IMAGE PROCESSING AND PHYSICO-MECHANICAL PROPERTIES OF BASIL SEED (*OCIMUM BASILICUM*)

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Accepted for Publication January 20, 2008

ABSTRACT

*Various physical properties of basil seed (*Ocimum basilicum*) were investigated at a moisture content of 5.32% (wet basis). In order to present a quick and an accurate method for measuring small seed dimensions, the image processing data was compared with the one measured experimentally, and the correlations between these were determined. The average length, width and thickness obtained by image processing and micrometer methods were 3.216, 3.220, 1.838, 1.840, 1.363 and 1.374 mm, respectively. The average projected area, sphericity and roundness evaluated by image processing were 4.407 mm^2, 0.95 and 0.54, respectively. However, the average geometric mean diameter, arithmetic mean diameter, surface area and sphericity calculated theoretically based on micrometer data were 2.009, 2.145 mm, 12.796 mm^2 and 0.62, respectively. The average unit mass, 1,000 grain mass, volume, true density, bulk density and porosity were measured as 0.0020 and 2.23 g; 7.55 mm^3; 1,038; 340.24 kg/m^3; and 67.2%, respectively. The friction coefficient ranged from 0.300 for basil seed on glass up to 0.547 on plywood surface. The filling and funning angles of repose were established as 14.64° and 12.35°, respectively. The terminal velocity was 4.26 m/s, and textural properties including rupture force, hardness and toughness were determined as 537.4, 926.13 g and 246.32 g/mm, respectively.*

PRACTICAL APPLICATIONS

According to the small size of some seeds, dimension measurement is difficult and time consuming; therefore, developing a rapid, easy, accurate and nondestructive method seems to be necessary. In recent years, computer vision system (CVS) has been increasingly used in the agricultural and food industry. Some examples of CVS application in food industry are: classification of

Journal of Food Process Engineering **33** (2010) 51–64.

DOI: 10.1111/j.1745-4530.2008.00259.x

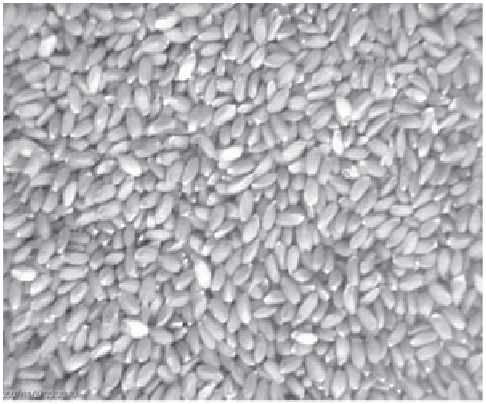
cereal grains, evaluation of pork color, measurement and classification of corn whiteness, automated sorting of pistachio nuts, quality inspection of bakery products, inspection of Golden Delicious apples, detection of pinhole damage in almonds and detection of bones in fish and chicken; therefore, we decided to examine the possibility and accuracy of this technique for measuring seed dimension for the first time.

In this study, in addition to introducing the CVS system for dimension measurement, the physico-mechanical properties of basil seed have been determined, which is necessary for the design of equipment for harvesting, transporting, cleaning, packing, processing, etc.

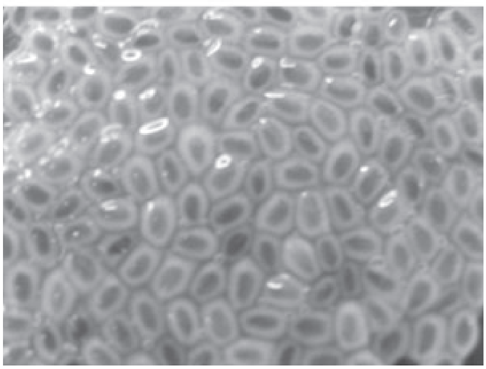
INTRODUCTION

Basil seed is the seed from the basil plant (*Ocimum basilicum*), which is a member of the Labiatae family (Fig. 1A). The plant is originally native to Iran; Turkey; India; and other tropical regions of Asia, Africa and Europe. Various parts of the basil plant can be used as food or drug. The fresh or dried leaves are used as seasoning all around the world, and its essential oils are used in pharmaceuticals and flavorings (Amin 2005). Basil seeds when soaked in water become gelatinous and are traditionally used in Asian drinks and desserts such as falodeh and sherbet (Fig. 1B). The high mucilage content of basil seeds can make it a novel source of edible gum, and continuing our research about new and local food hydrocolloids to determine the physical properties of this seed seems to be necessary.

