

Compression loading behaviour of sunflower seeds and kernels

Thasaiya A. Selvam¹, Musuvadi R. Manikantan^{2*}, Tarsem Chand¹, Rajiv Sharma²,
and Thirupathi Seerangurayar³

¹Department of Processing and Food Engineering, Punjab Agricultural University, Ludhiana-141004, Punjab, India

²Food Grains and Oilseeds Processing Division, Central Institute of Post Harvest Engineering and Technology (CIPHET),
Ludhiana-141004, Punjab, India

³Agricultural Machinery Research Centre, Tamil Nadu Agricultural University, Coimbatore-641003, Tamil Nadu, India

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Abstract. The present study was carried out to investigate the compression loading behaviour of five Indian sunflower varieties (NIRMAL-196, NIRMAL-303, CO-2, KBSH-41, and PSH-996) under four different moisture levels (6-18% d.b). The initial cracking force, mean rupture force, and rupture energy were measured as a function of moisture content. The observed results showed that the initial cracking force decreased linearly with an increase in moisture content for all varieties. The mean rupture force also decreased linearly with an increase in moisture content. However, the rupture energy was found to be increasing linearly for seed and kernel with moisture content. NIRMAL-196 and PSH-996 had maximum and minimum values of all the attributes studied for both seed and kernel, respectively. The values of all the studied attributes were higher for seed than kernel of all the varieties at all moisture levels. There was a significant effect of moisture and variety on compression loading behaviour.

Keywords: sunflower seed, compression loading, rupture energy, moisture content

INTRODUCTION

Sunflower (*Helianthus annuus* L) is one of the major oilseed crops used for oil production (90%) and fresh consumption (10%). The oil extracted from sunflower seeds is a good source of vegetable oil for cooking and manufacturing of margarine, paints, soaps, and cosmetics (Bamgboye and Adejumo, 2007). Its use as biodiesel, or as vegetable-oil based fuel for many vehicles, including farming equipment is feasible (Antolin *et al.*, 2002). In India, oil is mostly obtained by mechanical expression from sunflower seeds. However, this process suffers from certain drawbacks. The presence of a high percentage of hull in the seed (varies between 20 and 30% depending on the variety and is main-

ly full of crude fiber and unimportant quantity of fat) not only causes rapid wear of the moving parts of the expeller but also reduces the total oil yield, transfers pigments from the hull to the extracted oils, and yields cakes of lower food value (Khodabakhshian *et al.*, 2010). In order to design an efficient dehulling system and equipment for mechanical expression of oil and other processes, fracture characteristics of sunflower seed and kernel are essential at different moisture levels under compressive loading.

Many researchers have studied the mechanical properties of various agricultural materials such as corn seed (Babic *et al.*, 2013), soybean (Bargale *et al.*, 1999), white sesame seed (Darvishi, 2012), and maize (Barnwal *et al.*, 2012). Joshi (1993) observed that the force required to initiate seed coat rupture of pumpkin seed increased as moisture content increased from 5.1 to 10.5% d.b., beyond which it steadily decreased up to a moisture content of 21.7% d.b. It was also reported that deformation occurring at seed coat or kernel rupture increased as seed moisture content increased from 5.1 to 21.7% d.b. and it was substantially greater for the seed loaded in the vertical orientation than the horizontal one. Energy absorbed by the seed and kernel increased in both horizontal and vertical orientations of loading as the moisture content increased to 15% d.b. Beyond this moisture content, the energy absorbed declined. Kang *et al.* (1995) reported that mean values of bio-yield strain and energy to bio-yield of wheat decreased as the moisture content increased at a loading rate of 1 to 250 mm min⁻¹. Owolarafe *et al.* (2005) studied the average cracking force, and average pressure required for cracking of fresh palm

*Corresponding author e-mail: maniciphet@gmail.com

fruit are 2301 N and 5.79 N mm⁻², respectively. Baumler *et al.* (2006) studied the compression behaviour of safflower seed under quasi-static compressive loading at six levels of moisture content varying from 3.7 to 15.6% d.b. The samples were tested in horizontal and vertical orientations. It was observed that the force required for hull rupture decreased as the moisture content increased, and it attained a minimum value at 11% d.b. The energy absorbed at rupture per unit volume of seeds for the horizontal position was always higher than that for the vertical one.

