World Applied Sciences Journal 12 (11): 2014-2022, 2011
ISSN 1818-4952

Moisture-Dependent Physical Properties of Asparagus (*Asparagus officinalis* L.) Seed

[1]Behrooz Sarabi, [2]J. Khodaei and [2]H. Samimi Akhijhani

[1]Department of Horticultural Sciences, Faculty of Agriculture, University of Tehran, Karaj, Iran
[2]Department of Mechanics of Agricultural Machinery,
Faculty of Agriculture, University of Kurdistan, Sanandaj, Iran

Abstract: A range of physical properties of seed of edible asparagus were determined as a function of moisture content. As the moisture content increased from 8.7 to 31.2% dry basis (d.b.), the average length, width, thickness and geometric mean diameter varied from 3.8 to 4.45, 3.36 to 3.93, 2.36 to 2.72 and 3.11 to 3.62 mm respectively. In the same moisture range, studies on rewetted asparagus seed showed that the sphericity, surface area and thousand seed mass increased from 0.807 to 0.822, 30.37 to 41.15 mm^2 and 21.1 to 31.24 g respectively. As the moisture content increased from 8.7 to 31.2% d.b., the bulk density, true density and porosity were found to decrease from 630 to 530 kgm^{-3}, 1360 to 1040 kgm^{-3} and 53.67 to 49.03%, whereas the terminal velocity, dynamic and static angle of repose were found to increase from 9.79 to 11.44 ms^{-1}, 0.41 to 0.49° and 0.29 to 0.38° respectively. The static coefficients of friction on rubber, aluminum, plywood, glass, iron and galvanized iron sheet also increased linearly with increase in moisture content. The rubber and galvanized iron sheet offered the maximum and minimum friction respectively.

Key words: *Asparagus officinalis* · Sphericity · Porosity · Terminal velocity

INTRODUCTION

Asparagus officinalis L., (*Asparagaceae*; 2n = 2x = 20) is a well known vegetable widely cultivated as an important economic crop all over the temperate world [1]. Its native range is uncertain, but it may has originated in the Caucasus and Middle East, including Iran. It is now widely naturalized in most of Europe, northern Africa and western Asia [2]. The young shoots of the plant, known as spears, are low in calories and contain various essential nutrients, including dietary fiber, oligosaccharides, amino acid derivatives, vitamins and mineral [3]. Because of this, asparagus has been named “the King of Vegetables” [4]. Additional constituents, like flavonoids, lignans and steroidal saponins, were reported in the roots and seeds of this plant [3].

Knowledge of the moisture-dependent physical properties of asparagus seed is essential to facilitate the design of equipment for handling, harvesting, conveying, separation, drying, aeration, storing and processing the seed. Large-scale asparagus seed harvesting can be conducted by a modified grain combine harvest machine adjusted to remove berries from the foliage in the field. Harvested berries can be machine-crushed, and the pulp/seed mixture can then be water washed, and the low-density floating pulp separated from seeds. Various types of cleaning, grading and separation equipment are designed on the basis of the physical properties of grains or seeds. The properties of different types of grains and seeds such as gram seed, cashew nuts, lentil seed, white Lupin, millet, locust bean seed, Hemp Seed, Amaranth Seed, guna seeds, sweet corn seed, Linseed and barbunia bean have been determined by other researchers [5-16].

In Iran, asparagus is represented by native wild populations. Until now, there is no published literature on the physical properties of Iranian asparagus seed and their relationship with moisture content. The main objective of present study was to investigate some moisture-dependent physical properties of seed of Iranian edible wild asparagus namely size, sphericity, thousand seed mass, surface area, bulk density, true density, porosity, angle of repose, terminal velocity and coefficient of friction against different materials in the moisture range from 8.7 to 31.2 % dry basis (Table 1).

Corresponding Author: Behrooz Sarabi, Department of Horticultural Sciences, Faculty of Agriculture, University of Tehran, Karaj, Iran. Tel: +98-918-8779655, E-mail: sarabi.behrooz@gmail.com.

Table 1: Physical properties of asparagus seed evaluated

a	length, mm	R^2	coefficient of determination
b	width, mm	s	surface area, mm^2
C	thickness, mm	V_t	terminal velocity, ms^{-1}
D_a	arithmetic mean diameter, mm	W_i	initial mass of sample, Kg
de	diameter of a sphere of the same volume as seed, mm	ε	porosity, %
D_g	geometric mean diameter, mm	θ_d	angle of repose, deg dynamic
M	moisture content, % d.b.	θ_s	static angle of repose, deg
M_f	final moisture content of sample, % d.b.	μ	Coefficient of friction
M_i	initial moisture content of sample, % d.b.	ρ_b	bulk density, Kg m^{-3}
M_{1000}	1000 seed mass, g	ρ_t	true density, Kg m^{-3}
Q	mass of water to added, Kg	ϕ	sphericity, %

A B C D

Fig. 1: (A) Flowers, (B) green immature berry fruits, (C) red mature berry fruits and (D) seeds of asparagus.

