Electronic Journal of Polish Agricultural Universities (EJPAU) founded by all Polish Agriculture Universities presents original papers and review articles relevant to all aspects of agricultural sciences. It is target for persons working both in science and industry, regulatory agencies or teaching in agricultural sector. Covered by IFIS Publishing (Food Science and Technology Abstracts), ELSEVIER Science - Food Science and Technology Program, CAS USA (Chemical Abstracts), CABI Publishing UK and ALPSP (Association of Learned and Professional Society Publisher - full membership). Presented in the Master List of Thomson ISI.

ELECTRONIC JOURNAL OF POLISH AGRICULTURAL UNIVERSITIES

2011
Volume 14
Issue 1
Topic
FOOD SCIENCE AND TECHNOLOGY

JAFARI S., KHAZAEI J., ARABHOSSEINI A., MASSAH J., KHOSHTAGHAZA M.H., 2011. STUDY ON MECHANICAL PROPERTIES OF SUNFLOWER SEEDS, EJPAU, 14(1), #06.

Available Online http://www.ejpau.media.pl

STUDY ON MECHANICAL PROPERTIES OF SUNFLOWER SEEDS

Sahebeh Jafari[1], Javad Khazaei[1], Akbar Arabhosseini[1], Jafar Massah[1], Mohammad Hadi Khoshtaghaza[2]

[1]*Department of Agrotechnology, College of Abouraihan, University of Tehran, Tehran, Iran*
[2]*Department of Agricultural Technical Engineering, University of Tarbiat Modarres, Tehran, Iran*

ABSTRACT

Some physical and mechanical properties of sunflower seeds were studied. The measured parameters were linear dimensions, thousand grain mass, geometric mean diameter, sphericity, surface and projected area, volume, shape parameters (such as flakiness ratio and elongation ratio), true and bulk densities, porosity, angle of repose and static coefficient of friction of the Shamshiri variety in the moisture range from 6.3 to 20% (w.b.) using standard methods. Average rupture force, deformation and absorbed energy at rupture point of the sunflower seeds under compression as well as the extent of physical damage to seeds due to impact were also determined over a range of moisture contents between 1.8% and 20.3% (w.b). The results showed a variation of 14.32 to 31.00 mm for length, 4.73 to 9.82 mm for width and 2.36 to 6.67 mm for thickness of sunflower seeds. The values of the thousand grain mass, seed volume, true density, bulk density and porosity of sunflower seeds were between149.81–167.77g, 99.05-628.9 mm3, 444.39–521.78 kg/m3, 269.06–275.57 kg/m3 and 39.09–47.18% respectively. The rupture force, deformation, and absorbed energy increased with increase in moisture content from 1.8 to 14.5%, while decreased with further increasing of moisture content from 14.5 to 20.3%. The mean value of percentage of physically damaged seeds increased from 2.75 to 10.81% with increasing the impact velocity from 40.8 to 62.3 m/s. In both impact orientations, the total damaged seeds increased with increase in impact velocity for all moisture contents of seeds.

Key words: physical properties, mechanical properties, sunflower seed

Notation:

A_P	projected area (mm^2)	T_K	thickness of kernels (mm)
D_g	geometric mean diameter (mm)	T_S	thickness of seeds (mm)
Er	elongation ratio	V	volume (mm^3)
Fr	flakiness ratio	W	width (mm)
L	length (mm)	w.b.	wet basis
L_K	length of kernels (mm)	W_K	width of kernels (mm)
L_S	length of seeds (mm)	W_S	width of seeds (mm)
M	moisture content (% w.b.)	ε	porosity (%)
m_{1000K}	one thousand kernel mass (g)	ρ_b	bulk density (kg/m^3)
m_{1000S}	one thousand seed mass (g)	ρ_t	true density (kg/m^3)
S	surface area (mm^2)	φ	sphericity (%)
T	thickness (mm)		

INTRODUCTION

Sunflower (*Helianthus annuus* L.) is one of the world's most important oilseed crops. Sunflower kernel and its defatted meal have several advantages over other oilseed meal as human protein food, because of the absence of anti nutritional or toxic factors, flavour and of its high digestibility and biological value [9]. Sunflower seeds are excellent source of dietary fiber, protein, vitamin E, B vitamins, and minerals such as potassium, magnesium, iron, phosphorus, selenium, calcium and zinc. Some physical and mechanical properties of sunflower seed and kernel are considered to be necessary for designing of equipment of handling, conveying, separation, dehulling, drying, mechanical expression of oil, storage and other processes [19].

Several researchers reported some physical or mechanical properties of different seeds [2, 17, 18, 24, 30, 33, 37]. Despite of extensive searches on physical and mechanical of different agricultural seeds, a little published literature are available about physical and mechanical properties of sunflower seed and their dependency on operation parameter that would be useful for designing of processing equipment.

Gupta and Das [16] and Khazaei et al. [21] determined various physical and mechanical properties of sunflower seeds such as dimensions, sphericity, seed volume, thousand seed mass, projected area, terminal velocity, friction coefficient, bulk density, thermal velocity and angle of repose in the various moisture content. Gupta et al. [13] determined aerodynamic properties of sunflower seed. Sharma et al. [39] studied the effect of moisture content and variety on dehulling performance and textural characteristics of unshelled (seed) and shelled (kernel) sunflower seeds. Gupta and Das [14] evaluated the mechanical behavior of sunflower seeds and they found out that the rupture force reduced and the deformation increased by raising the moisture content from 3.8 to 16.6% (w.b.). As the literature review indicates, there isn't any published work on studying the effect of impact on mechanical properties of sunflower seeds.

Among the different varieties of sunflowers, the Shamshiri variety is widely and commercially cultured in Iran. This variety has long black seeds with thin hulls that are detached from the kernel. The objective of this study was to determine some properties of this sunflower variety namely: size, thousand seeds mass, true density, bulk density, porosity, static coefficient of friction, angle of repose, fracture resistance, and impact damage.