Basic physical properties of seeds are required in order to design the machines for handling, harvesting, transporting, cleaning, separating, packing and processing. The designs lead to inadequate application if the systems are designed without taking these physical properties into consideration. Some researchers have studied the physical and mechanical properties of grains and seeds, such as Singh and Goswami (1996) for cumin, Baryeh (2002) for millet, Sacilik *et al.* (2003) for hemp, Abalone *et al.*(2004) for amaranth seed, Yalcin and Ozarslan (2004) for vetch seed, Tunde-Akintunde and Akintunde (2004) for sesame, Calisir *et al.* (2005) for rapeseed, Altuntas *et al.* (2005) for fenugreek, Dursun and Dursun (2005) for caper, Kingsly *et al.* (2006) for dried pomegranate seeds, Mwithiga and Masika Sifuna (2006) for sorghum and Coskuner and Karababa (2007) for flaxseed. However, no published literature was found on the detailed physical properties of basil seed. The objectives of this study were: (1) to determine the physical properties of basil seed such as axial dimensions, projected area, roundness, sphericity, 1,000 grain mass, volume, true and bulk densities, filling and funning angles of repose, static coefficient of friction against selected surfaces, terminal velocity, rupture



A



B

FIG. 1. PICTORIAL VIEW OF (A) BASIL SEEDS (MAGNIFICATION = 55×), AND (B) SEEDS SOAKED IN WATER

force, hardness and toughness; and (2) to compare the image processing results for basil seeds with the ones measured experimentally, and present a quick and an accurate method for determining the physical properties of basil seed.

MATERIALS AND METHODS

Sample Preparation

The basil seeds used in this study were obtained from a local market in Mashhad, Iran (Fig. 1A). The seeds were cleaned manually to remove all foreign matter such as dust, dirt, stones and chaff. The moisture content of the seed was determined by the vacuum oven method (temperature 70C and pressure 250 mbar) until a constant mass was obtained (Singh and Goswami 1996). The experiment was replicated three times.

Physico-mechanical Properties Determination

The principle dimensions of basil seed, namely, length (*L*), width (*W*) and thickness (*T*) were measured using an electronic micrometer (model QLR digit-IP54, Qinghai, China) with an accuracy of 0.001 mm. According to Mohsenin (1978), the geometric mean diameter (D_g), arithmetic mean diameter (D_a) and sphericity (Φ) values determined as follows:

$$D_g = (LWT)^{0.333} \tag{1}$$

$$D_a = \frac{L+W+T}{3} \tag{2}$$

$$\phi = \frac{(LWT)^{0.333}}{L} \tag{3}$$

The surface area was also found by McCabe *et al.* (1986) to be given by:

$$S = \pi D_g^2 \tag{4}$$

To obtain the unit mass, each sample was weighted by a precision electronic balance (AS120, Ohaus, Pine Brook, NJ) reading to an accuracy of 0.0001 g; 10 replications were made. Thousand seed mass was determined by counting 1,000 seeds by seed counter (Numigral, Iticator, Stockholm, Sweden) and weighing them in an electronic balance of 0.01 g sensitivity. The pycnometric method described by Mohsenin (1978) was used to determine the volume and true density of seeds. Toluene was used instead of water because basil seeds absorb water rapidly and toluene has the advantages of little tendency to soak into seed; a low surface tension, enabling it to flow smoothly over the seed surface; little solvent action on constituents of the seed 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 solid density of basil seeds were determined using the following equation (Mohsenin 1978):

$$V = \frac{M_{td}}{\rho_t} = \frac{(M_t - M_p) - (M_{pts} - M_{ps})}{\rho_t} \tag{5}$$

$$\rho_s = \frac{M_{ps} - M_p}{V} \tag{6}$$

where V is the seed volume in m^3, M_{td} is the mass of displaced toluene in kg, ρ_t is the toluene density in kg/m^3, M_t 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 seeds in kg and ρ_s is the seed density in kg/m^3.