MATERIALS AND METHODS

Sample Preparation: Seeds of edible wild asparagus were collected from their main natural growing regions across the Alborz Mountains of Iran. Flowers appeared from early May to early June (Fig. 1A), and green fruits were formed about early July (Fig. 1B). The number of black seeds per fruit, which were reddish berries when mature (Fig. 1C), collected around early September, varied from 4 to 6 amongst individual plants (Fig. 1D). The seeds were hand-cleaned to remove any foreign material such as dust, dirt, stones and chaff as well as immature and broken seeds. The initial moisture content of seed was determined by using the standard hot air oven method at 105±1°C for 24 h [17]. The initial moisture content of the seeds was 8.7% dry basis (d.b.).

The samples of the desired moisture contents were prepared by adding the amount of distilled water as calculated from the following equation [11]:

$$Q = \frac{W_i\left(M_f - M_i\right)}{\left(100 - M_f\right)} \qquad (1)$$

Where: Q is the mass of water to added in kg; W_i, is the initial mass of sample in kg; M_i, is the initial moisture content of sample in % d.b. and M_f, is the final moisture content of sample in % d.b.

The samples were then poured into separate polyethylene bags and the bags sealed tightly. The samples were kept at 5 °C in a refrigerator for a week to enable the moisture to distribute uniformly throughout the sample. Before starting a test, the required quantity of the seed was taken out of the refrigerator and allowed to equilibrate to the room temperature for about 2 h [14]. All the physical properties of the seeds were assessed at moisture levels of 8.7, 16.8, 24.2 and 31.2 % d.b. with four replications at each moisture content. This rewetting technique to attain desired moisture content in seed and grain has frequently been used by [18,19].

The following methods were used in the determination of some physical properties of asparagus seed.

Size and Shape: The seed size was determined by picking 100 seeds randomly and measuring their three principal dimensions, namely length, width and thickness, using an electronic caliper (INSIZE CO., LTD) with an accuracy of 0.01 mm.

According to following formulas, the average diameter of seed in mm was calculated by using the geometric mean (D_g) and arithmetic mean (D_a) of the three axial dimensions [20].

$$D_g = (abc)^{1/3} \tag{2}$$

$$D_a = \frac{(a+b+c)}{3} \tag{3}$$

Where: a, the length, is the dimension along the longest axis in mm; b, the width, is the dimension along the longest axis perpendicular to a in mm; and c, the thickness, is the dimension along the longest axis perpendicular to both a and b in mm.

The average diameter was also determined similar to the one calculated by [18, 21] by considering it as an effective diameter in terms of the thousand seed mass and the true density as:

$$d_e = \left(\frac{6000 m_{1000}}{\pi \rho_t}\right)^{1/3} \tag{4}$$

Where: d_e is the diameter of a sphere of the same volume as the seed in mm; m_{1000} is the thousand seed mass in g and ρ_t is the true density of the seed in kgm^{-3}.

According to [22], the degree of sphericity can be expressed as follows:

$$\phi = \frac{(abc)^{1/3}}{a} \tag{5}$$

Where: ϕ is sphericity of seed in decimal.

Thousand Seed Mass: The 1000 seed mass was determined by means of a digital electronic balance having an accuracy of 0.001 gram. To evaluate the 1000 seed mass, 100 randomly selected seeds from the bulk sample were averaged and then multiplied by 10 to give mass of 1000 seeds.

Surface Area: The surface area of seeds was found by analogy with a sphere of the same geometric mean diameter, using the following equation cited by [17]:

$$s = \pi D_g^2 \tag{6}$$

Where: s is the surface area in mm^2 and D_g is the geometric mean diameter in mm.

Bulk and True Densities: The bulk density was determined by filling an empty 250 ml graduated cylinder with the seeds [22]. The weight of the seeds was obtained by subtracting the weight of the cylinder from the weight of the cylinder and seeds. To achieve uniformity in bulk density the graduated cylinder was tapped 10 times for the seeds to consolidate. No separate manual compaction of seeds was done. The volume occupied was then noted. The process was replicated four times and the bulk density for each replication was calculated from the following relation:

$$\rho_b = \frac{W_s}{V_s} \tag{7}$$

Where: the ρ_b is the bulk density in kgm^{-3}; W_s is the weight of the sample in kg; and V_s is the volume occupied by the sample in m^3.