MATERIALS AND METHODS

The Shamshiri variety of sunflower, used in this research, was collected from the Oilseeds Research Institute in Karaj, Iran. The seeds were cleaned manually to remove extra matters, along with broken and immature seeds. The initial moisture content of sunflower seeds were determined using the standard hot air oven drying method at temperature of 130°C for 18 h [27]. The desired moisture levels were obtained by adding certain amount of distilled water to the samples and sealed in polyethylene bags. The samples were placed in a refrigerator for one week to have uniform moisture distribution throughout samples. The required seed quantity was taken out of the refrigerator and allowed to equilibrate at room temperature before each test [40]. All the physical and mechanical properties measurements were taken at room temperature of about 24^{o}C.

To determine the seed and kernel size, 100 seeds were randomly selected following a similar method to that employed by Dutta et al. [11]. The dimensional properties of the sunflower seeds and kernels were measured at moisture content of 5.9%. For each seed and its kernel, the three principal axial dimensions namely length, width and thickness were measured using a vernier caliper with an accuracy of 0.01 mm. Mass of the seeds and kernels were measured using a balance with an accuracy of 0.01 g.

The geometric mean diameter, D_g, and sphericity, φ, of seeds was calculated by using the following equations [4, 16, 27]:

$$D_g = (L \times W \times T)^{1/3} \quad (1)$$

$$\varphi = \left[\frac{(L \times W \times T)^{1/3}}{L} \right] \times 100 \quad (2)$$

Where *L* is the length, *W* is the width and *T* is the thickness all in mm.
The surface area, S, was found by the following equation given by McCabe et al.[25]:

$$S = \pi \times D_g^2 \quad (3)$$

The projected area of the seeds and kernels, A_P, was determined by the equation given by Gupta et al. [13]:

$$A_p = \left(\frac{\pi}{4}\right) L \times W \quad (4)$$

The volume, V, of the seeds and kernels in mm^3 were determined by the following equation given by Ozarslan [34] and Abalone et al. [1]:

$$V = \frac{\pi}{6} D_g^3 \quad (5)$$

The shape parameters (flakiness ratio, Fr, and elongation ratio, Er) of each single sunflower seed and kernel were determined using the following equations [28]:

$$Fr = \frac{T}{W} \quad (6)$$

$$Er = \frac{L}{W} \quad (7)$$

The true density was determined using the pycnometer and toluene displacement method [38, 40]. The bulk density was determined using a container of a known volume. The container was weighed, filled with seeds and weighed. The bulk density was calculated as the mass of seed divided by the container volume. The porosity, ε, was then calculated using the equation given by Mohsenin [27]:

$$\varepsilon = \frac{\rho_t - \rho_b}{\rho_t} \times 100 \quad (8)$$

Where ρ_b is the bulk density and ρ_t is the true density.
Angle of repose was obtained using a constructed box with removable front panel. The box was filled with seeds and the front panel was quickly removed. This allowed the seeds to flow to their natural slope. The static coefficient of friction of seed on galvanized sheet and mild steel was determined using the inclined plane method [30, 40].

Shape, size, volume, density, porosity are important are important factors associated with design of a specific machine or analysis of the behavior of the product in handling of the material. The porosity is often needed in air flow and heat studies as well as other applications. Bulk and true density of agricultural products play an important role in drying and storage, design of silos and storage bins, separation from undesirable materials, and grading systems [27].

Quasi-static compression tests were performed with an Instron Testing Machine (Model HOUNSFIELD-H5KS). The average rupture force, deformation and energy absorbed at rupture point of the sunflower seeds under compression are examined over a range of moisture contents between 1.8 and 20.3% (w.b.) under two loading orientations. Knowledge of fracture characteristics of both the seed under compressive loading becomes imperative for the rational design of an efficient dehulling system as well as the optimization of the process and product parameters [14].

An impact device designed by Khazaei et al. [20] was used for determination of impact damage of the seeds (Fig. 1). The device has a seed holding disk that rotates horizontally and a plane including four radial impact arms with vertical rotation. The seeds were placed manually over the seed- supporting pedestals, made of flexible plastic tubes, in desired orientation and the seeds were impacted by the steel tip at the edge of the impact arm. The effects of impact velocity at 40.8, 50 and 62.3 m/s and impact orientation in vertical and horizontal situations were studied on percentage of physical damage to sunflower seeds in moisture content at 3, 8, 15, and 20% (w.b.).

To determine the effect of orientation of loading (or impact) on rupture (or damage), the seeds were positioned vertically (Fig. 2a), with the major axis of the seed in line with the direction of loading and horizontally, with the major axis perpendicular to the direction of loading (Fig. 2b).

The resistance to impact, among other mechanical and physical properties, play a very important role in the design of threshers, dehullers, equipment for loading and unloading, storage structures, harvesting machines, drying equipment, conveyors, spouting and free-fall dropping equipment because during operations in this equipment, grains are subjected to impact between seeds and other metallic, wooden and plastic surfaces which may result in mechanical damage [5].

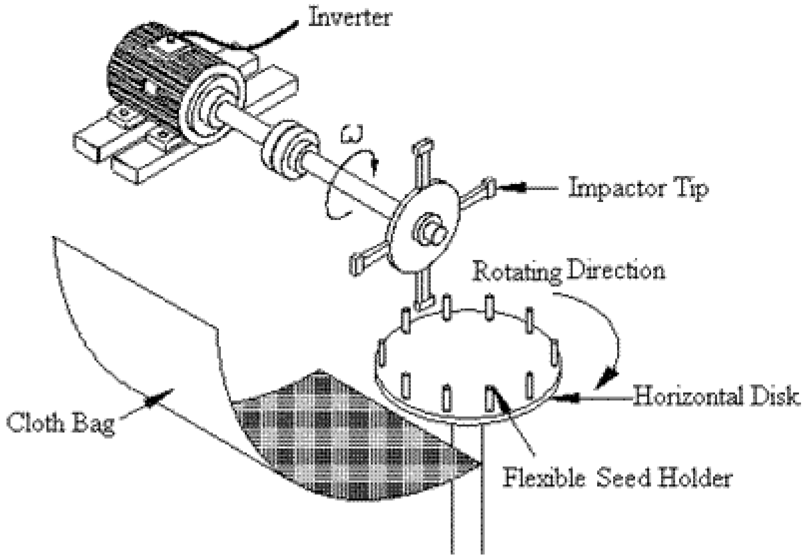

Fig. 1. Impact device (Khazaei et al., 2007)

