American-Eurasian J. Agric. & Environ. Sci., 6 (4): 447-453, 2009
ISSN 1818-6769

Mechanical Properties of Pomegranate Seeds Affected by Moisture Content

[1]Vahid Akbarpour, [2]Jafar Milani, [3]Khodayar Hemmati

[1]Department of Horticulture,
[2]Department of Food Science and Technology,
Sari University of Agricultural Sciences and Natural Resources, Sari, P.O. Box 578, Iran
[3]Department of Horticulture,
Gorgan University of Agricultural Sciences and Natural Resources, Gorgan, Iran

Abstract: In this study some physical properties of pomegranate seeds have been evaluated as a function of moisture content ranging from 10.06 to 22.91% (w.b.). Length, width, thickness, geometric mean diameter, sphericity and 1000 seed mass were increased linearly 3.55, 3.48, 8.87, 5.22, 1.61 and 30.04 percent, respectively with increasing moisture content from 10.06 to 22.91% (w.b.). Bulk density and true density increased linearly from 569.3 to 646.3 kg/m^3 and 1057.3 to 1147.2 kg/m^3, respectively, while porosity was decreased from 46.15 to 43.66%. The angle of repose was increased from 21.35 to 29.4° with increasing moisture content. The static coefficient of friction was increased linearly for concrete (7.00%), galvanized iron sheet (7.59%), plywood (8.05%) and glass sheet (9.26%), respectively. The highest static coefficient of friction was observed on concrete and the lowest on glass sheet among the materials tested.

Key words: Pomegranate seed · Moisture content · Physical properties · Coefficient of friction

INTRODUCTION

Pomegranate (*Punica granatum* L.) belongs to Punicacia family and is one of the most popular fruits native to Iran. However, it is now widely grown in many countries such as India, Spain, Egypt, Russia, France, Argentina, China, Japan and USA. Iran is a native land of the pomegranate which is grown in every area, both coastal and mountainous areas. The total pomegranate production in Iran was 670,000 tons in 2005 [1]. Pomegranate fruit has valuable compounds in different parts of the fruit whose functional and medicinal effects such as antioxidant, anticancer and anti-atherosclerotic effects have been confirmed [2-5].

Pomegranate fruits contain considerable amounts of seeds, ranging between 40 and 100 g/kg of fruit weight depending on variety. One of the conventional utilization of pomegranate seeds in Iran is pomegranate seed powder that is used in many home foods such as Zeytoon Parvardeh (Special Olive), Kaalekabab and etc. The pomegranate seeds have estrogenic and antioxidant activity [6-10]. In addition, seeds are rich in vitamin C and minerals such as potassium, sodium and calcium [11,12].

In the process of dehydration, grinding and in other related processes, the seeds undergo a series of changes and presently, limited information is available on engineering properties of seeds. Dried pomegranate seeds are highly hygroscopic and affect handling and processing with absorption of moisture. The objective of this study was to determine the physical properties of pomegranate seeds in the desired moisture range of 10.06–22.91% (w.b.), thus the knowledge gained will be used in design and development of equipments for cleaning, grading, dehydration, storage and handling of pomegranate seeds in the oil industry.

Dimensions are important to design the cleaning, sizing and grading machines. Bulk density, true density and porosity are major considerations in designing the drying and aeration and storage systems, as these properties affect the resistance to air flow of the mass. Angle of repose and coefficient of friction are important in designing equipment for solid flow and storage structures. The coefficient of friction between seed and wall is an important parameter in the prediction of seed pressure on walls.

In this study, moisture dependent selected physical properties of pomegranate seeds, namely, linear

Corresponding Author: Jafar Milani, Department of Horticulture,
Sari University of Agricultural Sciences and Natural Resources, Sari, P.O. Box 578, Iran

dimensions, geometric mean diameter, sphericity index, thousand seeds mass, true density, bulk density, porosity, angle of repose and static coefficient of friction against four surfaces were investigated.

MATERIALS AND METHODS

Ferdows variety pomegranates were obtained from Khorasan province in Iran from agricultural research center of Mashhad. The arils with seed were manually separated from mature fruits. After separation, the arils were dried to moisture content of 10 % (w.b.). Experiments were conducted in the moisture range of 10.06–22.91% (w.b.). The samples of the desired moisture content level were prepared by adding calculated amounts of distilled water in accordance with Eq. (1) [13].

$$Q = \frac{W_i(M_f - M_i)}{100 - M_f} \quad (1)$$

Where Q is mass of added water in grams, W_i is initial mass of seed sample in grams and M_i and M_f are the initial and final moisture contents in %w.b., respectively.