The true density was defined as the ratio between the mass of asparagus seeds and the true volume of the seeds and determined using the toluene (C_7H_8) displacement method [11]. Toluene was used instead of water because it is absorbed by seeds to a lesser extent. The volume of toluene displaced was found by immersing a weighted quantity of seeds in the measured toluene.

Porosity: The porosity of asparagus seed at various moisture contents was calculated from bulk and true densities using the relationship given by [22] as follows:

$$\varepsilon = \left(1 - \frac{\rho_b}{\rho_t}\right)100 \tag{8}$$

Where: ε is the porosity in %; ρ_b and ρ_t are the bulk and true densities in kgm^{-3} respectively.

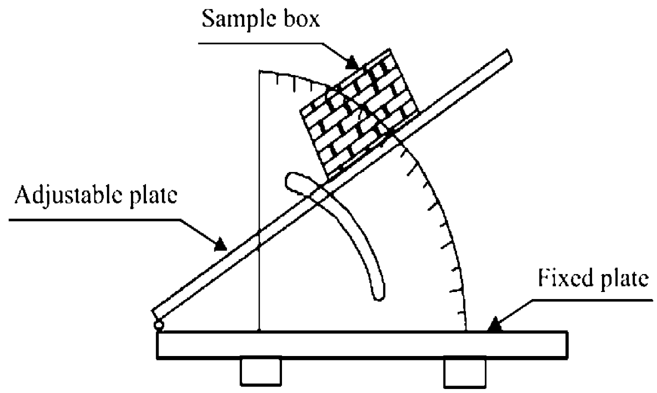

Fig. 2: Apparatus used to determine static angle of repose

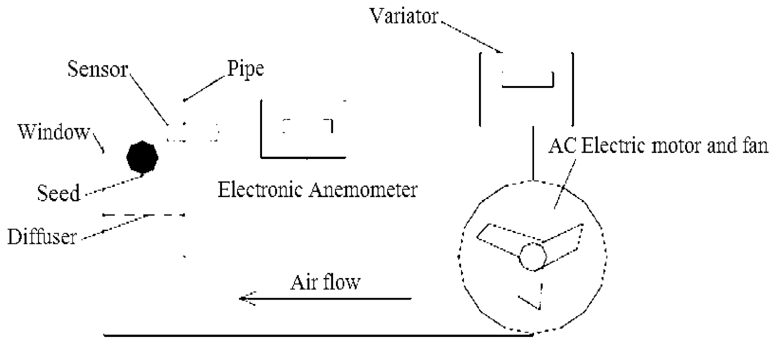

Fig. 3: Unit for measuring terminal velocity

Angle of Repose: The dynamic angle of repose (θ_d) is the angle with the horizontal at which the material will rest in a pile [20, 23]. To determine this, a specially constructed box 300 mm by 300 mm by 300 mm in size, having a removable front panel was filled with asparagus seeds and then the front panel was quickly removed, allowing the seeds to flow to their natural slope. The angle of repose was calculated from the measurements of the vertical depth of free surface of the sample at the centre.

The static angle of repose (θ_s) was determined by using the apparatus in Fig. 2, consisting of plywood box of 140×160×35 cm and two plates: fixed and adjustable. The box was filled with the sample and then the adjustable plate was inclined gradually allowing the seeds to follow and assume a natural slope [24].

Coefficient of Friction: Coefficient of static friction of asparagus seed on six surfaces (rubber, aluminum, plywood, glass, iron and galvanized iron steel) was determined. Asparagus seeds were put on the surface with changeable slip. When seeds started to move, the tangent of slip angle was taken as the coefficient of friction [25].

Terminal Velocity: The terminal velocities of asparagus seed at different moisture contents were measured using an air column device (Fig. 3). 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 seed became suspended in the air stream. The air velocity which kept the seed in suspension was measured using a pitot tube in conjunction with an electronic anemometer (Lutron AM-4206M) having a least count of 0.1 ms^{-1}. Each sample consisted of 10 seeds selected randomly at the same moisture content of seeds. Four replicates were measured for each sample [26].

Statistical Analysis: To examine the relationship between moisture levels and physical properties of asparagus seed, simple linear regression analysis was performed at 0.05 Type I error rate by use of SPSS statistical software (version 16; Norusis).