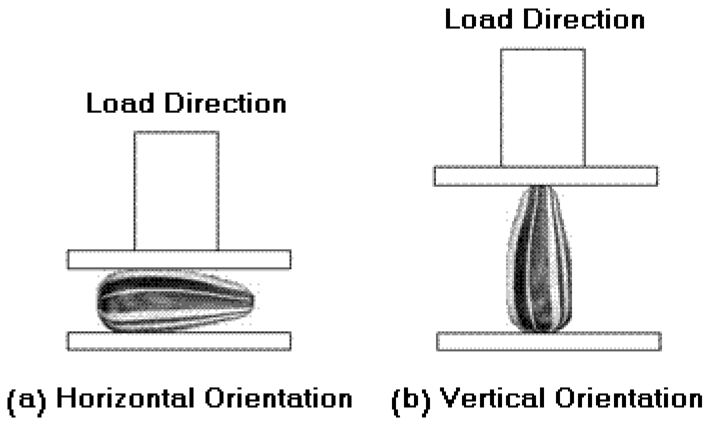

Fig. 2. Quasi-static compression test of sunflower seed and kernel under different orientations of loading

RESULTS AND DISCUSION

The dimensional properties of apricot pits and kernels are given in Table 1. The frequency distribution curves for the length, width and thickness are shown in Fig. 3 for seeds and in Fig.4 for kernels. Figure 5 shows the frequency distribution curves for the mass of the seeds and kernels. These figures show that the frequency distribution curves for all mentioned dimensions are approximately normally distributed. The following equations can be used to describe the relationship between mean values of length, width, thickness and mass of the sunflower seeds (indicated by the lower case *s*) with those for sunflower kernels (indicated by the lower case *k*)

$$m_K= 0.52m_S, \quad L_K=0.59L_S, \quad W_K=0.62W_S, \quad T_K =0.62T_S, \quad Dg_K=0.84Dg_S \tag{9}$$

The above parameters would be an important consideration in development of seed and kernel sizing and grading machines, and for separation from undesirable materials [30].

The mean value of length, width, thickness, and mass of the sunflower seeds and kernels, used in this study, were much higher than those reported by Gupta and Das [16] and Khazaei et al. [21], while the sphericity values reported by Gupta and Das [16] and Khazaei et al. [21] for the sunflower seeds and kernels were in the higher ranges compared with those of this study.

Low flakiness and high elongation ratios in Table 1 indicate that the tendency of the sunflower seeds and kernels to being flat oblong in shape. However, with a high elongation ratio, the sunflower seeds and kernels are more likely to slide than to roll. This could also be found from the sphericity data in Table 1. This data could be important information for designing of hopper, separator and conveyer equipments.

Table 1. Some engineering properties of sunflower seed and kernel at 6.3% moisture content (w.b.)

parameter	seed				kernel			
	mean	Min.	Max.	Std.	mean	Min.	Max.	Std.
Length, mm	22.80	14.32	31.00	3.30	13.66	9.81	17.99	1.42
Width, mm	7.06	4.73	9.82	1.025	4.42	2.49	5.94	0.63
Thickness, mm	3.98	2.36	6.67	0.75	2.49	0.79	3.63	0.43
Mass, g	0.15	0.04	0.26	0.05	0.08	0.01	0.14	0.02
Dg, mm	8.58	5.74	10.63	1.104	5.29	3.24	6.47	0.57
Sphericity, %	37.91	29.98	53.79	3.82	38.86	24.43	45.74	3.14
S, mm^2	235.20	103.5	354.9	58.222	89.06	32.97	131.46	18.095
Ap, mm^2	127.62	53.17	216.18	30.981	47.78	24.04	70.82	10.022
V, mm^3	347.10	99.05	628.90	124.82	80.29	17.81	141.77	23.444
Fr=T/W	0.57	0.34	0.99	0.09087	0.57	0.24	1.09	0.12197
Er=L/W	3.26	2.03	4.94	0.48337	3.18	2.39	4.08	0.42813

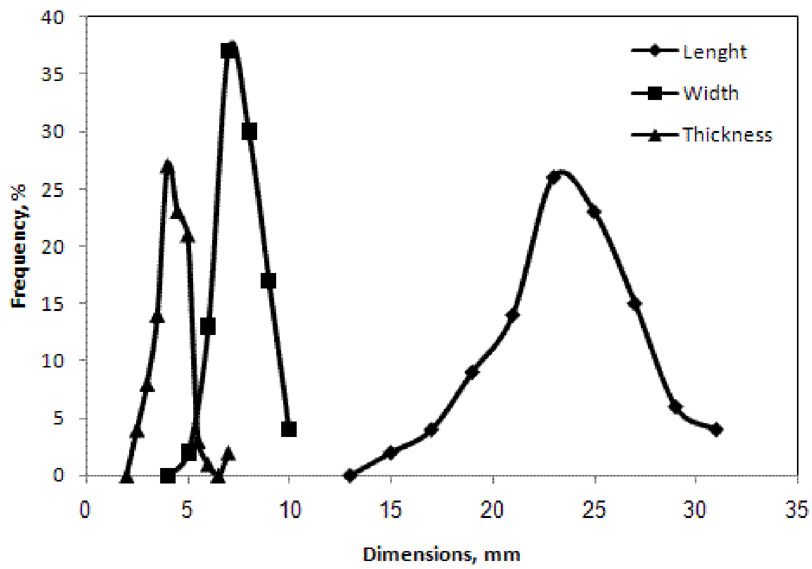

Fig. 3. Frequency curves for the length, width, and thickness of sunflower seeds at 6.3% (w.b.) moisture content