The bulk density was determined by filling a container with a known volume from a height of 150 mm at a constant rate and then weighing the contents. No separate compaction of seed was done. The bulk density was calculated by dividing the mass of the seeds on the volume of the container (Abalone 2004; Kingsly *et al.* 2006). The porosity of basil seed was calculated from bulk and true densities using the relationship given by Mohsenin (1978) as follows:

$$\varepsilon = \left(1 - \frac{\rho_b}{\rho_t}\right) \times 100 \tag{7}$$

where ρ_b is the bulk density in kg/m^3 and ρ_t is the true density in kg/m^3.

The static coefficient of friction of basil seeds 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 (Mohsenin 1978):

$$\mu_s = \tan\alpha \tag{8}$$

The filling or static angle of repose is the angle with the horizontal at which the seeds will stand when piled. This was determined using a topless and bottomless cylinder of 0.15 m diameter and 0.25 m height. The cylinder was placed at the center of a raised circular plate having a diameter of 0.35 m and was filled with basil seeds. The cylinder was raised slowly until it formed a cone on a circular plane. The height of the cone was measured and the filling angle of repose (θ_f) was calculated by the following relationship (Tunde-Akintunde and Akintunde 2004; Kingsly *et al.* 2006):

$$\theta_f = \tan^{-1}\left(\frac{2H}{D}\right) \tag{9}$$

where H and D are the height and diameter of the cone, respectively.

In order to determine the emptying or dynamic angle of repose, a plywood box of 0.2 × 0.2 × 0.2 m, having a removable front panel was used. The box was filled with the seed from 150 mm height, and then the front panel quickly slid upward 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 heap and the horizontal distance between two points (x_1 and x_2) using the following equation (Sacilik *et al.* 2003; Coskuner and Karababa 2007):

$$\theta_e = \tan^{-1}\left(\frac{h_2 - h_1}{x_2 - x_1}\right) \tag{10}$$

The experiments were replicated five times to avoid error.

The terminal velocity of seeds was measured using an air column device. Samples were dropped into an airstream from the top of the air column, and then airflow rate was gradually increased until the seed became suspended in the airstream. The air velocity which kept the seeds in suspension was measured using a digital anemometer having a least count of 0.1 m/s; the experiment replicated 20 times (Singh and Goswami 1996; Baryeh 2002).

The mechanical properties of basil seeds were determined according to the method of Kingsly *et al.* (2006) with some modifications. For measuring the mechanical properties, a texture analyzer (QTS Texture analyzer, CNS Farnell, Essex, U.K.) with a TA41 (6 mm, platen) probe was used. The operation conditions of texture analyzer were kept as compression test, 0.5 mm target value, one cycle and 6 mm/min test speed. The peak force of the compression cycle, taken as hardness (g), work done (energy) required to obtain given deformation to target value taken as toughness (g/mm) and the first significant break in compression cycle reported as rupture force (g); 15 replications were conducted for each test.

Image Processing

A CVS was developed for determining some physical properties of basil seeds. The system consists of a digital camera (Canon A550, Kuala Lumpur, Malaysia), an image-capturing box and an 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 a white translucent material. Two fluorescent lamps (Farhad lightening 10 W, 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 (Kilic *et al.* 2007). The software offered the possibility of extracting the values of some physical properties such as dimensions, area, sphericity and roundness.

Before image processing, the first and one of the most important steps is calibration; a correct calibration is required to obtain an accurate measurement. To perform calibration, we took an image from a caliper in exactly the same condition we were going to take images from samples, then loaded the image in the image window of the software and adjusted the software caliper between the minimum distance which can be seen on the caliper and introduced the width of selected distance, then the software determined the width of each pixel at various magnifications. After calibration, the sample's image loaded and some picture modifications have been carried out. Finally, the physical properties of basil seeds such as length, width, thickness, projected area, sphericity and roundness were extracted by the image processing software. Picture modification operation consists of three main steps:

(1) Delineation: the delineation filter used to remove intermediate gray levels to increase contrast, and it was selected from gray operation section of the software toolbox;
(2) Thresholding: the gray threshold function used to define the seed on the background, and it was selected from the gray transformation section of the software toolbox;
(3) Chord size: Chord size is used for eliminating small and unwanted objects from the picture, and it was selected from the binary operation section of the software toolbox.

In this research, the results of the image processing were compared to the data obtained experimentally, and then the correlation between them was determined. For both CVS and experimental measurements, 50 basil seeds were randomly selected.

