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EFFECTS OF SOME PARAMETERS ON FRACTURE RESISTANCE OF SUNFLOWER SEED

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ABSTRACT. The fracture resistance of sunflower seeds (*Helianthus annuus* L.) was measured in terms of average compressive force, deformation and energy absorbed at rupture. Sunflower seeds with moisture contents varying from 1.8 to 20.3% (wet basis) were loaded in vertical and horizontal orientations between two parallel rigid plates. The average compressive forces required to cause seed rupture were 43.36 N for the vertical and 27.37 N for horizontal orientations of loading. Deformation and the energy absorbed at rupture point of the seeds increased in magnitude with an increase in moisture content for loading in both vertical and horizontal orientations. The results provide useful information for engineers to design suitable sunflower seed dehuller machine.

Keywords: Sunflower seed; Fracture resistance; Compressive force; Deformation; Loading orientation.

INTRODUCTION

Sunflower (*Helianthus annuus* L.) seed is considered to be an important oilseed because it contains large quantity of highly nutritious oil (Gupta and Das, 2000). The dehulled seeds also have widely been consumed in salads and bakery products (Khazaei *et al.* 2006).

During harvesting, handling and storage operations, the seeds go through several static and dynamic pressures such as high speed impacts which cause bruises, crushes and cracks that increase the susceptibility of deterioration during storage (Correa *et al.,* 2007).

Knowledge of fracture characteristics of the seed under compressive loading becomes

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necessary for the rational design of an efficient dehulling system as well as optimizations of the process and product parameters (Gupta and Das, 2000). Information on the fracture characteristics of many agricultural seeds is available, but very little is known about the sunflower seed or its kernel.

Fracture characteristics of an oilseed, soybean, were first reported by Bilanski (1966). Gupta and Das (2000) evaluated the mechanical behavior of sunflower seeds and they found out that the rupture force was reduced and the deformation increased by raising the moisture content from 3.8 to 16.6% (w.b.). Makanjuola (1972) measured the bending properties of melon seed as a function of moisture content and orientation of loading. Joshi (1993) determined the rupture failure of pumpkin seed and its kernel at various moisture contents and loading orientations.

The objective of this study is to document the fracture resistance of sunflower seed to compressive loading, considering moisture content and loading orientation. 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 and loading orientations.

MATERIALS AND METHODS

The Shamshiri variety 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 contents of sunflower seeds were determined using the standard hot air oven drying method at temperature of 130°C for 18 h (Mohsenin, 1986).

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 to room temperature before each test (Tunde-Akintunde, 2007). All the physical properties measurements were taken at room temperature of 24^{o}C.

Quasi-static compression tests were performed with an Instron Testing Machine (Model HOUNSFIELD-H5KS). Each individual seed was placed on the moving platform at 1mm/min speed (Paolsen, 1978; Gupta and Das, 2000) and pressed with a plate fixed on the load cell, which had a capacity of 500N until the hull of the seed ruptured. The rupture point was determined from the force-deformation curve, where there is a sudden drop in force. As soon as the rupture point was detected, the loading was stopped. To determine the effect of orientation of loading on rupture, the seeds were positioned vertically, 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. Similar loading orientations were used by Olaniyan and Oje (2002) for sheanut, by Gupta and Das (1998) for sunflower seed, and by Vursavus and Ozguven (2005) for pine nut.

The seeds were tested at four levels of moisture content between 1.8% and 20.3% w.b. under both the loading orientations. At each conditions five seeds were tested which gives a total of 40 seeds for all tests. The energy absorbed by the sample at rupture was directly read from the instrument.

RESULTS AND DISCUSSION

Force-deformation characteristics exhibited by sunflower seeds at moisture content of 1.8% (w.b) under compressive loading in two orientations are shown in *Fig. 1*. For all moisture contents and loading orientations, the compressive force on the seed hull increased with an increase in deformation. There was a decrease in the force after rupture occurred in the specimen and this point was denoted as the fracture point. However, with further increase in deformation, the force applied to the specimen increased, but the force-deformation curve was no longer smooth and became highly undulated. The force beyond the fracture point was not considered as it essentially represented the force required to crush the specimen after rupture had occurred. In most cases, rupture could be easily observed because the hull of the seed split along the sutures under both the loading orientations.

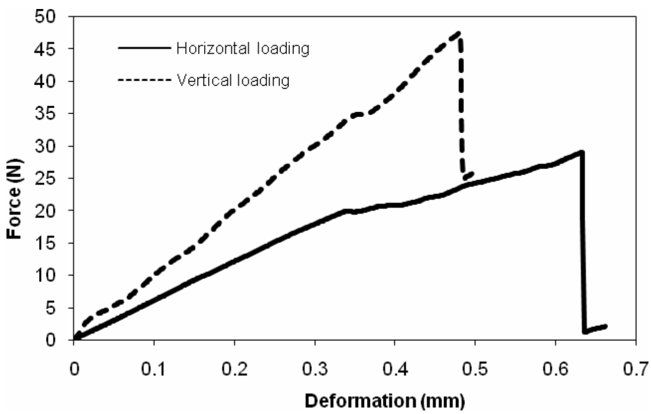

Figure 1 - Force-deformation characteristics for sunflower seed at moisture content of 1.8% (w.b) deformed at 1.0 mm/min under different loading orientations

The analysis of variance of the data *(Table 1)* indicated that moisture content and loading orientation and interaction between them significantly affect the rupture force, deformation and energy absorbed at rupture at 1% level of significance.