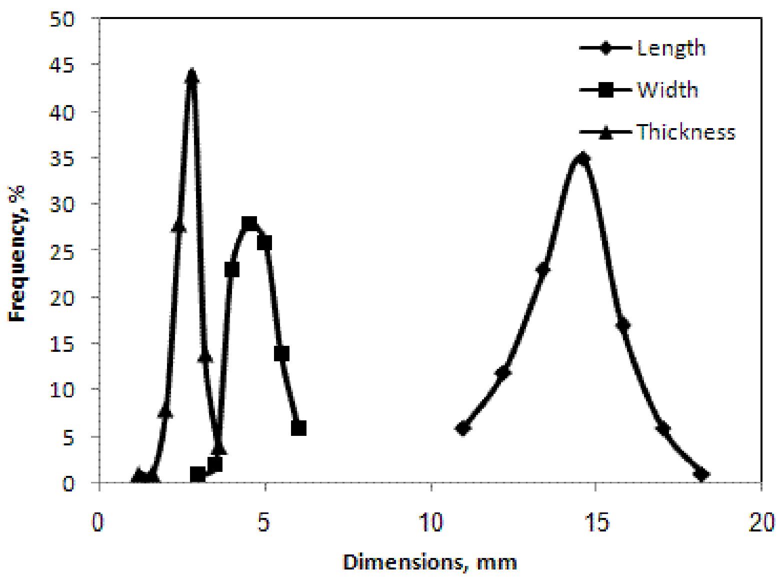

Fig. 4. Frequency curves for the length, width, and tickness of sunflower kernels at 6.3% (w.b.) moisture content

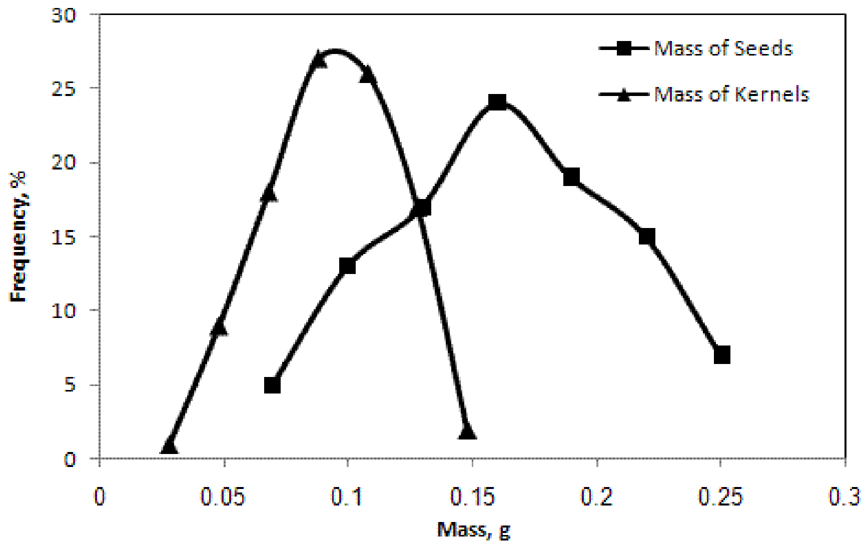

Fig. 5. Frequency curves for mass of sunflower seeds and kernels at 6.3% (w.b.) moisture content

The thousand seed mass of sunflower seeds at different moisture contents are presented in Fig. 6. The mass of thousand seed were appeared to be dependent on moisture content and increased linearly with increase in moisture content. The following regression equations were developed for both mass of thousand seed and kernel at the moisture range of 6.3 to 20% (w.b.).

$$m_{1000S} = 1.334 * M + 140 \quad (10)$$

$$m_{1000K} = 0.454 * M + 79.47 \quad (11)$$

Which M is moisture content, in % w.b.

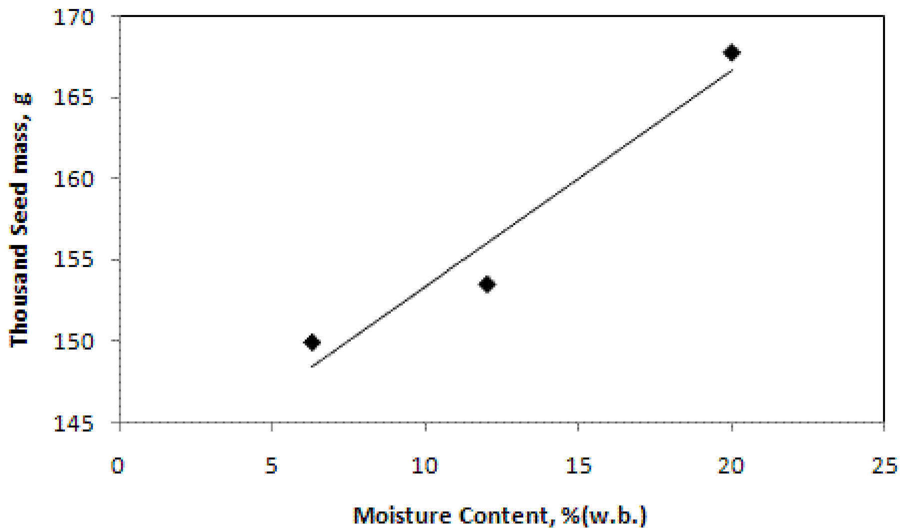

Fig. 6. Effect of moisture content on thousand seed mass

The effect of moisture content of the seeds on bulk density and true density are given in Fig. 7. The true density increased from 444.39 to 521.78 kg/m^3 when the moisture content increased from 5% to 20% (w.b.). This increase may be due to the increase in volume because of absorption of moisture (Kingsly et al., 2006). The bulk density decreased slightly with increase of moisture content and the relationship is shown in Eq.12:

$$\rho_b = 0.438 * M + 266.3 \quad (12)$$

The same trend has also been reported by Khazaei et al. [21] and Gupta and Das [16] for other sunflower seed varieties and by Ogut [31], Milani et al. [26] and Desphande et al. [10] for lupin seeds, cucurbit seeds, and soybean, respectively. However, when the moisture content increased, the bulk density values increased in coffee seeds [8], in pumpkin seeds [18] and in karingda seeds [42]. These changes conclude from the structural properties of the grains [12].