RESULTS

Seed Moisture Content: The initial moisture content of the dry seeds was found to be 8.7 % d.b. The three other moisture levels obtained after conditioning the seeds were

Table 2: Means and standard errors of the axial dimensions of asparagus seed

Moisture Content, d.b.%	Axial dimension, mm Length (a)	Width (b)	Thickness (c)	Average diameter, mm Arithmetic mean $\frac{(a+b+c)}{3}$	Geometric mean $(abc)^{1/3}$	Equivalent sphere $\left(\frac{6000m_{1000}}{\pi\rho_t}\right)^{1/3}$
8.7	3.8±0.15	3.36±0.16	2.36±0.14	3.17	3.11	3.09
16.8	3.97±0.26	3.52±0.22	2.49±0.17	3.33	3.26	3.49
24.2	4.19±0.25	3.55±0.3	2.6±0.21	3.45	3.38	3.69
31.2	4.45±0.25	3.93±0.34	2.72±0.15	3.7	3.62	3.86

ρ_t, true density in kg m^{-3}; m_{1000}, thousand seed mass in g

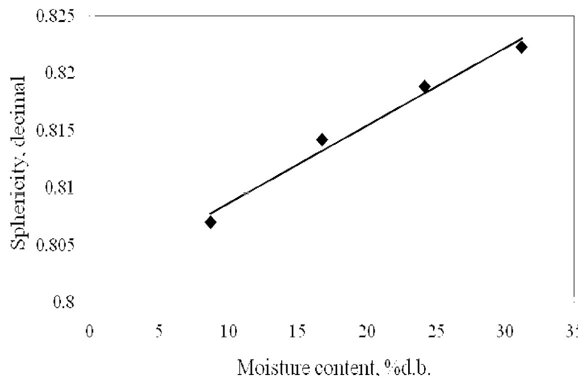

Fig. 4: Effect of moisture content on sphericity of asparagus seed

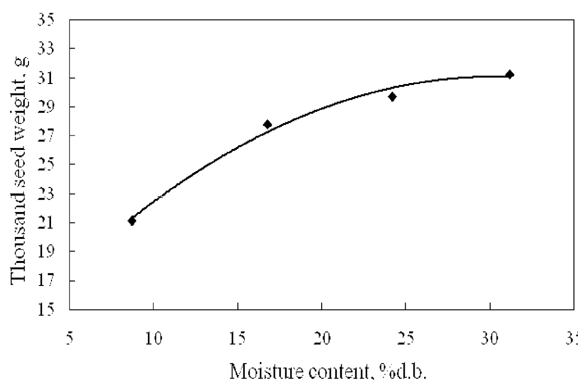

Fig. 5: Effect of moisture content on 1000 seed mass of asparagus seed

16.8, 24.2 and 31.2% d.b.. The investigations were carried out at the above moisture levels to determine the effect of moisture content on the physical properties of asparagus seed.

Size and Shape: Means and standard errors of the axial dimensions of asparagus seed at different moisture contents are given in table 2. As shown in table 2, the dimensional increases in length, width and thickness were 17.1, 16.96 and 15.25%, respectively. The asparagus seed expanded more along its length in comparison with its other two principal axes. Such dimensional changes are important in designing of equipment for cleaning, grading and conveying. ANOVA results shows that the three axial dimensions increased significantly (*P<0.05*) with moisture content in the moisture range of 8.7 to 31.19% d.b. The average diameters calculated by the arithmetic mean, geometric mean and equivalent sphere method were 3.17, 3.11 and 3.09 mm at a moisture content of 8.7% d.b. respectively. Table showed that the arithmetic, geometric mean diameter and equivalent sphere increased with increase in moisture content. These could be of important consideration in the theoretical determination of the seed volume at different moisture contents. Similar results of increase were reported for hemp seed and green wheat [11, 27].

Sphericity: The sphericity of the asparagus seed increased from 0.807 to 0.822 when the moisture content increased from 8.7 to 31.19% d.b. Similar trends have been reported for apricot kernels and cotton seed [28, 29].

The relationship existing between sphericity and moisture content was found to be linear and can be expressed using the following equation with a coefficient of determination $R^2 = 0.98$ (Fig. 4):

$$\phi = 0.0007M + 0.8019 \quad (9)$$

The variation in sphericity with moisture content was also significant at a significance level of 0.05.

Thousand Seed Mass: The variation of the thousand seed mass with seed moisture content is plotted in Fig. 5 (*P<0.05*). The figure indicated that the 1000 seed mass increased with increase in seed moisture content as a parabola from 21.1 g at 8.7% d.b. to 31.24 g at 31.19% d.b. The variation can be represented by the regression equation:

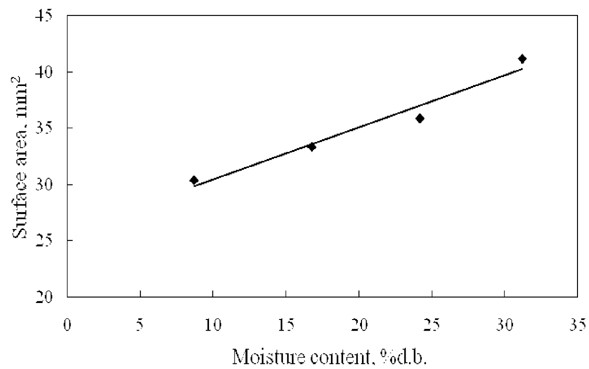

Fig. 6: Effect of moisture content on surface area of asparagus seed

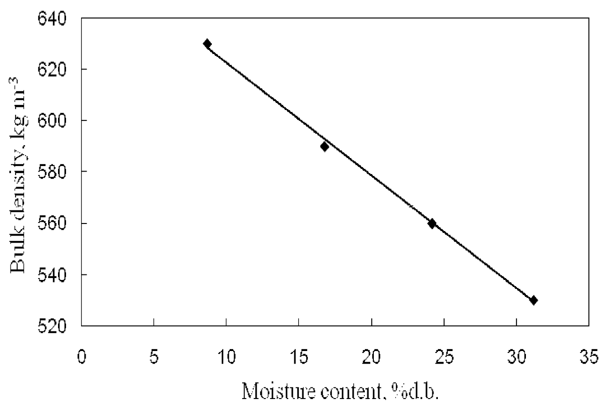

Fig. 7: Effect of moisture content on bulk density of asparagus seed

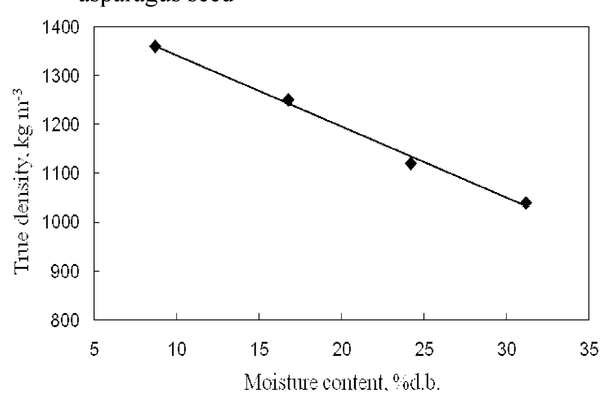

Fig. 8: Effect of moisture content on true density of asparagus seed

$$M_{1000} = -0.021M^2 + 1.276M + 11.77 \qquad (10)$$

With a value for the coefficient of determination R^2 of 0.99. Linear increases in the thousand seed mass as the seed moisture content increases were found for cotton seed [29], the QP-38 variety pigeon pea [30] and hemp seed [11].

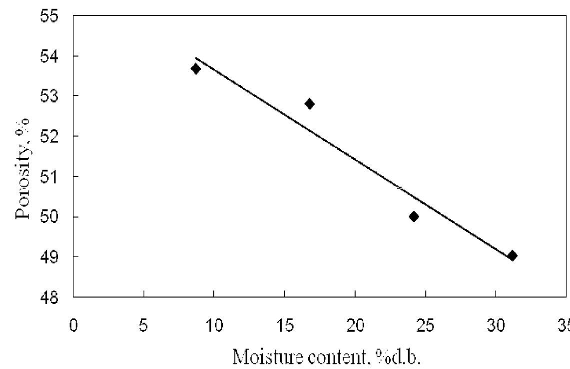

Fig. 9: Effect of moisture content on porosity of asparagus seed

Surface Area: The surface area of asparagus seed increased linearly while the moisture content of asparagus seed increased from 8.7 to 31.19% d.b. (Fig. 6). The variation of moisture content and surface area can be expressed by the following equation:

$$S = 0.462M + 25.83 \qquad (11)$$

With a value for R^2 of 0.96.

Linear increases in surface area with increase in seed moisture content have also been reported for cotton seed [29], chickpea seed [31] and fenugreek seed [17].

Bulk and True Densities: The experimental results of the bulk and true densities for asparagus seed at different moisture levels are presented in figures 7 and 8. As the moisture content increased from 8.7 to 31.19% d.b., the bulk and true densities decreased from 630 to 530 kgm^{-3} and 1360 to 1040 kgm^{-3} respectively (*P<0.05*). The correlations between bulk and true densities were found to be linear with the moisture content and can be expressed as follows:

$$\rho_b = -4.411M + 666.6 \qquad (12)$$

$$\rho_t = -14.56M + 1486 \qquad (13)$$

With values for R^2 of 0.99.

Similar decreasing trends in bulk and true densities have been observed for pigeon pea [18], gram [5], guna seed [13] and green gram [19]. The decrease in bulk density of asparagus seeds may have resulted from increase in size with moisture content which gives rise to decrease in quantity of seeds occupying the same bulk volume.