Sunflower oil is mostly obtained by mechanical expression from sunflower seeds, the process mainly consists of flaking and crushing which is related to the external forces on each seed between the crushing surfaces. Considering a varietal effect dependency on moisture content, no detailed published literature was found according to authors best of knowledge. However, Gupta and Das (2000) studied fracture resistance characteristics of the Morden sunflower variety with two different orientations. It was found that rupture force decreased from 59.12 to 35.26 N for seed and from 13.59 to 8.50 N for the kernel, respectively. The deformation and energy absorbed at rupture increased for both seed and kernel under horizontal and vertical orientations. Khodabakhshian *et al.* (2010) investigated mechanical properties of Iranian sunflower seed under quasi-static loading. It was observed that rupture force for both seed and kernel decreased with increasing moisture content from 3 to 14% even as the absorbed energy and deformation at rupture increased for all sizes (small, medium and large) in both horizontal and vertical loading orientations.

Thus keeping in view, the major objective of this study was to investigate the compression loading behaviour of five widely cultivated Indian sunflower hybrids at different moisture content. The initial cracking force, mean rupture force, and rupture energy of the sunflower seeds as well as kernels under compression loading were examined over a range of moisture content 6-18% d.b.

MATERIALS AND METHODS

Five varieties of widely cultivated Indian sunflower hybrids having high seed yield, high oil content, low hull content and tolerance to diseases, namely PSH-996, NIRMAL-196, NIRMAL-303, KBSH-41, and CO-2 were obtained from different regions in India during July 2012. The seeds were cleaned and graded using an appropriate set of sieves in a cleaner and grader developed by the Central Institute of Agricultural Engineering (CIAE, India) to remove foreign matter as well as broken and immature seed. To obtain whole kernel, the seeds were dehulled using an impact-type sunflower dehuller (CIPHET, India). The mean initial moisture content of the seed and kernel was determined by the standard hot air oven method with the temperature settings of 130±1°C for three hours (ASAE, 1999). The initial average moisture content of the whole seed

as well as kernel varied from 5.6 to 7.3 and 4.8 to 6.7% d.b., respectively. The experimental moisture of the samples (6, 10, 14 and 18% d.b.) was chosen according to the prevailing processing practices and obtained with either adding or removing water using the expression followed by Khodabakhshian *et al.* (2010).

The conditioned samples were sealed in low density polyethylene bags of 90 µm thickness and kept in a refrigerator at 4°C for one week for uniform distribution of moisture throughout the sample. Before starting the experiment, a required quantity of the sample was taken out from the refrigerator and allowed to equilibrate with room temperature for two hours (Singh and Goswami, 1996).

Compression loading tests such as initial cracking force, mean rupture force and rupture energy were performed with a Texture Analyzer (TA-HDi., Stable micro systems). The conditioned samples were visually inspected and randomly selected prior to testing, and those with visible immature seeds were discarded. Each individual seed or kernel was kept in natural rest position under the test probe and it was compressed at the pre-set condition until rupture occurred as is denoted by a bio-yield point (Sukumaran and Singh, 1989). The condition-set up in the texture analyzer for measuring compression test were: pre-test speed – 1.0; test speed – 2; post-test speed – 5 mm s⁻¹; test distance – 5 mm; trigger type – auto; trigger force – 0.10 N; load cell – 50 kg; stainless steel cylinder probe – 5 mm diameter. A graph was drawn between the force resisted by the test material and time. From the graph, the initial peak position was considered as initial cracking of the test material and the force related to this initial peak position was considered as initial cracking force. The mean force experienced by the test material from zero to the test distance is considered as mean rupture force and the area under this curve is known as rupture energy.