The samples were packed in polyethylene bags and stored at 5°C in a refrigerator for 48 h before using them for the experiments. The experiments were replicated 3 times to avoid error.

To determine the size of seeds, a sample of 50 seeds was randomly selected. Linear dimensions, i.e. major (L), medium (W) and minor diameter (T), were measured by using a digital caliper with a 0.01 mm accuracy. to calculate the geometric mean diameter (D_g). The geometric mean diameter (D_g) was computed using the following equation:

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

The sphericity index value (Φ) of seeds was calculated using the following formula [14]:

$$\Phi = \frac{(LWT)^{1/3}}{L} \times 100 \quad (3)$$

Thousand seed mass (W_{1000}) was determined by counting 100 seeds and weighting them in an electronic balance of 0.001 g sensitivity and then multiplied by 10 to give the mass of 1000 seeds.

Bulk density (ρ_b) of pomegranate seed was determined by filling the grains in a cylinder of known volume (1000 cm^3) and weighed in an electronic balance. The bulk density was then calculated from the mass and volume [15,16].

The true density (ρ_t) defined as the ratio between the mass of pomegranate seed and the true volume of the seed, was determined using the toluene displacement method. Toluene was used in place of water because it is absorbed by seeds to a less extent. The volume of toluene displaced was found by immersing a weighted quantity of pomegranate seed in the toluene [13]. The percent porosity (ε) was calculated from the relationship between bulk and true density [14]:

$$\varepsilon = \frac{\rho_t - \rho_b}{\rho_t} \times 100 \quad (4)$$

The angle of repose (φ) was determined from the height (H) and diameter (D) of the naturally formed heap of seeds on a circular plate [17]. For this purpose, the seeds were allowed to fall from a height of 20 cm on a circular plate of 200 mm diameter for the heap formation.

$$\varphi = \tan^{-1}\left(\frac{2H}{D}\right) \quad (5)$$

The static coefficients of friction of pomegranate seeds were determined on the surfaces of concrete, galvanized iron sheet, plywood and glass sheet. It was determined by filling a hollow plastic box of dimensions 70 ×70 ×70 mm with seeds as suggested by Kaleemullah (1992) [18]. The box was pulled parallel to the surface in such a way that it just started to move and static coefficient of friction(μ)was determined using the formula:

$$\mu = \frac{F}{W_{b+s}} \quad (6)$$

Where, F = the force required just to move the box with seeds and W_{b+s} = weight of box plus seeds.

RESULTS AND DISCUSSIONS

Seed Size: The major, medium, minor and geometric mean diameter of dried pomegranate seed at moisture contents of 10.06, 12.31, 14.53, 16.07, 18.39, 20.66 and 22.91% (w.b.) are presented in Table 1. It is observed from Table 1 that all dimensions of seed were increased with increasing

Table 1: Variation of principal dimensions of pomegranate seed with moisture content (% w.b.)

Moisture content (% w.b.)	Major diameter (mm)	Medium diameter (mm)	Minor diameter (mm)	Geometric mean diameter (mm)
10.06	5.861	3.390	2.278	3.519
12.31	5.943	3.422	2.351	3.583
14.53	5.993	3.477	2.390	3.632
16.07	5.991	3.479	2.392	3.633
18.39	6.040	3.489	2.466	3.683
20.66	6.062	3.493	2.469	3.690
22.91	6.069	3.508	2.480	3.702
Mean	5.994	3.465	2.404	3.635
SD	0.074	0.043	0.074	0.066

moisture content. For the increase in moisture contents from 10.06 to 22.91% (w.b.), the increase of major, medium, minor and geometric mean diameter were 3.55, 3.48, 8.87, 5.22 and 1.61 % respectively. Therefore, all dimensions of seeds were increased linearly when the moisture content was increased from 10.06 to 22.91% (w.b.). The medium dimension had the smallest percentage increase (with increase in moisture content), while the minor diameter had largest percentage increase. The geometric mean diameter of seeds as computed using Eq. (2) increased 1.61% with increasing moisture contents. Kingsly *et al.* [12], Amin *et al.* [20]. Garnayak *et al.* [21], Solomon and Zewdu [30], Karababa and Coskuner [31] and Mwithiga and Sjfuna [34] found similar results for lentil seeds, jatropha seeds, sweet corn kernels, ,pomegranate seeds, sorghum seeds and niger seeds.