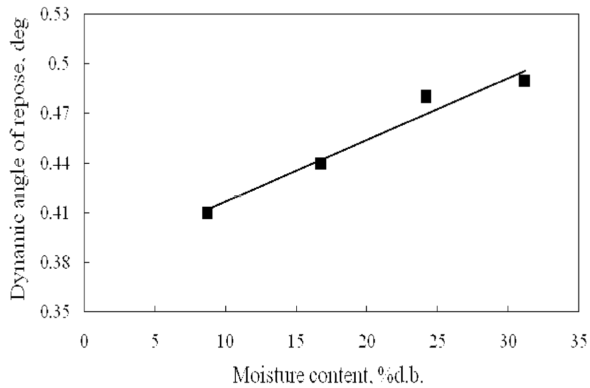

Fig. 10: Effect of moisture content on dynamic angle of repose of asparagus seed

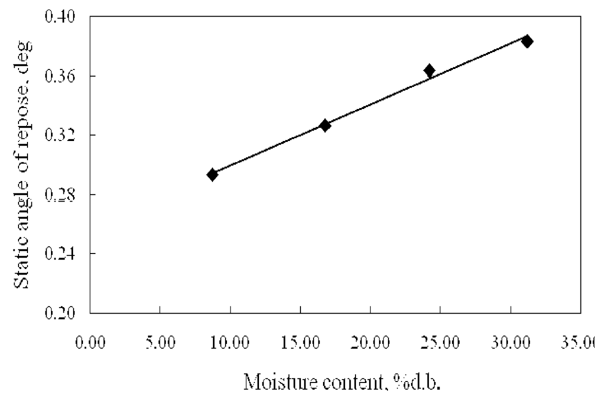

Fig. 11: Effect of moisture content on static angle of repose of asparagus seed

Porosity: The porosity calculated for relevant experimental data decreased from 53.67% to 49.03% as the moisture content increased from 8.7 to 31.2% d.b. (Fig. 9). The relationship existing between moisture content and porosity was linear and can be represented by the regression equation:

$$\varepsilon = -0.222M + 55.87 \quad (14)$$

With a value for R^2 of 0.95.

[29] Reported a similar decrease in porosity from 41.1 to 39% for cotton seed.

Angle of Repose: The results for dynamic and static angle of repose in degree with respect to moisture content are shown in Figures 10 and 11. Both the dynamic and static angle of repose increased linearly ($P<0.05$) in the moisture range of 8.7 to 31.19% d.b. from 0.41 to 0.49 and 0.29 to 0.38 respectively. Also, the dynamic angle of repose was higher than the static angle of repose at each moisture content. The relationship existing between the dynamic and static angle of repose and moisture content can be expressed using the following equations:

$$\theta_d = 0.003M + 0.379 \quad (15)$$

$$\theta_s = 0.004M + 0.258 \quad (16)$$

With values for R^2 of 0.96 and 0.99 respectively.

These results were similar to those reported for hemp seed [11] and linseed [15].

Coefficient of Friction: The effect of moisture content of asparagus seed on the static coefficients of friction against the various test surfaces are given in Fig. 12.

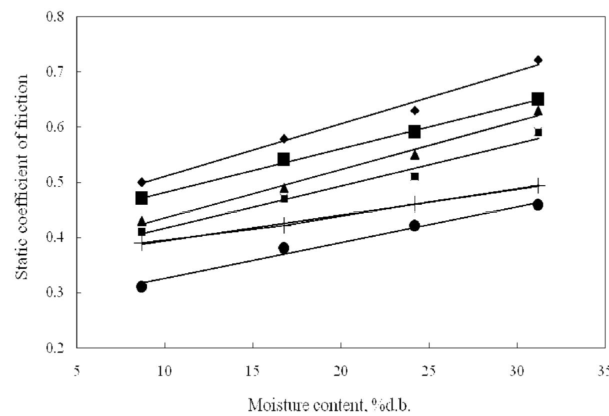

Fig. 12: Effect of moisture content on static coefficient of friction of asparagus seeds against various surfaces: ♦, rubber; ■, aluminum; ▲, plywood; ■, glass; +, iron; ●, galvanized iron sheet

The static coefficients of friction increased linearly with respect to moisture content for all six surfaces ($P<0.05$). The maximum value of 0.72 was obtained on the surface of rubber and the minimum value of 0.31 was on the surface of galvanized iron sheet. This may be owing to smoother and more polished surface of galvanized metal than other test surfaces.

The linear equations for static coefficients of friction on all six surfaces can be formulated as:

$$\mu = A + BM \quad (17)$$

Where: μ is the coefficient of friction and A and B are regression coefficients. These values are given in Table 3.