Table 2 gives the mean and standard deviations for rupture force, deformation, and absorbed energy by the sample for rupture at different moisture contents and orientations of loading by applying the Duncan Multiple Range Test (DMRT) at 1% level of significance. 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%. Oluwole *et al*. (2007) have also found that a decrease in moisture content appeared to increase the brittleness of the bambara ground nuts.

Table 1- Analysis of variance showing the effect of moisture content on rupture force, deformation and absorbed energy for sunflower seed

Variable	df	MS		
		F_{max}	D_{max}	E_{max}
M	**3**	608.617**	8.415**	2.739**
D	**1**	2557.920**	2.710**	$0.049^{n.s}$
M*D	**3**	$11.816^{n.s}$	0.324*	$0.040^{n.s}$
Error	**32**	63.885	0.096	0.049

** Significant at 1% level; * Significant at 5% level; $^{n.s}$ Non- significant.
M: Moisture content, D: Deformation

Table 2 - The multiple Duncan's comparison of means for rupture force, deformation and energy absorbed at various moisture contents

Moisture content (w.b%)	Force (N)		Deformation (mm)		Absorbed Energy ($\times 10^{-3}$J)	
	Horizontal	Vertical	Horizontal	Vertical	Horizontal	Vertical
%1.8	18.696^{e} (1.421)	31.560^{bcde} (12.983)	0.4070^{c} (0.160)	0.2370^{c} (0.066)	3.9^{c} (1.2)	4.4^{c} (3.0)
%7	27.074^{de} (6.107)	43.254^{abc} (10.703)	0.7596^{c} (0.153)	0.5090^{c} (0.149)	11.6^{c} (3.3)	12.4^{c} (4.6)
%14.5	35.212^{bcd} (6.851)	52.780^{a} (3.513)	2.5944^{a} (0.597)	1.7470^{b} (0.442)	41.3^{a} (8.3)	39.1^{ab} (13.5)
%20.3	28.488^{cde} (7.363)	45.850^{ab} (8.666)	2.3182^{a} (0.225)	1.5038^{b} (0.305)	34.5^{ab} (9.4)	26.5^{b} (3.8)

Means followed by the same letter are not significantly different at P<0.05**.** The numbers in parentheses are standard deviation values.

Rupture force. The force required to initiate seed rupture increased significantly (probability P<0.01) 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. 2)*. Similar trends were also observed by Makanjuola (1972) for melon seeds. When seeds are dried to reduce the moisture content, the outer coating (hull) becomes hard and brittle so the hull resistance decreases.

Relationship between the various dependent parameters (rupture force, deformation and absorbed energy) at rupture (y) and the moisture content (m%, w.b.) of the sunflower seed are expressed by Eq. (1):

$$y = a_0 + a_1 m + a_2 m^2 \qquad (1)$$

Table 3 gives the parameters of these second order equation.

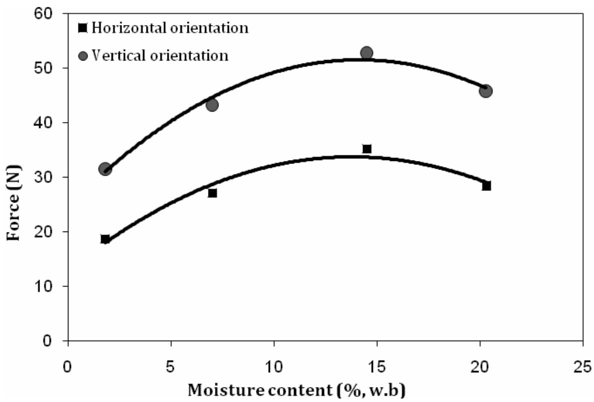

Figure 2 - Fracture force of sunflower seed at various moisture content under horizontal and vertical loading orientations and the regression models described in Table 3

Table 3 - Relationship between the various dependent parameters at rupture (y) and the moisture content (m%,w.b.) of the sunflower seed

Parameters Y	Coefficients	Orientation of loading	
		Horizontal	Vertical
Rupture force (N)	a_2	-0.109	-0.135
	a_1	3.021	3.816
	a_0	12.921	24.540
	r^2	0.958	0.982
Deformation (mm)	a_2	-0.005	-0.004
	a_1	0.240	0.175
	a_0	-0.203	-0.197
	r^2	0.872	0.869
Energy absorbed (mJ)	a_2	-0.116	-0.156
	a_1	4.540	4.974
	a_0	-7.039	-7.225
	r^2	0.875	0.824

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. The required loads to have initiate rapture of sunflower seeds in the vertical and horizontal orientation were 31.6 and 18.7N at moisture contents of 1.8% w.b. and 45.9 and 28.5N at moisture content of 20.3% w.b. These results revealed that sunflower seed required less compressive force to dehull when loaded under the horizontal compared to the vertical orientation. Similar trends were also observed by Bilanski (1966) for soybean, Makanjuola (1972) for melon seed and Joshi (1993) for pumpkin seed. Since an externally applied force creates shear stresses in internal tissues causing rupture of the cotyledon, and because there is a definite cellular arrangement in the cotyledon tissues, a greater or smaller force may be required to cause rupture depending on the direction of the applied force (Gupta and Das, 2000).