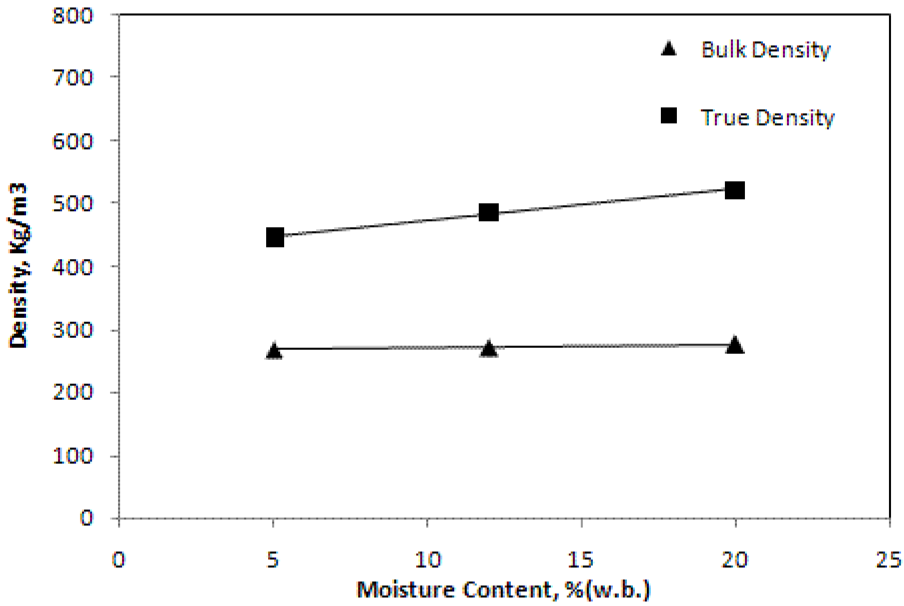

Fig. 7. Effect of moisture content on true and bulk density of sunflower seeds

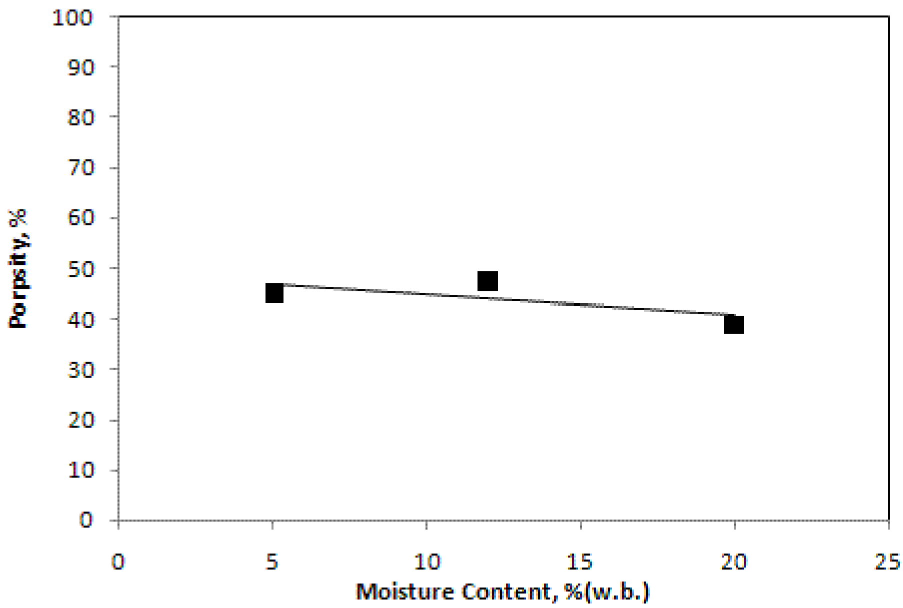

Fig. 8. Sunflower seeds as a function of moisture content – porosity

The porosity (ε) calculated from relevant experimental data increased from 37.99 to 48.43% when moisture content increased from 5 to 20% (w.b.) (Fig. 8). The form of the plot was similar to those for other sunflower seed varieties were observed by Khazaei et al. [21] and Gupta and Das [16]. Also the researches of Peker [36] for corn, Milani et al. [26] for cucurbit seeds, Carman [7] for lentil and Ogut [31] for lupin showed the porosity value increase with increase of moisture content.

The angle of repose of sunflower seed at different moisture contents are shown in Fig. 9. It increased from 15.69° to 38.83° at moisture range of 8–20% (w.b.). The angle of repose was higher than that of reported by Khazaei et al. [21] and Gupta and Das [16] for other sunflower seed varieties. This may be due to the rough surface or shape factor of this variety that imposes resistance to the seeds in sliding on one another [16].

The experimental results showing the effect of moisture content and structural surfaces on the static coefficient of friction are given in Fig. 10. It was found that for sunflower seed the static coefficient of friction increased with increase in the corresponding moisture content of 5-20% (w.b.) against both mild and galvanized steel sheets. This is due to the increased adhesion between the seed and material surfaces at higher moisture values [17]. These values for galvanized sheet were slightly higher than for mild steel. This may be due to the smoother surface of mild steel compared with galvanized sheet[16]. Gupta and Das [16], Joshi et al. [18], Khazaei et al. [21]; Gezer et al. [12] and Isik and Unal [17] stated that the coefficient of static friction increased when the moisture content increased.