Similar findings were reported for pumpkin seed [20], millet [9] and hemp seed [11].

Table 3: Regression coefficients and coefficients of determination for static coefficients of friction of asparagus seed on various test surfaces

	Regression coefficient		
Surface	A	B	Coefficient of determination (R^2)
Rubber	0.414	0.009	0.99
Aluminum	0.403	0.007	0.99
Plywood	0.347	0.008	0.99
Glass	0.339	0.007	0.98
Iron	0.346	0.004	0.99
Galvanized iron sheet	0.260	0.006	0.98

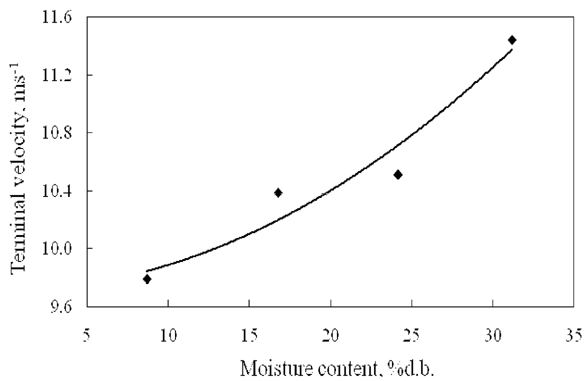

Fig. 13: Effect of moisture content on terminal velocity of asparagus seed

Terminal Velocity: Experimental results for the terminal velocity (V_t, ms^{-1}) of asparagus seed at various moisture levels are plotted in Fig. 13. As moisture content increased, the terminal velocity increased as a parabola from 9.79 to 11.44 ms^{-1} in the specified moisture range. The relationship between terminal velocity and moisture content can be represented by the following equation:

$$V_t = 0.002M^2 + 0.001M + 9.713 \tag{18}$$

With a value for R^2 of 0.94.

These results were similar to those reported for green gram [19], terebinth fruits [32], chick pea [31] and hemp seed [11] respectively. The increase in terminal velocity with increase in moisture content within the study range can be attributed to the increase in mass of an individual seed per unit frontal area presented to the airflow.

CONCLUSIONS

The following conclusions are drawn from the investigation of physical properties of asparagus seed, as the moisture content increased from 8.7 and 31.2% d.b.

- The average length, width, thickness, arithmetic and geometric mean diameter of the asparagus seed ranged from 3.8 to 4.45, 3.36 to 3.93, 2.36 to 2.72, 3.17 to 3.7 and 3.11 to 3.62 mm respectively.
- The sphericity, surface area and thousand seed mass varied from 0.807 to 0.822, 30.37 to 41.15 mm^2 and 21.1 to 31.24 g respectively.
- The bulk density, true density and porosity decreased from 630 to 530 kgm^{-3}, 1360 to 1040 kgm^{-3} and 53.67 to 49.03 respectively.
- The terminal velocity, dynamic and static angle of repose increased from 9.79 to 11.44 ms^{-1}, 0.41 to 0.49° and 0.29 to 0.38° respectively.
- The coefficients of friction on various surfaces increased linearly with increase in moisture content. At all moisture contents, the static coefficient of friction ranged from 0.5 to 0.72, 0.47 to 0.65, 0.43 to 0.63, 0.41 to 0.59, 0.39 to 0.49 and 0.31 to 0.46 for rubber, aluminum, plywood, glass, iron and galvanized iron sheet respectively.
- This knowledge of the physical properties can now be applied in designing appropriate asparagus seed harvesting, processing and storing equipments.

ACKNOWLEDGEMENTS

This research was financed by Department of Mechanics of Agricultural Machinery, Faculty of Agriculture, University of Kurdistan, Sanandaj, Iran.