The following regression equations were developed for major, medium, minor and geometric mean diameter with moisture content (%w.b.).

$$L = 0.0154M + 5.7414 \; (R^2 = 0.9066) \qquad (7)$$
$$W = 0.0086M + 3.3247 (R^2 = 0.8328) \qquad (8)$$
$$T = 0.0155M + 2.1488 (R^2 = 0.9167) \qquad (9)$$
$$D_g = 0.0138M + 3.4079 (R^2 = 0.9123) \qquad (10)$$

The regression lines of mentioned dimensions are shown in Fig.1. It is obvious from this Figure that the dimensions of pomegranate seeds were linearly increased with increasing moisture content.

Sphericity Index: The sphericity index of seeds as calculated using Eq. (3) was increased from 0.600 to 0.610 with increasing the moisture content from 10.06 to 22.91% (Fig. 2). Therefore, a moderate increment in sphericity index was seen. The increase in the sphericity index was due to greater increase in thickness (minor diameter) as compared to other dimensions. The sphericity index of pomegranate seeds was lower than most seeds such as

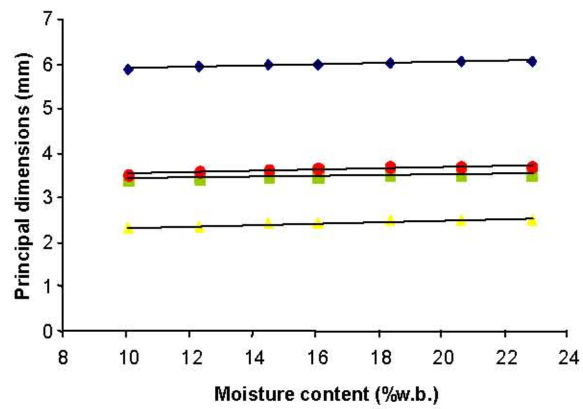

Fig. 1: Variation of seed dimensions with moisture content. ◆; major diameter, ■; medium diameter, ▲; minor diameter, ●; geometric mean diameter

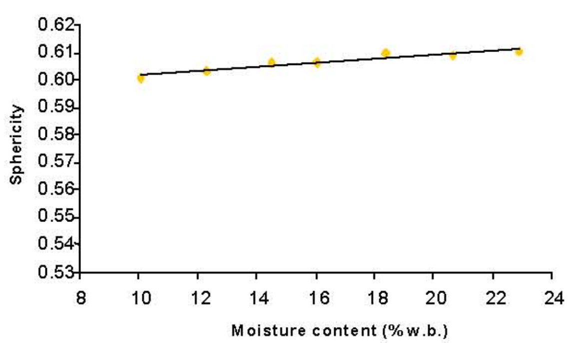

Fig. 2: Variation of sphericity of seeds with moisture content

chickpea [15], millet [22], hazelnut [19], cacao [24], safflower [25], popcorn kernels [26], pistachio [27], tef seed [28], roselle seed [29] and jatropha seeds [21], but it was more than niger seed [30].

The relationship between sphericity index and moisture content (%w.b.) can be represented by the following equation:

$$\Phi = 0.0007M + 0.594 \; (R^2 = 0.8922) \qquad (11)$$

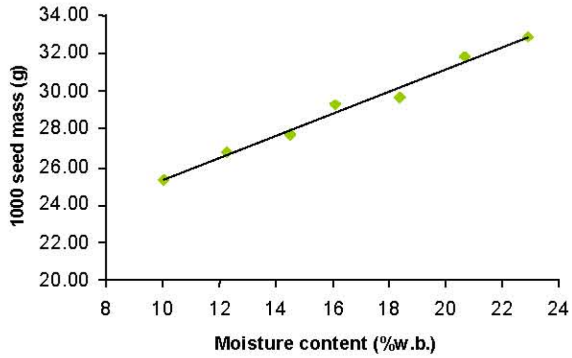

Fig. 3: Variation of the thousand seed mass with moisture content

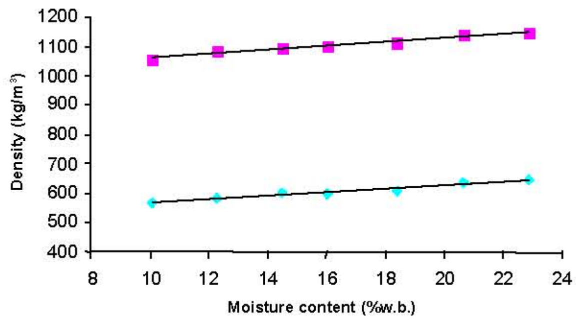

Fig. 4: Bulk and true densities of seeds as a function of moisture content. ■; true density ◆; bulk density

The different results have been reported for moisture dependence of sphericity. Zewdu and Solomon [28] reported an initial decrease followed by an increase in sphericity for tef seed. However, an increase in the sphericity with increasing moisture content was reported for safflower seeds [25], pistachio kernels [27], sweet corn kernels [31] and jatropha seeds [21].

Thousand Seed Mass: The variation of thousand seed mass with increasing moisture content is shown in Fig. 3. It is clear that the thousand seed mass was increased from 25.30 to 32.90 g with the corresponding increase in moisture content from 10.06 to 22.91% w.b.

The linear relationship between thousand seed mass and moisture content could be expressed in the form of Eq. (12).

$$W_{1000} = 0.5899M + 19.378\ (R^2 = 0.9855) \qquad (12)$$

Such linear relationship between thousand seed mass and moisture content has been reported for gram [32], millet [22], cacao [24], caper seed [33], pomegranate seeds [12], popcorn [26], sweet corn kernels [31], tef seed [28], jatropha seeds [21] and niger [30].

Bulk Density and True Density: The bulk and true densities of samples was increased with increasing moisture content (Fig. 4). An increase from 569.3 to 646.3 kg/m^3 and 1057.3 to 1147.2 kg/m^3 was observed in bulk and true densities, respectively, for an increase in moisture content from 10.06 to 22.91% (w.b.). The bulk density was found to be lower than true density at the same moisture content.

The following linear regression equations were developed for bulk density and true density, respectively.

$$\rho_b = 6.6458M + 993.99\ (R^2 = 0.9716) \qquad (13)$$
$$\rho_t = 5.8589M + 509.3\ (R^2 = 0.9598) \qquad (14)$$

The same trend has also been reported by Aydin and Ozcan (2002) for terebinth fruits [23]. The increase in bulk and true densities of pomegranate seeds with increasing moisture content indicates that the increase in mass owing to moisture gained in the samples is more compared to the increase in their volume.

The different trend has been observed for gram [32], lentil seed [20], sorghum seeds [34], sweet corn kernels [31] and tef seeds [28]. The explanation for these discrepancies could be relate to the range of seed moisture content studied, the cell structure and the volume and mass increase characteristics of the seeds as seed moisture content increases.

Porosity: Porosity is the property of seeds that depends on its bulk and true density and this dependence is different for every seed. The porosity was calculated from the bulk density and true density of the seeds. The porosity was decreased from 46.15 to 43.66 % with increasing moisture content from 10.06 to 22.91% (Fig. 5).

The relationship between the porosity and moisture content for seeds can be represented by the following equation:

$$\varepsilon = 0.1994M- 48.406\ (R^2 = 0.906) \qquad (15)$$

While most of the researcher has reported linear increasing trend for gram [32], cashew nut [35], chickpea [21], millet [22], hazelnut [19], cacao [24], lentil seeds [20], popcorn [26], tef seed [28], sweet corn kernels [31], roselle seed [29], jatropha [21] and niger seeds [30], decreasing trends has reported by Kingsly *et al.* [12] and Kashaninejad *et al.* [27] and Chandrasekar and Viswanathan [36] for coffee, pomegranate seed and pistachio, respectively.