The experiments were conducted with three replications for each moisture level and variety, and the mean values are reported. The effect of variety and moisture content on compression loading behaviour of both sunflower seeds and kernels was investigated using analysis of variance (ANOVA) at 5% significance with the help of SPSS 20.0 software.

RESULTS AND DISCUSSION

The variation of initial cracking force of sunflower seed and kernel with standard error at 5% significance at different moisture contents are given in Fig. 1a,b, respectively. The force required to initiate rupture of sunflower seed as well as kernel for each variety decreased as the moisture content increased from 6 to 18% d.b. The mean initial cracking force of NIRMAL-196, NIRMAL-303, CO-2, KBSH-41, and PSH-996 sunflower seed ranged from 75.05-59.14, 58.88-52.48, 52.15-48.93, 47.08-41.88, and 36.50-28.88 N, respectively. The values for kernels varied

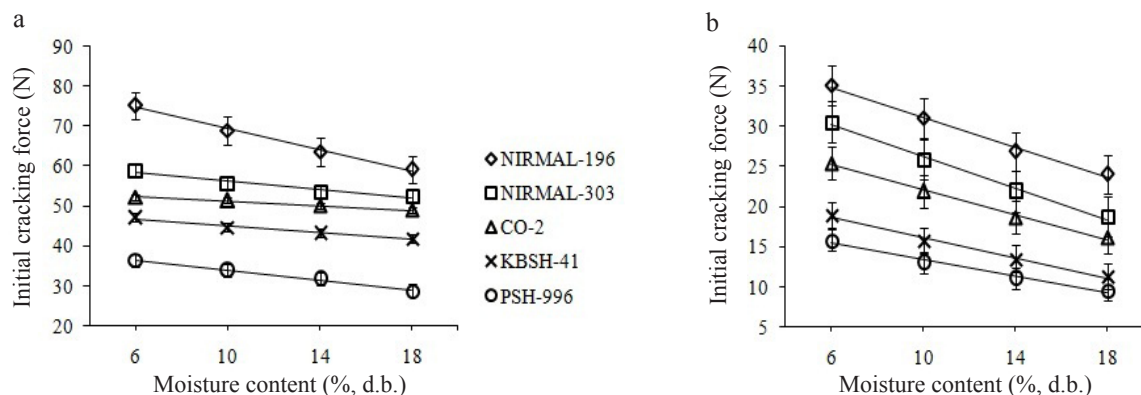


Fig. 1. Effect of moisture content on initial cracking force of sunflower: a – seed, b – kernel.

from 35.06-24.04, 30.54-18.77, 25.40-16.11, 18.91-11.28, and 15.77-9.57 N, respectively. This may be due to the fact that at higher moisture content, the seed became softer and required less force (Saiedirad *et al.*, 2008). Among all the studied varieties, the maximum force required to initiate the crack was exhibited by NIRMAL-196 for both seed and kernel followed by NIRMAL-303, CO-2, KBSH-41, and PSH-996. The trend of decreasing initial cracking force at higher moisture content might also be due to a gradual change in the integrity of the cellular matrix (Khodabakhshian *et al.*, 2010). Similar trends were also observed by Khodabakhshian and Shakeri (2012) for safflower, Gupta and Das (2000) for the 'Morden' variety of sunflower, and Darvishi (2012) for white sesame seed. The effect of moisture and variety on initial cracking force for sunflower seed and kernel was also studied using ANOVA and it is shown in Table 1. The moisture content and variety significantly influenced the initial cracking force ($p < 0.05$) for both seed and kernel. The interaction of moisture content and variety was also found to have a significant effect on initial cracking force. The regression equations and their respective coefficients of determination (R^2) for the measured initial cracking force of seed and kernel as a function of moisture content are presented in Table 2. As the coefficient of determination (R^2) was adequately high, it seems that the moisture content had a remarkable influence on the measured parameters.