Deformation of seed at rupture. Deformation of the seeds as a function of moisture content and orientation of loading is shown in *Fig. 3*. Deformation at rupture point increased at higher moisture content of the seeds. However, the differences among deformation values of sunflower seeds at the moisture content of 14.5% and 20.3% was found to be statistically insignificant for both loading orientations.

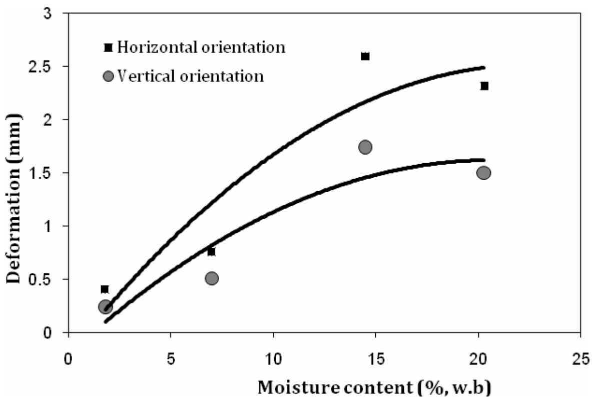

Figure 3 - Deformation at rupture of sunflower seed at various moisture contents under horizontal and vertical loading orientations and the regression models described in Table 3

At lower moisture contents, the seed hull is fragile and its rupture would be initiated at small deformations irrespective of the orientation of the applied compressive load. These results are consistent with those of Gupta and Das (2000). Similar trends in variation of deformation with moisture content under compressive loading were also observed for melon seed (Makanjuola, 1972), African nutmeg (Burubai et *al*., 2007) and pumpkin seeds (Joshi, 1993).

According to Duncan's multiple range tests, the deformation values for sunflower seed loaded in the horizontal orientation were always higher than for those loaded in vertical orientation for the entire range of moisture content *(Table 2)*. This shows that fracture for sunflower seed loaded in the horizontal orientation occurs in lower deformation than for those loaded in vertical orientation.

Absorbed energy. 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 *(Fig. 4)*. The analysis of variance indicated that the effect of sunflower seed orientation was insignificant at the absorbed energy (*Table 2*). 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. However Gupta and Das (2000) reported that dehulling would be greater when there is a higher probability that the seed receives an impact or compressive load in the horizontal direction.

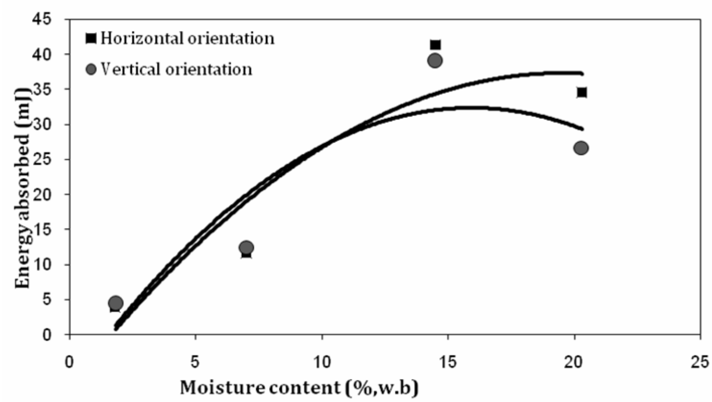

Figure 4 - Effect of moisture content on absorbed energy at rupture for sunflower seed under horizontal and vertical loading orientations and the regression models described in Table 3

Fig. 4 shows also that a higher percentage of sunflower seeds will be dehulled, with lower consumption of energy, when the seeds are low in moisture content in appropriate dehulling equipment. These results are consistent with those of the other researchers; Burubai *et al.* (2007) reported that the African nutmeg seeds had an average strain energy value of 0.0201 mJ at 8% moisture content, but increased to 0.0341 mJ at 28.7% moisture content. Bilanski (1966) have also found that the absorbed energy for fracture of corn seeds was increased 1.2 times with increasing of the moisture content from 8% to 17%.

CONCLUSIONS

The force required to initiate seed rupture increased significantly (probability $P<0.01$) 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.

Deformation at rupture point increased at higher moisture content of the seeds. However, the differences among deformation values of sunflower seeds at the moisture content of 14.5% and 20.3% was found to be statistically insignificant for both 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. The analysis of variance indicated that the effect of sunflower seed orientation was insignificant at the absorbed energy

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