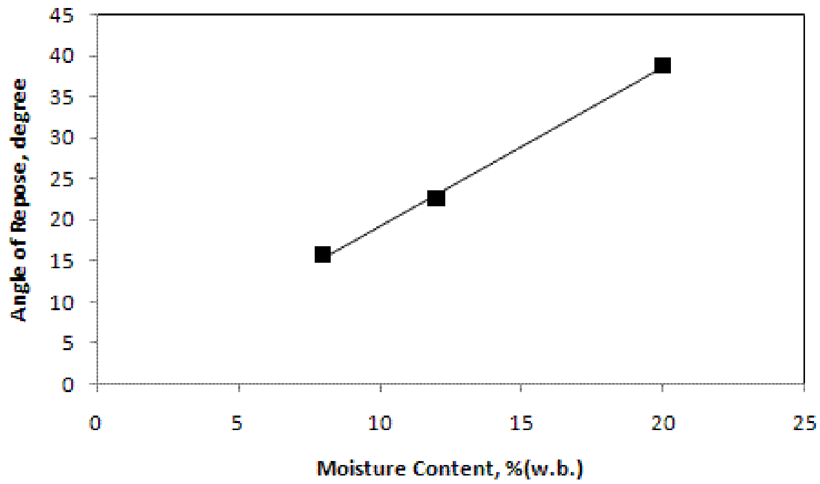

Fig. 9. Angle of repose for sunflower seeds as a function of moisture content

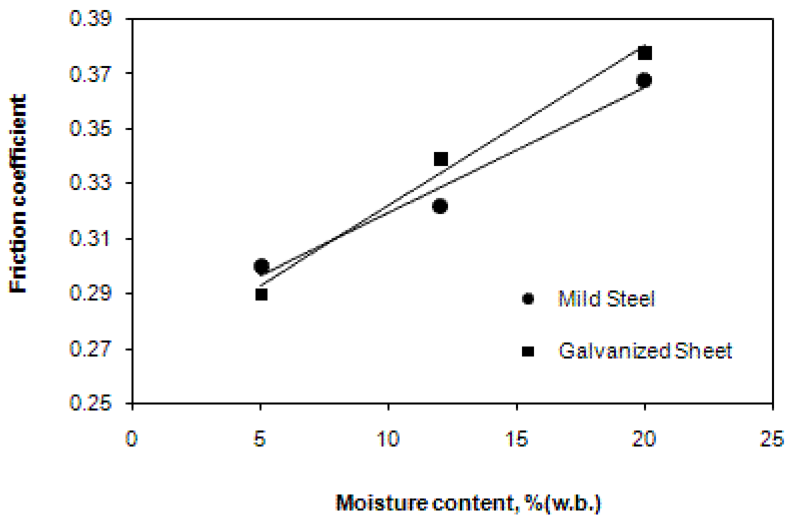

Fig. 10. Static coefficient of friction of sunflower seeds on mild steel and galvanized sheet as a function of moisture content

The force required to initiate seed rupture increased in the vertical and horizontal orientations when the moisture content increased from 1.8 to 14.5% (w.b.), while for a further increase in moisture content from 14.5 to 20.3%, the rupture force decreased (Fig. 11). Similar trends were also observed by Makanjuola [24] for melon seeds. When seeds are dried to reduce the moisture content, the outer coating (hull) becomes hard and brittle [29] so the hull resistance decreases. Figure 11 shows also that sunflower seeds loaded in the horizontal orientation require substantially less force in comparison to those loaded in the vertical orientation for all moisture contents of seeds.

Figure 12 shows that the deformation at rupture point increased at higher moisture content of the seeds. Values of deformation for sunflower seed, loaded in the horizontal orientation were always higher than for those loaded in vertical orientation in the entire range of moisture content. This shows that fracture for sunflower seed, loaded in the horizontal orientation occurs in lower deformation than for those loaded in vertical orientation. These results are consistent with those of Gupta and Das [14]. Similar trends in variation of deformation with moisture content under compressive loading were also observed for melon seed [24], soybean [35], African nutmeg [6] and pumpkin seeds [18].

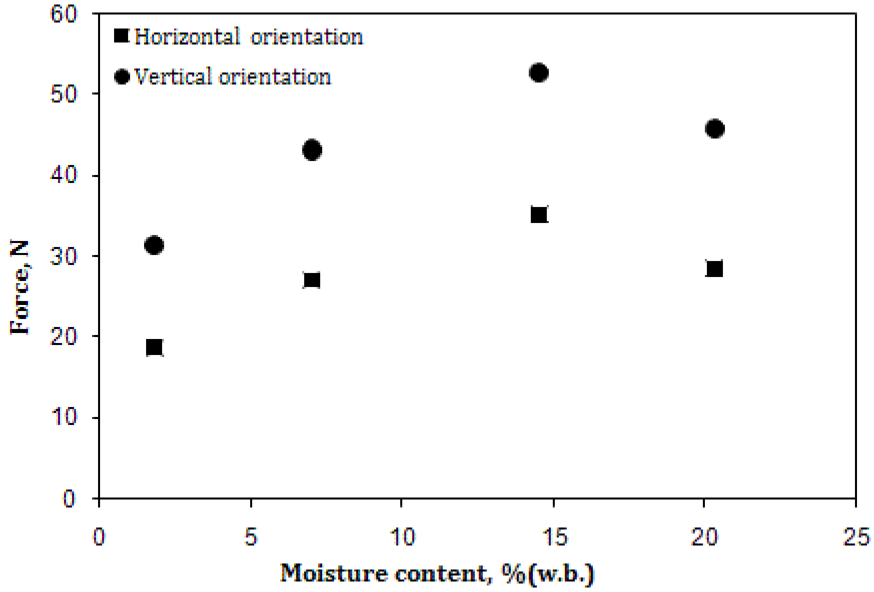

Fig. 11. Fracture force of sunflower seed at various moisture content under horizontal and vertical loading orientations

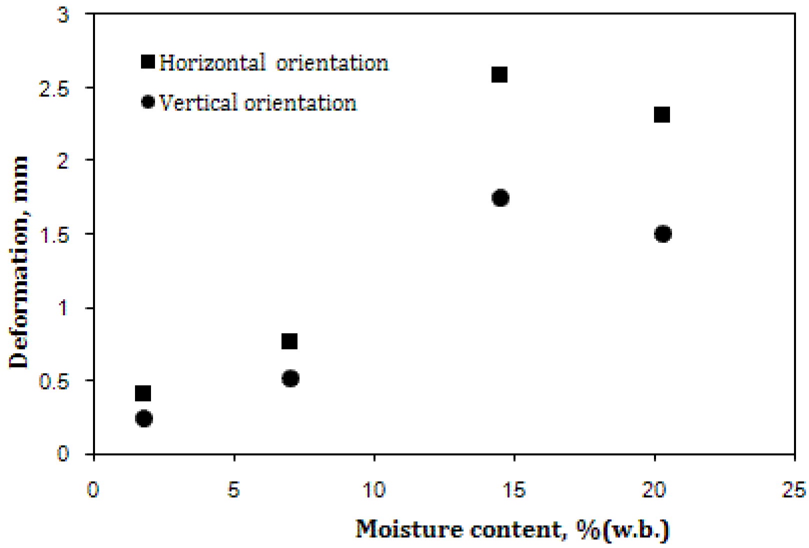

Fig. 12. Deformation at rupture of sunflower seed at various moisture contents under horizontal and vertical loading orientations