The mean rupture force of sunflower seed and kernel of the different varieties with standard error at 5% significance at different moisture contents are presented in Fig. 2a, b, respectively. For all the varieties, the mean rupture force decreased linearly with the increase in moisture content. The mean rupture force of NIRMAL-196, NIRMAL-303, CO-2, KBSH-41, and PSH-996 sunflower seed ranged from 138.54-110.15, 109.48-89.49, 106.91-85.86, 98.13-76.46, and 82.88-67.92 N, respectively. Similarly, the mean rupture force for kernel decreased from 72.95-58.90, 66.22-44.21, 60.19-37.88, 56.85-29.28, and 54.06-19.44 N, respectively. The experimental results showed that NIRMAL-196 and

PSH-996 had maximum and minimum values of mean rupture force for both seed kernel respectively. While comparing the values of mean rupture force, the values for seed were always found higher than those for kernel. A similar trend was observed by Bargale *et al.* (1995) for canola and wheat. Table 1 summarized the analysis of variance which was carried out to investigate the effect of moisture content and variety on mean rupture force for sunflower seed as well as kernel. From the tables, it was observed that the changes in variety and moisture content influenced significantly the mean rupture force of seed and kernel ($p < 0.05$). Regression equations and their coefficients of determination (R^2) obtained for the mean rupture force of sunflower seed and kernel are presented as a function of variety and moisture content in Table 2. These equations and coefficients confirm a linear behaviour for all the varieties.

The variations of rupture energy as a function of moisture content and variety for sunflower seed and kernel with standard error at 5% significance are shown in Fig. 3a, b, respectively. The rupture energy for all five varieties of sunflower seed and kernel increased linearly with moisture content. The rupture energy of NIRMAL-196, NIRMAL-303, CO-2, KBSH-41, and PSH-996 sunflower seed increased from 27.98-56.59, 25.40-52.94, 23.60-48.76, 19.15-46.22, and 16.97-43.37 N mm, respectively. In turn, the values for kernel varied from 17.16-27.73, 14.71-24.65, 12.97-22.01, 9.79-18.44, and 6.18-11.95 N mm, respectively. Among all the studied varieties, the least rupture energy for both seed and kernel was obtained for PSH-996, with 16.97 and 6.18 N mm, respectively. On the other hand, NIRMAL-196 had the highest rupture energy for both seed and kernel, with 56.59 and 27.73 N mm, respectively. Similar to the mean rupture force, the rupture energy was also observed higher in the case of seed as compared to kernel at each level of moisture content. The increasing trend may be due to the fact that rupture energy is a function of both force and deformation up to bio-yield point (Mohsenin, 1986). At low moisture content, the seed requires high force to be ruptured and its deformation was low but at high moisture content,

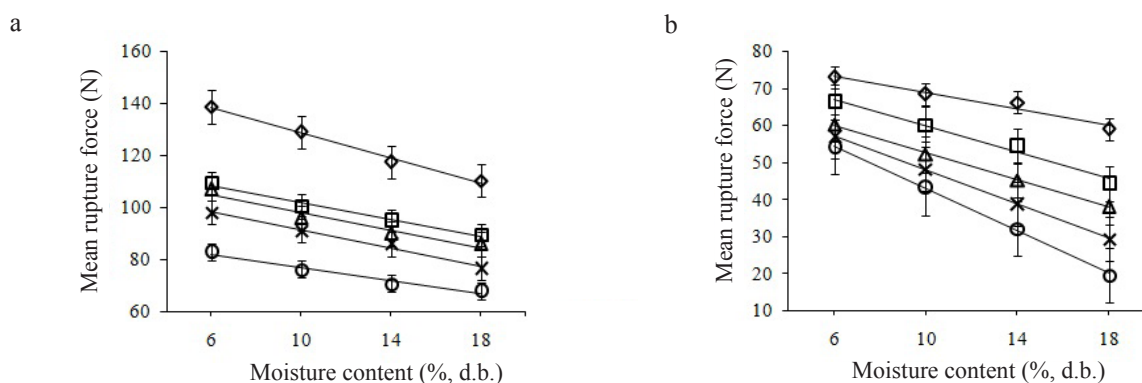
Table 1. ANOVA to study the effect of variety and moisture content on compression loading behaviour of sunflower seed and kernel