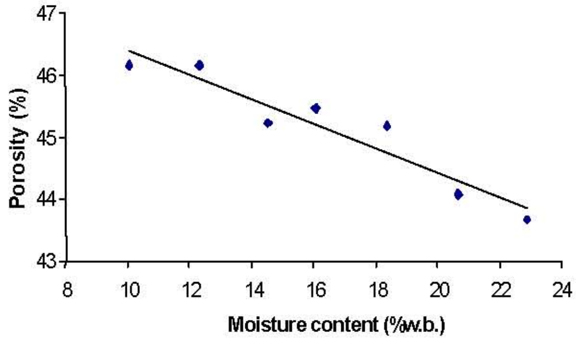

Fig. 5: Porosity of seeds as a function of moisture content

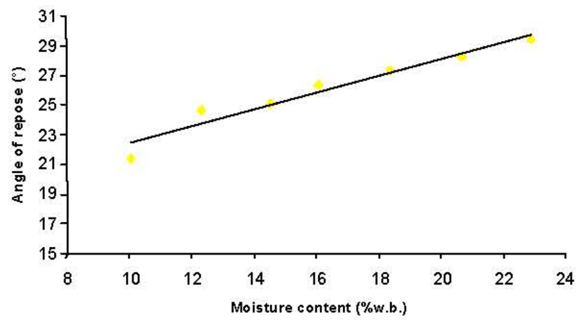

Fig. 6: Variation of the angle of repose with moisture content

Angle of Repose: The angle of repose obtained at different moisture contents are shown in Fig. 6. A rise in the moisture content from 10.06 to 22.91% (w.b.) resulted in increment of angle of repose from 21.346° to 29.412°. At higher moisture content seeds tend to stick together resulting in enhanced stability and less flow ability, which increases the value of φ.

A linear relationship described the dependence of *ö* on moisture content as presented below:

$$\varphi = 0.5699M + 16.703 \ (R^2 = 0.9432) \quad (16)$$

The similar trend has also been reported for green gram [37], okra seed [38], chickpea [15], arecanut kernel [39], lentil seeds [20], sweet corn kernels [31], tef seed [28], jatropha [21] and niger seeds [30].

Static Coefficient of Friction: It is observed from Fig. 7 that the static coefficients of friction for pomegranate seeds was increased with increasing moisture content on all four surfaces. A similar trend was reported by Demir *et al.* [40] for hackberry fruits. The highest static coefficients of friction were observed on the concrete surface followed by plywood and galvanized iron and were lowest on the glass surface. Therefore static

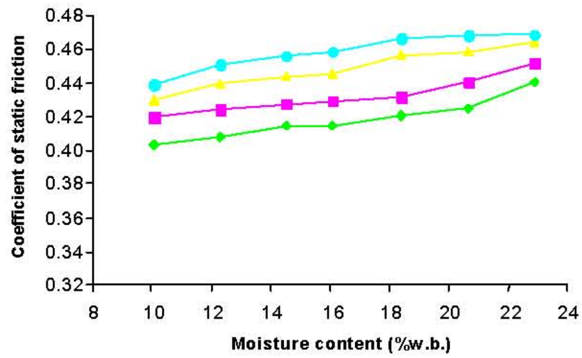

Fig. 7: Coefficient of friction of seeds as a function of moisture content. ◆; glass, ■; galvanized iron, ▲; plywood, ●; concrete sheet

coefficient of friction varied from material to material due to their surface smoothness and also varied with the wetness of the seeds. The static coefficients of friction for pomegranate seeds were found lower than those which were reported by Kingsly *et al.* [12] and Amin *et al.* [20] and higher than lentil seeds on galvanized iron, plywood and glass surfaces.

CONCLUSIONS

Several properties of Ferdows pomegranate variety seeds were investigated in the range of moisture contents from 10.06 to 22.91% (w.b.). The length, width, thickness, geometric mean diameter, sphericity and thousand seed mass of seeds increased linearly with the increase of moisture content. Bulk density and true density were increased linearly with the raise of moisture content, whereas porosity was decreased with increasing moisture content. Angle of repose increased from 21.346° to 29.412° as the moisture content was increased from 10.06 to 22.91% (w.b.). Static coefficient of friction varied from material to material and depended on the roughness of surface and wetness of the seeds. Static coefficient of friction was determined on the surfaces of concrete, galvanized iron sheet, plywood and glass sheet. The highest coefficient of static friction was found on the concrete surface and the lowest for glass sheet among the materials tested.