RESULTS AND DISCUSSION

The mean value and standard deviation of all physico-mechanical properties of basil seeds measured experimentally are summarized in Table 1. According to the results obtained by image processing (Figs. 2–4), it can be found that the length of basil seeds ranged from 2.725 to 5.025 mm with the mean value as 3.216 mm, the width ranged from 1.400 to 2.925 mm with the mean value as 1.838 mm and the thickness ranged from 1.027 to 1.703 mm with the mean value as 1.363 mm, while the range values of length, width and

TABLE 1.
SOME PHYSICO-MECHANICAL PROPERTIES OF BASIL SEEDS AT A MOISTURE CONTENT OF 5.32 ± 0.002 (% W.B.)

Physical properties	Observation	Mean value	Standard deviation
Length (mm)	50	3.220	0.33
Width (mm)	50	1.840	0.24
Thickness (mm)	50	1.374	0.15
Surface area (mm^2)	50	12.796	2.81
Geometric mean diameter (mm)	50	2.009	0.20
Arithmetic mean diameter (mm)	50	2.145	0.22
Sphericity	50	0.62	0.04
Unit mass (g)	10	0.0020	0.0002
Mass of 1,000 seeds (g)	5	2.13	0.03
Volume (mm^3)	5	7.55	0.09
True density (kg/m^3)	5	1,038	11.99
Bulk density (kg/m^3)	5	340.24	1.82
Porosity (%)	5	67.20	0.46
Filling angle of repose (°)	5	14.64	0.88
Emptying angle of repose (°)	5	12.35	0.86
Static coefficient of friction on			
Glass	5	0.300	0.01
Fiberglass	5	0.394	0.01
Galvanized iron	5	0.460	0.02
Rubber	5	0.533	0.01
Plywood	5	0.547	0.01
Terminal velocity (m/s)	20	4.26	0.23
Hardness (g)	15	926.13	156
Rupture force (g)	15	537.40	111
Toughness (g/mm)	15	246.32	70.8

thickness measured by the micrometer were 2.729–5.028 mm, the mean value as 3.220 mm; 1.403–2.927 mm, the mean value as 1.840 mm; and 1.026–1.705 mm, the mean value as 1.374 mm, respectively (Table 1). The correlations between CVS and experimental results for length, width and thickness were 1, 1 and 0.84, respectively. These results showed that there is an excellent potential to use CVS for measuring small seed dimensions, which is a rapid and nondestructive method.

As shown in Figs. 5–7, the projected area, sphericity and roundness of basil seeds ranged from 2.8 to 8.56 mm^2, from 0.55 to 1 and from 0.43 to 0.65, respectively. The projected area of basil seeds was higher than the value reported for caper seed (Dursun and Durson 2005). Furthermore, the average sphericity of basil seeds was more than the values reported for sesame (Tunde-Akintunde and Akintunde 2004), fenugreek (Altuntas *et al.* 2005), hemp (Sacilik *et al.* 2003), caper (Dursun and Durson 2005) and vetch seed (Yalcin and Ozarslan 2004).

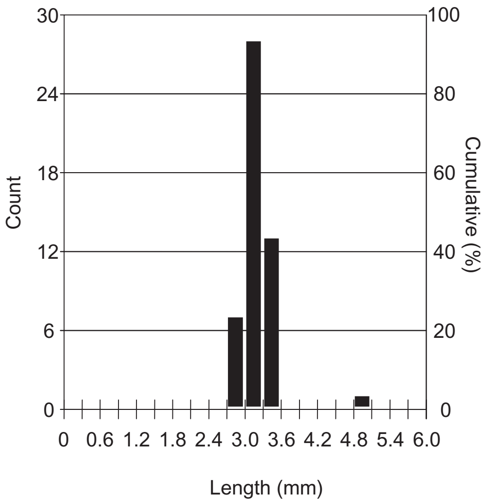


FIG. 2. LENGTH DISTRIBUTION OF BASIL SEEDS DETERMINED BY IMAGE PROCESSING TECHNIQUE

The maximum and minimum values of length obtained were 5.025 and 2.725 mm, respectively. Average and standard deviation were 3.216 mm and 0.335.