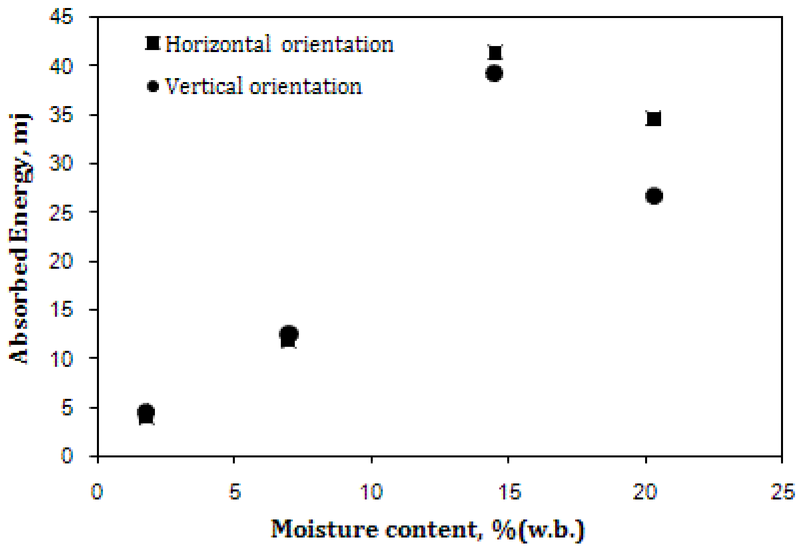

Fig. 13. Effect of moisture content on absorbed energy at rupture for sunflower seed under horizontal and vertical loading orientations

In both horizontal and vertical loading orientations, the absorbed energy at rupture increased when the moisture content increased. For a further increase in moisture content, the absorbed energy at rupture decreased, but the effect of sunflower seed orientation was insignificant at the absorbed energy (Fig. 13). So, assuming that the behavior for impact loading is the same as in the quasi-static loading used in these experiments, the chances of dehulling would be similar in horizontal and vertical loading orientations.

Effect of impact velocity and orientation on damaged seeds at different moisture content is show in Fig. 14. The percentage of total damaged seeds that include cracked seeds, broken seeds (intact kernels) and chipped kernels decreased with increase in moisture content because at low moisture level, the sunflower seeds are brittle, which makes them susceptible to mechanical damage [3]. Oluwole et al. [32] have also found that a decrease in moisture content causes an increase of the brittleness of the bambara ground nuts. Khazaei et al. [21] have reported that moisture content of chickpeas was a major factor in controlling the damage.

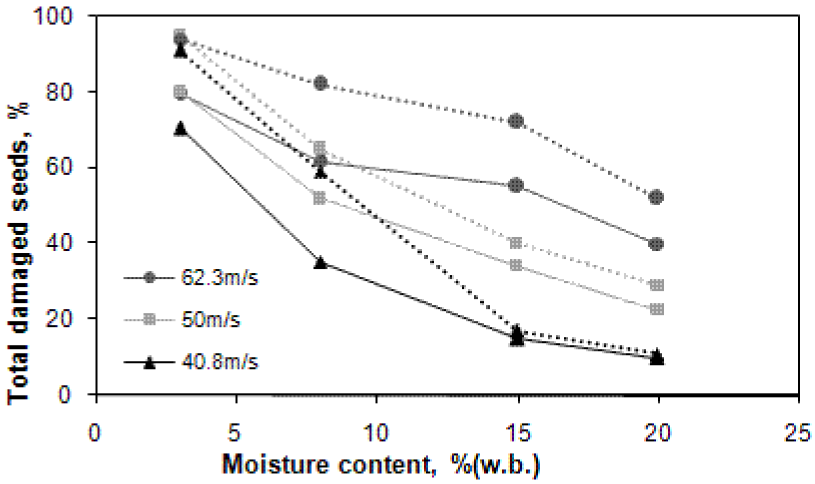

Fig. 14. Effect of moisture content on damaged seeds in different impact velocities and horizontal (- - -) and vertical (——) impact orientations

The percentage of total damaged seeds decreased with decrease in impact velocity. The higher amount of damaged seeds at higher impact velocity was possibly due to inducing a larger impact and shear force on the seeds by impactor tips of device [15, 41]. Similar findings are reported by Lashgari et al. [23] and Atiku et al. [3] for mechanical damage of wheat and bambara ground nut, respectively.

Figure 14 shows also that in all impact velocities and moisture content of the seeds, the vertical orientation (impact on top of seeds) resulted a higher average of cracked seeds, broken seeds and chipped kernels than the horizontal orientation (impact on side of seeds).

CONCLUSION

This study confirmed that the properties of sunflower seeds and kernels are a function of the moisture content. The thousand grain mass, true density, friction coefficient, and the angle of repose increase approximately linearly with increase in moisture content within the range of 6.3 to 20% (w.b.), while the bulk density decrease approximately linearly with increase in moisture content within the same range of moisture content. The percentage of the damaged seeds increased with decreasing in moisture content of the seeds at all impact velocity levels. The percentage of total damaged seeds was greater in the vertical than the horizontal impact orientation at all moisture content levels of the seeds.

REFERENCES

1. Abalone R., Cassinera A., Gaston A., Lara M. A., 2004. Some Physical Properties of Amaranth Seeds. Biosystems Eng. 89, 1, 109–117.
2. Aktas T., Polat R., Atay U., 2007. Comparison of mechanical properties of some selected almod cultivars with hard and soft shell under compression loading. J. Food Proc. Eng. 30, 773–789.
3. Atiku A.A., Aviara N.A., Haque M.A., 2004. Performance evaluation of a bambara ground nut sheller. Agricultural Engineering International, the CIGR Journal of Scientific Research and Development. Manuscript PM 04 002, 6, July 2004.
4. Aydin C., 2003. Physical properties of almond nut and kernel. J. Food Eng. 60, 315–320.
5. Baryeh E.A., Mangope., 2002. Physical properties of QP-38 variety pigeon pea. J. Food Eng. 51, 39–46.
6. Burubai W., Akor A.J., Igoni A.H., Puyate Y.T. 2007. Effects of temperature and moisture content on the strength properties of African nutmeg (Monodora myristica). Int. Agroph. 21, 217–223.

