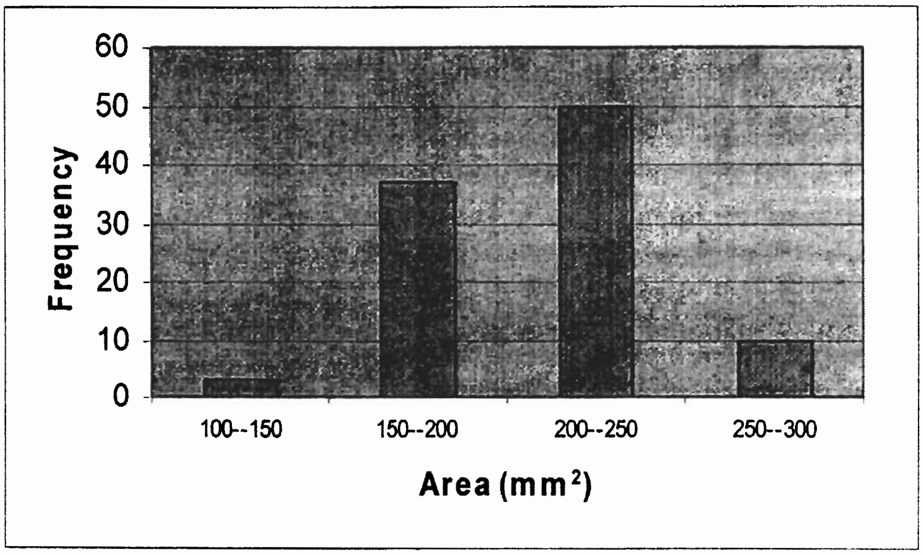

Figure 6. Projected area distribution of wild pistachio nuts (Baneh) determined by image processing technique.

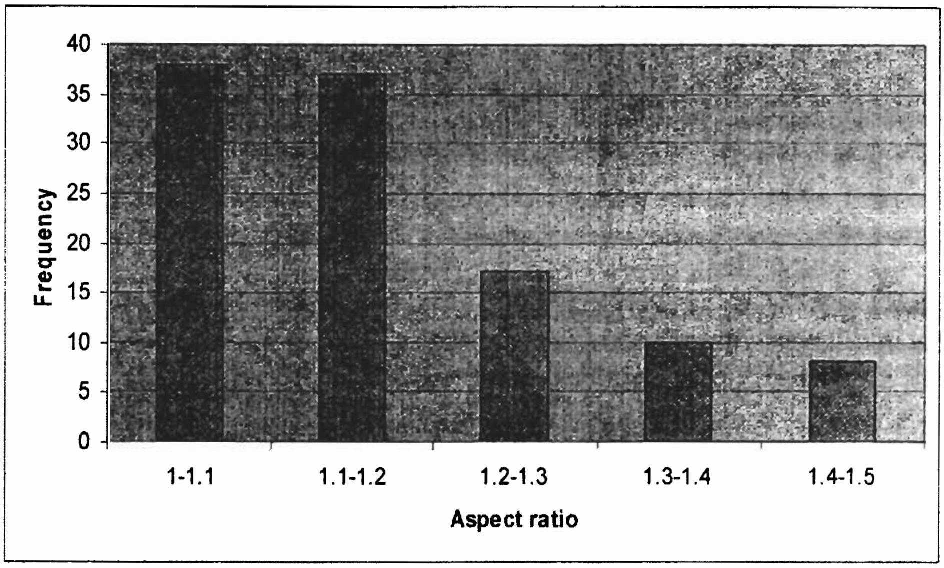

Figure 7. Aspect ratio distribution of wild pistachio nuts (Baneh) determined by image processing technique.

Conclusion

This research showed that the computer vision system is an accurate and excellent method for measurement of some geometrical properties of Baneh nut. The image analysis and experimental method showed very good correlation for the length, width, and aspect ratio of Baneh nut. The unit mass and thousand nut mass of the Baneh nut were 0.2045 g and 194.878 g, respectively. The true and bulk densities were measured as 995.68 kgm^{-3}, and 596.36 kgm^{-3}, the filling and emptying angle of repose obtained 16.01° and 19.92°, respectively. The highest coefficient of friction were against plywood and rubber (0.459 and 0.436), respectively, while the lowest was for glass

(0.138). The average terminal velocity of wild pistachio nut was 8.22 ms^{-1} and according to the nature of the nut, higher or lower air velocities can be used for separation or cleaning processes. Totally, it can be concluded that the computer vision system is an effective and rapid method to evaluate geometrical properties of Baneh nut.

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خواص فیزیکی و پردازش تصویر دانه پسته وحشی (بنه)

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چکیده

تعدادی از ویژگی های فیزیکی دانه پسته وحشی (بنه) توسط روش های تجربی تعیین و نتایج آن با اطلاعات حاصله از روش پردازش تصویر مقایسه شد. نتایج بدست آمده وجود یک همبستگی بالا با مقادیر R^2 بین ۰/۶۵ تا ۰/۹۰را میان این دو روش نشان داد. میانگین مقادیر اندازه گیری شده توسط روش پردازش تصویر برای نسبت نما، سطح تصویری جسم، ضریب کرویت و ضریب گردی به ترتیب برابر ۱/۱۶۴، ۲۰۶/۶mm^2، ۰/۸۲ و ۰/۸۴ بودند. میانگین مقادیر محاسبه شده برای قطر هندسی ، قطر حسابی ،نسبت نما، مساحت سطحی و ضریب کرویت بر اساس داده های ابعاد بدست آمده توسط میکرومتر به ترتیب ۷/۴۵۳۱mm ، ۱۳۴/۵۲۸۵mm، ۱/۷، ۱۷۵/۲۴ mm^2 و ۰/۸۶ بودند. میانگین مقادیر برای وزن واحد، وزن هزار دانه، حجم، دانسیته واقعی، دانسیته توده، نسبت دانسیته و تخلخل به ترتیب برابر ۰/۲۰۴۵g، ۱۹۴/۸۷۸g، ۰/۱۹۳cm^3، ۹۹۵/۶۸ $kg\ m^{-3}$، ۵۹۶/۳۶ $kg\ m^{-3}$، ۵۹/۹۷ و ۴۰/۰۲٪ تعیین شدند. ضریب اصطکاک استاتیک روی ۵ نوع سطح از ۰/۱۳۸ برای شیشه، ۰/۱۸۰ برای صفحات آهنی گالوانیزه، ۰/۲۶۶ برای فایبرگلاس، ۰/۴۳۶ برای لاستیک تا ۰/۴۵۹ برای تخته چندلا افزایش یافت. زوایای ریپوز تخلیه و پر کردن به ترتیب °۱۶/۰۱ و °۱۹/۹۲ بدست آمدند. سرعت حد دانه پسته وحشی برابر ۸/۲۲ $m\ s^{-1}$ بود.

کلمات کلیدی: پردازش تصویر، خواص فیزیکی، پسته وحشی، بنه

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