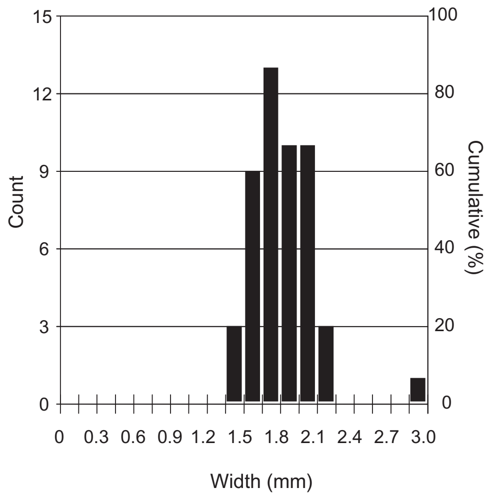


FIG. 3. WIDTH DISTRIBUTION OF BASIL SEEDS DETERMINED BY IMAGE PROCESSING TECHNIQUE

The maximum and minimum values of width obtained were 2.925 and 1.400 mm, respectively. Average and standard deviation were 1.838 mm and 0.244.

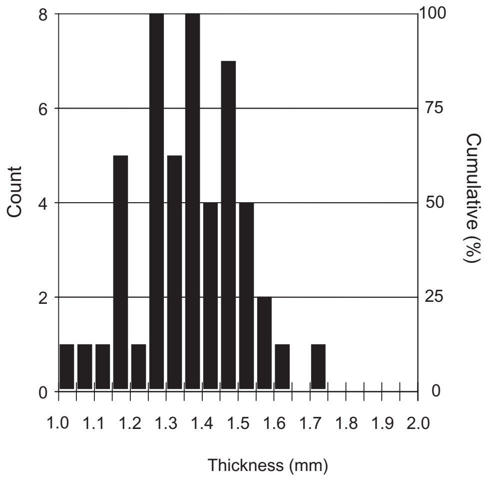


FIG. 4. THICKNESS DISTRIBUTION OF BASIL SEEDS DETERMINED BY IMAGE PROCESSING TECHNIQUE

The maximum and minimum values of thickness obtained were 1.703 and 1.027 mm, respectively. Average and standard deviation were 1.363 mm and 0.142.

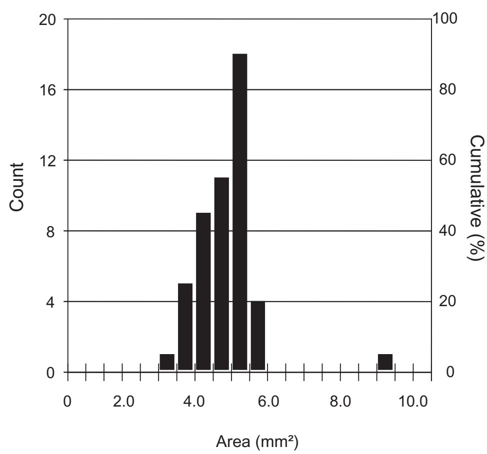


FIG. 5. PROJECTED AREA DISTRIBUTION OF BASIL SEEDS DETERMINED BY IMAGE PROCESSING TECHNIQUE

The maximum and minimum values of projected area obtained were 2.8 and 8.56 mm^2. Average and standard deviation were 4.41 mm^2 and 0.834.

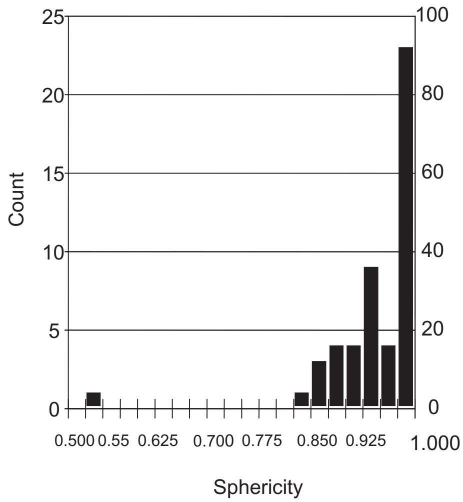


FIG. 6. SPHERICITY DISTRIBUTION OF BASIL SEEDS DETERMINED BY IMAGE PROCESSING TECHNIQUE

The maximum and minimum values of sphericity obtained were 1 and 0.54, respectively. Average and standard deviation were 0.94 and 0.0743.