7. Carman K., 1996. Physical properties of lentil seeds. J. Agric. Eng. Res. 63, 87–92.
8. Chandrasekar V., Viswanathan R., 1999. Physical and thermal properties of coffee. J. Agric. Eng. Res. 73, 2, 227–234.
9. Clandinin D.R., 1958. Processed Protein Foodstuffs. New York: Academic Press.
10. Deshpande S.D., Bal S., Ojha T.P., 1993. Physical properties of soya bean. J. Agric. Eng. Res. 56, 89–98.
11. Dutta S.K., Nema V.K., Bhardwaj R.K., 1988. Physical properties of gram. J. Agric. Eng. Res. 39, 269–275.
12. Gezer I., Haciseferogullari H., Demir F., 2002. Some physical properties of Hacihaliloglu apricot pit and kernel. J. Food Eng. 56, 49–57.
13. Gupta R.K., Gopika A., Sharma R., 2006. Aerodynamic properties of sunflower seed (Helianthus annuus L.). J. Food Eng. 79, 3, 899–904.
14. Gupta R.K., Das S.K., 2000. Fracture resistance of sunflower seed and kernel to compressive Loading. J. Food Eng. 46, 1–8.
15. Gupta R.K., Das S.K., 1999. Performance of centrifugal dehulling system for sunflower seeds. J. Food Eng. 42, 191–198.
16. Gupta R.K., Das S.K., 1997. Physical properties of sunflower seeds. J. Food Eng. 66, 1–8.
17. Isik E., Unal H., 2007. Moisture-dependent physical properties of white speckled red kidney bean grains. J. Food Eng. 82, 209–216.
18. Joshi D.C., Das S.K., Mukherjee R.K., 1993. Physical properties of pumpkin seed. J. Agric. Eng. Res. 54, 219–229.
19. Kachru R.P., Rai D.R., 1993. Physical constituents and some engineering properties of peanut pods. J. Oilseeds Res.10, 145–153.
20. Khazaei J., Lotfi A., Aminnayeri M., Zaki M., 2007. Modelling the mechanical damage to lentil seeds under impact loading. Lucari Stiintifice, Vol. 49, Seria Agronomie.
21. Khazaei J., Sarmadi M., Behzad J., 2006. Physical properties of sunflower seeds and kernels ralated to harvesting and dehulling. Lucrari Stiintifice, Vol. 49, Seria Agronomie.
22. Kingsly A.R.P., Singh D.B., Manikantan M.R., Jain R.K., 2006. Moisture dependent physical properties of driepomegranate seeds (Anardana). J. Food Eng. 75, 492–496.
23. Lashgari M., Mobli H., Omid M., Alimardani R., Mohtasebi S., 2006. Mechanical damage to wheat during combines harvesting. Proceedings of the international conference on Innovations in Food and Bioprocess Technologies, 12–14 December 2006, AIT, Pathumthani, Thailand.
24. Makanjuola G.A., 1972. A study of some of the physical properties of melon seeds. J. Agric.l Eng. Res. 17, 128–137.
25. McCabe W.L., Smith J.C., Harriott P., 1986. Unit operations of chemical engineering. McGraw-Hill Book Co, New York.
26. Milani E., Razavi S.M.A., Koocheki A., Nikzadeh V., Vahedi N., MoeinFard M., GholamhosseinPour A., 2007. Moisture dependent physical properties of cucurbit seeds. Int. Agroph. 21, 157–168.
27. Mohsenin N.N., 1986. Physical Properties of Plant and Animal Materials. Gordon and Breach Sci. Publ., New York.
28. Mora C.F., Kwan A.K.H., 2000. Sphericity, shape factor, and convexity measurement of coarse aggregate for concrete using digital image processing. Cement and Concrete Research, Vol. 30, 351–358.
29. Nag K.N., Singh P.R., Bhandari., 1983. Agricultural mechanization in Asia, Africa and Latin America. Vol. 14, Nov. 1983.
30. Ogunjimi L.A.O., Aviara N.A., Aregbesola O.A., 2002. Some engineering properties of locust bean seed. J. Food Eng. 55, 95–99.
31. Ogut H., 1998. Some physical properties of white lupin. J. Agric. Eng. Res. 69, 237–277.
32. Oluwole F.A., Abdulrahim1 A.T., Olalere R.K., 2007. Effect of moisture content on crackability of bambara groundnut using a centrifugal cracker. Int. Agroph. 21, 179–184.
33. Omobuwajo T.O., Akande E.A., Sanni L.A., 1999. Selected physical, mechanical and aerodynamic properties of African breadfruit (Treculia africana) seeds. J. Food Eng. 40, 241–246.
34. Ozarslan C., 2002. Physical properties of cotton seed. Biosystems Eng., 83, 2, 169–174.
35. Paulsen M.R., 1978. Fracture resistance of soybeans to compressive loading. Trans. of the ASAE, 21, 6, 1210–1216.
36. Peker A., 1996. The determination of some physical properties of corn kernel. Selcuk Univ. J. Agric. Faculty, 10, 12, 22–65 [in Turkish].
37. Razavi S.M.A., Milani E., 2006. Some physical properties of the watermelon seeds. African J. Agric. Res. 1, 3, 65–69.
38. Sahay K.M., Singh K.K., 1994. Unit operations in agricultural processing. Vikas Publishing House Pvt Ltd, New Delhi.
39. Sharma R., Sogi D.S., Saxena D.C., 2009. Dehulling performance and textural characteristics of unshelled and shelled sunflower (Helianthus annuus L.) seeds. J. Food Eng. 92, 1, 1–7.
40. Singh K.K., Goswami T.K., 1996. Physical properties of cumin seed. J. Agric. Eng. Res. 64, 93–98.
41. Subramanian R., Sassuy M.C.S., Venkateshmurthy K., 1990. Impact dehulling of sunflower seeds. J. Food Eng. 12, 83–94.
42. Suthar S.H., Das S.K., 1996. Some physical properties of karingda seeds. J. Agric. Eng. Res. 65, 15–22.

Sahebeh Jafari, Javad Khazaei, Akbar Arabhosseini, Jafar Massah,
Department of Agrotechnology,
College of Abouraihan, University of Tehran, Tehran, Iran
e-mail: sayeh1898@gmail.com

Mohammad Hadi Khoshtaghaza
Department of Agricultural Technical Engineering,
University of Tarbiat Modarres, Tehran, Iran

Accepted for print: 24.01.2011