Parameters	Source	Sum of squares	Degrees of freedom	Mean square	F _{Calculated}
Sunflower seed					
Initial cracking force (N)	Moisture content	490.177	3	163.392	27.401*
	Variety	7620.223	4	1905.056	319.484*
	Moisture content x variety	162.537	12	13.545	2.271*
	Error	238.517	40	5.963	
	Total	157817.658	60		
Mean rupture force (N)	Moisture content	3753.177	3	1251.059	377.952*
	Variety	15736.000	4	3934.000	1188.484*
	Moisture content x variety	214.217	12	17.851	5.393 ¹
	Error	132.404	40	3.310	
	Total	571232.347	60		
Rupture energy (N mm)	Moisture content	6088.893	3	2029.631	1229.273*
	Variety	803.850	4	200.962	121.716*
	Moisture content x variety	41.038	12	3.420	2.071*
	Error	66.043	40	1.651	
	Total	82723.848	60		
Sunflower kernel					
Initial cracking force (N)	Moisture content	709.880	3	236.627	273.539*
	Variety	2259.749	4	564.937	653.064*
	Moisture content x variety	38.275	12	3.190	3.687*
	Error	34.602	40	0.865	
	Total	27628.036	60		
Mean rupture force (N)	Moisture content	4753.510	3	1584.503	171.699*
	Variety	6292.394	4	1573.099	170.463*
	Moisture content x variety	428.788	12	35.732	3.872*
	Error	369.135	40	9.228	
	Total	164358.155	60		
Rupture energy (N mm)	Moisture content	647.475	3	215.825	268.964*
	Variety	1234.470	4	308.618	384.604*
	Moisture content x variety	25.210	12	2.101	2.618*
	Error	32.097	40	0.802	
	Total	18052.564	60		

Moisture content x variety – interaction of moisture content and variety. *Significant at $p \leq 0.05$.

Table 2. Regression equations and coefficient of determination (R^2) for compression loading behaviour of sunflower seed and kernel as a function of moisture content (M, % d.b.)

Parameters	Variety	Sunflower seed		Sunflower kernel	
		Regression equation	R^2	Regression equation	R^2
Initial cracking force (N)	NIRMAL-196	$-5.304 M + 79.91$	0.994	$-3.719 M + 38.53$	0.993
	NIRMAL-303	$-2.134 M + 60.52$	0.959	$-3.926 M + 34.06$	0.991
	CO-2	$-1.098 M + 53.34$	0.993	$-3.114 M + 28.29$	0.994
	KBSH-41	$-1.707 M + 48.47$	0.978	$-2.512 M + 21.14$	0.991
	PSH-996	$-2.501 M + 39.02$	0.997	$-2.051 M + 17.48$	0.981
Mean rupture force (N)	NIRMAL-196	$-9.664 M + 147.9$	0.993	$-4.443 M + 77.68$	0.958
	NIRMAL-303	$-6.577 M + 115.1$	0.986	$-7.188 M + 74.22$	0.979
	CO-2	$-6.919 M + 111.9$	0.948	$-7.375 M + 67.26$	0.998
	KBSH-41	$-7.014 M + 105.3$	0.987	$-9.232 M + 66.32$	0.999
	PSH-996	$-5.045 M + 87.04$	0.970	$-11.5 M + 65.930$	0.998
Rupture energy (N mm)	NIRMAL-196	$9.451 M + 17.08$	0.977	$3.488 M + 13.56$	0.997
	NIRMAL-303	$9.138 M + 15.15$	0.986	$3.335 M + 10.88$	0.984
	CO-2	$8.446 M + 14.74$	0.998	$3.061 M + 9.679$	0.995
	KBSH-41	$9.086 M + 9.771$	0.999	$2.880 M + 6.818$	0.999
	PSH-996	$8.855 M + 8.427$	0.998	$1.904 M + 4.310$	0.999