In this study, the physical parameters of pomegranate seeds were expressed in the form of regression equations as a function of moisture content, that the highest coefficient of correlation (R^2) was seen for thousand seed mass equation and the lowest was reported for width equation. Once the moisture content is known the physical parameters can be obtained from these equations.

REFRENCES

1. Anonymous, 2005. Statistical Book of Agricultural of Iran. Iranian Statistical Centre, Tehran, Iran.
2. Hora, J.J., E.R. Maydem, E.P. Lansky and C. Dwivedi, 2003. Chemopreventive effect of pomegranate seed oil on skin tumor development in CD_1 mice. J. Med. Food, 6: 157-161.
3. Mertens-Talcott S.U., P. Jilma-Stohlawetz, J. Rios, L. Hingorani and H. Derendorf, 2006. Absorption, metabolism and antioxidant effects of pomegranate (*Punica granatum* L.). polyphenols after ingestion of a standardized extract in healthy human volunteers. J. Agric. and Food Chem., 54: 8956-8961.
4. Mousavinejad G., Z. Emam-Djomeh, K. Rezaei and M.H. Haddad-Khodaparast, 2009. Identification and quantification of phenolic compounds and their effects on antioxidant activity in pomegranate juices of eight iranian varieties. Food Chem., 115: 1274-1278.
5. Perze-Vicente A., A. Izquierdo and C. Garcia-Viguera, 2002. In vitro gastrointestinal digestion study of pomegranate juice phenolic compounds, anthocyanins and vitamin C J. Agric. and Food Chem., 50: 2308-2312.
6. Choi, D.W., J.Y. Kim, S.H. Choi, H.S. Jung, H.J. Kim, S.Y. Cho, C.S. Kang and S.Y. Chang, 2006. Identification of steroid hormones in pomegranate (*Punica granatum*) using HPLC and GC-Mass spectrometry. Food Chem., 96: 562-571.
7. Moneam, N.M., A.S. El-Sharaky and M.M. Badreldin, 1988. Oestrogen content of pomegranate seeds. J. Chromatogr., 438: 438-442.
8. Poyrazoglu, E., V. Gokmen and N. Aruk, 2002. Organic acids and phenolic compounds in pomegranates (*Punica granatum* L.) grown in Turkey. J. Food Compos. and Analysis, 15: 567-575.
9. Singh, D. and V. Sethi, 2003. Screening of pomegranate genotypes for the preparation of quality grade anardana. J. Food Sci. and Technol., 40(2): 236-238.
10. Schubert, S.Y., E.P. Lansky and I. Neeman, 1999. Antioxidant and eicosanoid enzyme iinhibition properties of pomegranate seed oil and fermented juice flavonoids. J. Ethnopharmacol, 66L 11-17.
11. Al-Maiman, S.A. and D. Ahmad, 2002. Changes in physical and chemical properties during pomegranate (*Punica granatum*) fruit maturation. Food Chem., 76: 437-441.
12. Kingsly, A.R.P., D.B. Singh, M.R. Manikantan and R.K. Jain, 2006. Moisture dependent physical properties of dried pomegranate seeds (Anardana). J. Food Eng., 75: 492-496.
13. Sacilink, K., R. Ozturk and R. Kesikin, 2003. Some physical properties of hemp seeds. Biosys. Eng., 86(2): 191-198.
14. Mohsenin, N.N., 1986. Physical properties of plant and animal materials, 2nd Edn. Gordon and Breach Science Publishers, New York.
15. Konak, M., K. Çarman and C. Aydin, 2002. Physical properties of chick pea seeds. Biosys. Eng., 82(1): 73-78.
16. Paksoy, M. and C. Aydin, 2004. Some physical properties of edible squash (*Cucurbita pepo* L.) seeds. J. Food Eng., 65: 225-231.
17. Visvanathan, P.T., L. Palanisamy and V.V. Sreenarayanan, 1996. Physical properties of neem nut. J. Agric. Eng. Res., 63: 19-26.
18. Kaleemullah, S., 1992. The effect on moisture content on the physical properties of groundnut kernels. Trop. Sci., 32: 129-136.
19. Aydin, C., 2002. Physical properties of hazel nuts. Biosys. Eng., 82: 297-303.
20. Amin, M.N., M.A. Hossain and K.C. Roy, 2004. Effects of moisture content on some physical properties of lentil seeds. J. Food Eng., 65: 83-87.
21. Garnayak, D.K., R.C. Pradhan, S.N. Naik and N. Bhatnagar, 2008. Moisture-dependent physical properties of jatropha seed (*Jatropha curcas* L.). Ind. Crop. Prod., 27: 123-129.
22. Baryeh, E.A., 2002. Physical properties of millet. J. Food Eng., 51: 39-46.
23. Aydin, C. and M. Ozcan, 2002. Some physico-mechanic properties of terebinth (*Pistacia terebinthus* L.) fruits. J. Food Eng., 53: 97-101.
24. Bart-Plange, A. and E.A. Baryeh, 2003. The physical properties of category B cocoa beans. J. Food Eng., 60: 219-227.
25. Baümler, E., A. Cuniberti, S.M. Nolasco and I.C. Riccobene, 2006. Moisture dependent physical and compression properties of safflower seed. J. Food Eng., 72: 134-140.
26. Karababa, E., 2006. Physical properties of popcorn kernels. J. Food Eng., 72: 100-107.
27. Kashaninejad, M., A. Mortazavi, A. Safekordi and L.G. Tabil, 2006. Some physical properties of pistachio (*Pistacia vera* L.) nut and its kernel. J. Food Eng., 72: 30-38.