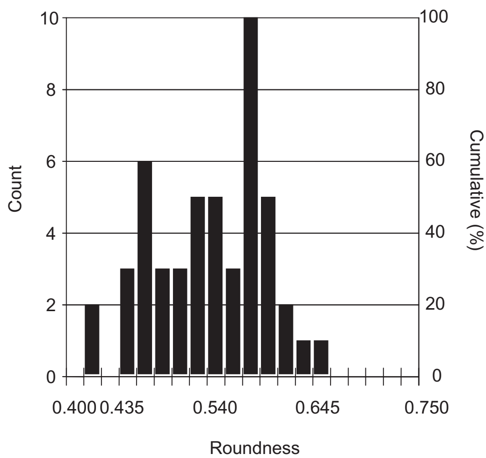


FIG. 7. ROUNDNESS DISTRIBUTION OF BASIL SEEDS DETERMINED BY IMAGE PROCESSING TECHNIQUE

The maximum and minimum values of roundness obtained were 0.646 and 0.4312, respectively. Average and standard deviation were 0.5421 and 0.0554.

The average geometric mean diameter, arithmetic mean diameter, surface area and sphericity calculated by Eqs. (1)–(4) were 2.009, 2.145 mm, 12.796 mm^2 and 0.62, respectively (Table 1). The surface area of basil seeds was higher than amaranth (Abalone 2004) and hemp seed (Sacilik *et al.* 2003) and lower than caper seed (Dursun and Durson 2005) and fenugreek (Altuntas *et al.* 2005).

The unit mass of basil seeds ranged from 0.0017 to 0.0025 g. However, the thousand grain mass of basil seeds was between 2.176 and 2.259 g, which was lower than millet (Baryeh 2002), rapeseed (Calisir *et al.* 2005), hemp seed (Sacilik *et al.* 2003), vetch seed (Yalcin and Ozarslan 2004), fenugreek seed (Altuntas *et al.* 2005) and similar to sesame seed (Tunde-Akintunde and Akintunde 2004).

The volume of basil seeds ranged from 7.46 to 7.63 mm^3, which was lower than fenugreek volume (Altuntas *et al.* 2005) and higher then amaranth volume (Abalone 2004). The bulk density of basil seeds varied between 339.21 and 343.16 kg/m^3 which was lower than rapeseed (Calisir *et al.* 2005), amaranth (Abalone 2004), flaxseed (Coskuner and Karababa 2007), cumin seed (Singh and Goswami 1996), millet (Baryeh 2002), fenugreek seed (Altuntas *et al.* 2005) and sesame (Tunde-Akintunde and Akintunde 2004). The basil seeds had on average a true density of 1037 kg/m^3, which was higher than flaxseed (Coskuner and Karababa 2007), pomegranate seed (Kingsly *et al.* 2006), rapeseed (Calisir *et al.* 2005) and caper seed (Dursun and Durson 2005), and lower than amaranth (Abalone 2004), sesame seed (Tunde-Akintunde and Akintunde 2004), vetch seed (Yalcin and Ozarslan 2004), hemp seed (Sacilik *et al.* 2003) and millet (Baryeh 2002).

The porosity of seed ranged from 66.7 to 67.8%. This is higher than the value reported for flaxseed (Coskuner and Karababa 2007), pomegranate seed (Kingsly *et al.* 2006), fenugreek (Altuntas *et al.* 2005), rapeseed (Calisir *et al.* 2005), caper seed (Dursun and Durson 2005), amaranth (Abalone 2004), vetch seed (Yalcin and Ozarslan 2004) and hemp seed (Sacilik *et al.* 2003). This trend may be because of the higher sphericity and therefore larger intergrain spaces.

The static coefficient of friction of basil seeds was obtained experimentally on five surfaces, namely plywood, galvanized iron, rubber, fiberglass and glass. Plywood 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 to other sheets used. The coefficient of friction of basil seed was higher than flaxseed (Coskuner and Karababa 2007), rapeseed (Calisir *et al.* 2005), sesame seed (Tunde-Akintunde and Akintunde 2004) and millet (Baryeh 2002). The shape of basil seed makes it difficult to roll on surface; therefore, statistic coefficient of friction of basil seeds was found higher than those of some other seeds and grains.

The filling angle of repose of basil seeds ranged from 13.44 to 15.91 with the mean value as 14.64 ± 0.88 (Table 1); this is lower than those reported for pomegranate seed (Kingsly *et al.* 2006), fenugreek (Altuntas *et al.* 2005), caper seed (Dursun and Durson 2005) and sesame seed (Tunde-Akintunde and Akintunde 2004). The emptying angle of repose varied between "11.17 and 13.55" with the mean value as 12.35 ± 0.86 (Table 1); this is lower than values obtained for flaxseed (Coskuner and Karababa 2007), hemp seed (Sacilik *et al.* 2003) and millet (Baryeh 2002).