**Fig. 2.** Effect of moisture content on mean rupture force of sunflower: a – seed, b – kernel. Legends as in Fig. 1.

the rupture force was low and the deformation was high (Khodabakhshain *et al.*, 2010). The increasing trend of rupture energy with an increase in moisture content was also documented for some other seeds, such as safflower and white sesame seed by Khodabakhshian and Shakeri (2012), and Darvishi (2012), respectively. The results of statistical analysis indicated that moisture content and variety had a significant effect on rupture energy for both

seed and kernel at $p < 0.05$ (Table 1). Similarly, the interaction of moisture content and variety also had a significant effect on rupture energy ($p < 0.05$) for both seed and kernel. The regression equations and their respective coefficients of determination (R^2) for the measured rupture energy of seed and kernel as a function of moisture content are presented in Table 2.

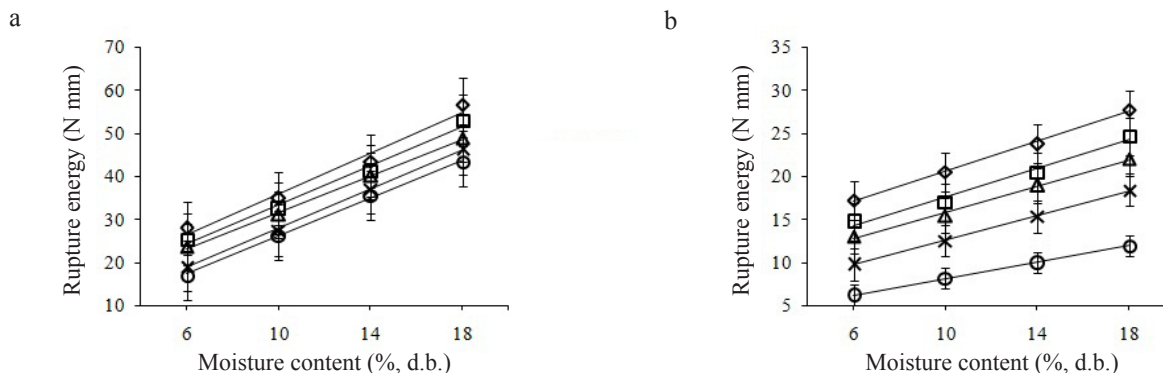


Fig. 3. Effect of moisture content on rupture energy of sunflower: a – seed, b – kernel. Legends as in Fig. 1.

CONCLUSIONS

1. Initial cracking force of sunflower seed and kernel decreased with an increase in moisture content for all the studied varieties, NIRMAL-196 had a maximum initial cracking force for both seed and kernel.

2. The mean rupture force also linearly decreased with an increase in moisture content from 6-18% d.b. Among all the varieties studied, NIRMAL-196 and PSH-996 had maximum and minimum values for both seed and kernel, respectively.

3. The rupture energy for both seed and kernel increased linearly with moisture content. Moreover, rupture energy of kernel was lower than that of seed for all the varieties in the whole range of moisture content.

4. Among the studied varieties, NIRMAL-196 had the highest rupture energy for both seed and kernel, with 56.59 and 27.73 N mm, respectively.

5. Changes in moisture content and varieties of five Indian sunflower seed and kernel exerted a significant effect on its compression loading behaviour. This study will be helpful to determine the force and energy required for dehulling and oil expression.

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