28. Zewdu, A.D. and W.K. Solomon, 2007. Moisture-dependent physical properties of tef seed. Biosys. Eng., 96(1): 57-63.
29. Sanchez-Mendoza, J., A. DomInguez-Lopez, S. Navarro-Galindo and J.A. Lopez-Sandoval, 2008. Some physical properties of roselle (*Hibiscus sabdariffa* L.) seeds as a function of moisture content. J. Food Eng., 87: 391-397.
30. Solomon, W.K. and A.D. Zewdu, 2009. Moisture-dependent physical properties of niger (*Guizotia abyssinica Cass.*) seed. Ind. Crop. Prod., 29: 165-170.
31. Karababa, E. and Y. Coskuner, 2007. Moisture dependent physical properties of dry sweet corn kernels. Int. J. Food Prop., 10: 549-560.
32. Chowdhury, M.M.I., R.I. Sarker, B.K. Bala and M.A. Hossain, 2001. Physical properties of gram as a function of moisture content. Int. J. Food Prop., 4: 297-310.
33. Dursun, E. and I. Dursun, 2005. Some physical properties of caper seed. Biosys. Eng., 92: 237-245.
34. Mwithiga, G. and M.M. Sifuna, 2006. Effect of moisture content on the physical properties of three varieties of sorghum seeds. J. Food Eng., 75: 480-486.
35. Balasubramanian, D., 2001. Physical properties of raw cashew nut. J. Agric. Eng. Res., 78: 291-297.
36. Chandrasekar, V. and R. Viswanathan, 1999. Physical and thermal properties of coffee. J. Agric. Eng. Res., 73: 227-234.
37. Nimkar, P.M., P.K. Chattopadhyay, 2001. Some physical properties of green gram. J. Agric. Eng. Res., 80(2): 183-189.
38. Sahoo, P.K. and A.P. Srivastava, 2002. Physical properties of okra seed. Biosys. Eng., 83(4): 441-448.
39. Kaleemullah, S. and J.J. Gunasekar, 2002. Moisture-dependent physical properties of arecanut kernels. Biosys. Eng., 82: 331-338.
40. Demir, F., H. Dogan, M. Ozcan and H. Haciseferogullari, 2002. Nutritional and physical properties of hackberry (*Celtis australis* L.). J. Food Eng., 54: 241-247.

Notation

Q Mass of added water, g
W_i Initial mass of seed sample, g
M_i Initial moisture content, %w.b.
M_f Final moisture content, %w.b.
L Major diameter, mm
W Medium diameter, mm
T Minor diameter, mm
D_g Geometric mean diameter, mm
Φ Sphericity index
W_{1000} Thousand seed mass, g
ρ_b Bulk density, kg/m3
ρ_t True density, kg/m3
ε Porosity, %
φ Angle of repose, deg
H Height of heap, mm
D Diameter of heap, mm
μ Static coefficient of friction
F Force required move box with seeds, N
W_{b+s} Weight of box plus seeds, Kg