The terminal velocity of basil seeds ranged from 3.9 to 4.8 m/s with the mean value as 4.26 ± 0.23 (Table 1). This characteristic can be used to design separating, cleaning and handling process for seed, because the high tendency for water absorption by the seed makes washing and using the water impossible.

The hardness, toughness and rupture force values of the seeds were between 750 and 1,259 g, 175.83 and 364.75 g/mm and 370 and 691 g. These values were lower than those reported for pomegranate seed (Kingsly *et al.* 2006).

CONCLUSION

In the present study, a CVS was used to measure the geometrical properties of seeds. The system included a hardware which was developed to capture a standard image from the samples and CVS software. Length, width and thickness of the samples were determined and gave high correlations with the values obtained by micrometer that shows the efficiency of image processing method.

The unit mass and thousand grain mass of the seeds were 0.0020 and 2.13 g, respectively. The true and bulk densities of the seeds were 1,038 and 340.24 kg/m^3. The filling and emptying angles of repose were 14.64° and 12.35°, respectively. The average coefficient of friction against plywood, 0.547, was the highest, while 0.300 for glass was the lowest. The average terminal velocity of basil seed was 4.27, and according to the mucilaginous nature of the seed higher or lower air velocities can be used for separation or cleaning process. The hardness, toughness and fracture force values were 926.13 g, 246.32 g/mm and 537.40 g, respectively.

ACKNOWLEDGMENT

The authors are grateful to Mr. A. PoorAkbar for his help in the image processing of this research.

REFERENCES

ABALONE, R., CASSNERA, A., GASTONE, A and LARA, M.A. 2004. Some physical properties of amaranth seeds. Biosyst. Eng. *89*(1), 109–117.

ALTUNTAS, E., OZGOZ, E. and FARUK TASER, O. 2005. Some physical properties of fenugreek seeds. J. Food Eng. *71*, 37–43.

AMIN, G.H. 2005. *Medicinal Plants of Iran*, 1st Ed., p. 106, Tehran University Publication, Tehran, Iran (in Persian language).

BARYEH, E.A. 2002. Physical properties of millet. J. Food Eng. *51*, 39–46.

CALISIR, S., MARAKOGLU, T., OGUT, H. and OZTURK, O. 2005. Physical properties of rapeseed. J. Food Eng. *69*, 61–66.

COSKUNER, Y. and KARABABA, E. 2007. Some physical properties of flaxseed. J. Food Eng. *78*, 1067–1073.

DURSUN, E. and DURSUN, I. 2005. Some physical properties of caper seed. Biosyst. Eng. *92*(2), 237–245.

KILIC, K., BOYACI, I.H., KOKSEL, H. and KUSMENGOGLU, I. 2007. A classification system for beans using computer vision system and artificial neural networks. J. Food Eng. *78*, 897–904.

KINGSLY, A.R.P., SINGH, D.B., MANIKANTAN, M.R. and JAIN, R.K. 2006. Moisture dependent physical properties of dried pomegranate seeds. J. Food Eng. *75*, 492–496.

MCCABE, W.L., SMITH, J.C. and HARRIOTT, P. 1986. *Unit Operations of Chemical Engineering*, McGraw-Hill, New York, NY.

MOHSENIN, N.N. 1978. *Physical Properties of Plant and Animal Materials*, Gordon and Breach Science Publishers, New York, NY.

MWITHIGA, G. and MASIKA SIFUNA, M. 2006. Effect of moisture content on the physical properties of three varieties of sorghum seeds. J. Food Eng. *75*, 480–486.

SACILIK, K., OZTURK, R. and KESKIN, R. 2003. Some physical properties of hemp seed. Biosyst. Eng. *86*(2), 191–198.

SINGH, K.K. and GOSWAMI, T.K. 1996. Physical properties of cumin seed. J. Agric. Eng. Res. *64*, 93–98.

TUNDE-AKINTUNDE, T.Y. and AKINTUNDE, B.O. 2004. Some physical properties of sesame seed. Biosyst. Eng. *88*(1), 59–65.

YALCIN, I. and OZARSLAN, C. 2004. Physical properties of vetch seed. Biosyst. Eng. *88*(4), 507–512.