REFERENCES

1. Prohens, J., F. Nuez and M.J. Carena, 2008. Handbook of Plant Breeding. Springer Publishing, pp: 364.

2. Kay, Q.O.N., E.W. Davies and T.C.G. Rich, 2001. Taxonomy of the western European endemic Asparagus prostratus (*A. officinalis* subsp. *prostratus*) (*Asparagaceae*). Botanical J. the Linnean Society, 137: 127-137.
3. Thomas, S.C.L., 2008. Vegetables and fruits, nutritional and therapeutic values. CRC Press/ Taylor & Francis Group, pp: 298.
4. Zhouxuan, S., H. Xuefeng and K. Lingyi, 2010. A new steroidal saponin from the dried stems of *Asparagus officinalis* L.. Fitoterapia, 81: 210-213.
5. Dutta, S.K., V.K. Nema and R.K. Bhardwaj, 1988. Physical properties of gram. J. Agricultural Engineering Res., 39: 259-268.
6. Oloso, A.O. and B. Clark, 1993. Some aspects of strength properties of cashew nuts. J. Agri. Engineering Res., 55: 27-43.
7. Carman, K., 1996. Some physical properties of lentil seeds. J. Agricultural Engineering Res., 63(2): 87-92.
8. Ougt, H., 1998. Some physical properties of white lupin. J. Agricultural Engineering Res., 69: 273-277.
9. Baryeh, E.A., 2002. Physical properties of millet. J. Food Engineering, 51: 39-46.
10. Ogunjimi, L.A.O., N.A. Aviara and O.A. Aregbesola, 2002. Some engineering properties of locust bean seed. J. Food Engineering, 55(2): 95-99.
11. Saçılık, K., R. Ozturk and R. Keskin, 2003. Some physical properties of hemp seed. Biosystems Engineering, 86(2), 191-198.
12. Abalone, R., A. Cassinera, A. Gastón and M.A. Lara, 2004. Some physical properties of Amaranth seeds. Biosystems Engineering, 89(1), 109-117.
13. Aviara, N.A., M.I. Gwandzang and M.A. Haque, 1999. Physical properties of guna seeds. J. Agri. Engineering Res., 73(2): 105-111.
14. Coskun, M.B., I. Yalcin and C. Ozarslan, 2006. Physical properties of sweet corn seed (*Zea mays* saccharata sturt). J. Food Engineering, 74: 523-528.
15. Kemal, Ç.S., Y. Pinar and E. Yesiloglu, 2006. Some physical properties of linseed. Biosystems Engineering, 95(4): 607-612.
16. Cetin, M., 2007. Physical properties of barbunia bean (*Phaseolus vulgaris* L. cv. 'Barbunia') seed. J. Food Engineering, 80: 353-358.
17. Altuntas, E., E. Özgöz and Ö.F. Taser, 2005. Some physical properties of fenugreek (*Trigonella foenum-graceum* L.) seeds. J. Food Engineering, 71: 37-43.
18. Shepherd, H. and R.K. Bhardwaj, 1986. Moisture-dependent physical properties of pigeon pea. J. Agri. Engineering Res., 35(4): 227-234.
19. Nimkar, P.M. and P.K. Chattopadhyay, 2001. Some physical properties of green gram. J. Agri. Engineering Res., 80(2), 183-189.
20. Joshi, D.C., S.K. Das and R.K. Mukherjiee, 1993. Physical properties of pumpkin seeds. J. Agri. Engineering Res., 54(3): 219-229.
21. Kaleemullah, S. and J.J. Gunasekar, 2002. Moisture-dependent physical properties of arecanut kernels. Biosystems Engineering, 82(3): 331-338.
22. Mohsenin, N.N., 1970. Physical properties of plant and animal materials. Gordon and Breach Science Publishers, New York.
23. Fraser, B.M., S.S. Verma and W.E. Muir, 1978. Some physical properties of fababeans. J. Agri. Engineering Res., 23(1): 53-57.
24. Jain, R.K. and S. Bal, 1997. Properties of pearl millet. Journal of Agricultural Engineering Res., 66: 85-91.
25. Colak, A. and K. Saçılık, 2002. Determination of the coefficients of friction of olive (*Olea europaea* L. cv. Memecik). J. Agri. Sciences (Ankara, Turkey), 8(2): 114-118.
26. Özcan, M.M. and H. Hacıseferogulları, 2007. The strawberry tree (*Arbutus unedo* L.) fruits: Chemical composition, physical properties and mineral contents. J. Food Engineering, 78: 1022-1028.
27. Al-Mahasneh, M.A. and T.M. Rababah, 2007. Effect of moisture content on some physical properties of green wheat. Jo. Food Engineering, 79: 1467-1473.
28. Gezer, I., H. Haciseferogulları and F. Demir, 2002. Some physical properties of Hacihaliloglu apricot pit and its kernel. J. Food Engineering, 56(1): 49-57.
29. Özarslan, C., 2002. Physical properties of cotton seed. Biosystems Engineering, 83(2): 169-174.
30. Baryeh, E.A. and B.K. Mangope, 2002. Some physical properties of QP-38 variety pigeon pea. J. Food Engineering, 56: 59-65.
31. Konak, M., K. Carman and C. Aydin, 2002. Physical properties of chickpea seeds. Biosystems Engineering, 82(1): 73-78.
32. Aydin, C. and M. Özcan, 2002. Some physico-mechanic properties of terebinth (*Pistacia terebinthus* L.) fruits. J. Food Engineering, 53(1): 97-101.