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Investigation on some mechanical aspects of safflower seed to the design of processing equipment

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In this research, mechanical aspects of whole safflower seed was measured in terms of seed rupture force, deformation, *modulus of elasticity* and rupture energy. Safflower seeds were *quasi-statically* loaded in vertical orientation with moisture contents in four levels: 4%, 8%, 14% and 20%; seed size in three levels: small, medium, and large; and two varieties: *Golshid* and *Afshan*. The results showed that the force required for initiating seed rupture decreased from 38.5 to 42.9 N and 36.87 to 40.8 N, while the rupture energy at seed rupture increased from 197.13 to 259.14 Jm^{-3} and 264.87 to 322.06 Jm^{-3} and seed deformation increased from 1.03 to 1.48 mm and 1.15 to 1.52 mm with increase in moisture content from 4% to 20% d.b., for *Golshid* and *Afshan*, respectively. The average *modulus of elasticity* of safflower seed from 106.13 to 90.35 Mpa and 77.85 to 65.90 Mpa were obtained for moisture levels ranging from 4 to 20%, for *Golshid* and *Afshan* varieties, respectively. Investigating effect of size revealed that all studied mechanical aspects of safflower seed increased as size of the seed increased from small to large.

Key words: Modulus of elasticity, Quasi-static loading, Rupture force, safflower seed.

Introduction

Knowledge of apparent elastic properties such as *Poisson's ratio* and elastic modulus of agricultural produce are important for the prediction of their load-deformation behavior. These elastic properties could be used to compare the relative strengths of different biomaterials and investigating these technological characteristics will contribute to the design of processing equipment (Mohsenin, 1986). Owing to the complex shape of most agricultural produce and their associated complex structure, the determination of a reliable elastic modulus presents a number of problems. For instance, one of the major problems for determination of the modulus of the elasticity of agricultural

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produce is that they display characteristic of both elastic solids and viscous liquid, so they are called *viscoelastic*. However, many researches have found that when the small loads are occurred in short times, these problems can be overcome, to a certain extent, using methods based on elasticity theory (Misra and Young, 1981; Balastreire *et al.*, 1982; Bargale and Irudayaraj, 1995; Khazaei, 2002; Burubai *et al.*, 2008; Kiani *et al.*, 2009).

Literature review which has been done by the authors indicates that many of studies have determined elastic modulus of agricultural produce from the force-deformation curves using the *Boussinesq* and *Hertz* theories (Mohsenin, 1986). Meanwhile, much of these studies result in widely varying values being obtained. Burubai *et al.* (2008) reported modulus of elasticity of African *nutmeg* as a function of moisture content and loading rate from an average value of 201.5 to 41.30 Pa, in view of this apparent variability, the techniques for performing axial compression tests on intact, convex-shaped agricultural produce which have been used in the past should be examined with a view to making recommendations to reduce this variability. As it can be found from literature review, despite of an extensive search on *elastic modulus* of agricultural produce, no published literature was found on the selection of the best method among methods existing in elasticity theory for determining of elastic modulus of agricultural produce. Hence, the object of this study was investigation the applicability of three different methods existing in elasticity theory namely *Hook's* theory, *Hertz* theory and *Boussinesq's* theory for evaluation of the modulus of elasticity of agricultural produce (Pumpkin seed as a case study). Selection the best theory to be able to explain well the behavior of agricultural produce (pumpkin seed as a case study) was also the other object of this study.

Materials and methods

Sample preparation

The samples selected from two major prevalent varieties in Iran namely *Golshid* and *Afshan*. These cultivars were obtained randomly from different regions of Khorasan Razavi province, Iran, in 2011 (Fig.1). Twenty kilograms seeds of each variety were randomly selected and transported to the laboratory of department of Agricultural Machinery Engineering of Ferdowsi university of Mashhad, Iran. At first, the seeds were manually cleaned to remove all foreign matters such as dust, dirt, stones, immature and broken seeds. Then initial moisture of the seeds was determined by using the standard hot air oven method with a temperature setting of 105 ± 1°C for 24 h. The initial moisture content of the seeds was found 7.9% and 8.2% d.b for *Golshid* and *Afshan*, respectively. According to Khodabakhshian *et al.* (2010), the seeds were sieved into three size categories (small, medium, and large) using 5.5, 6.5, and 8 mm square mesh sieves. All the mechanical aspects of the seeds were investigated for four moisture contents in the range of 4 to 20% (d.b.). To provide the seeds with the desired moisture contents, sub-samples of both seeds of each variety and size category (small, average and big), each weighing 0.5 kg, were drawn from the bulk of sample and dried (by putting them in the oven at 75°C for 2 h) or adding calculated quantity of water to the seeds (Gupta and Das, 2000). Finally, the sub-samples were kept in double-layered low-density polyethylene bags of 90 µm thickness, sealed and stored at low temperature (5°C in a refrigerator). Before starting the tests, the required quantities of seed and kernel was taken out of the refrigerator and allowed to be warmed to room temperature for approximately 2 h (Joshi *et al.*, 1993; Gupta and Das, 2000; Khodabakhshian *et al.*, 2010).

Fig. 1. Pictorial view of Iranian safflower seed.

Mechanical aspects measurement

An Instron Universal Testing Machine (Model H5KS, Tinius Olsen Company) equipped with a 5000 kg compression load cell and integrator was used for the compression test of the safflower seed. The accuracy of measurements for force and deformation was ±0.001 N and 0.001 mm, respectively. Individual seed was loaded between two parallel plates of the machine vertically (Fig. 2), compressed at the preset condition until rupture occurred as is denoted by a bio–yield point in the force–deformation curve. A typical obtained force–deformation curve is shown in Fig. 3. At a fixed crosshead speed of 2 mm/min, 24 series of tests (two varieties: *Golshid* and *Afshan*; moisture content in four levels: 4%, 8%, 14% and 20% and size category in three levels: small, average and big) were conducted. Data on the strength properties (force, deformation and modulus of elasticity) were automatically obtained from the integrator. Absorbed energy by the sample at the rupture point and sample deformation was directly read from the instrument. The absorbed energy was determined by calculating the area under the *force–deformation* curve up to rupture point.

Fig. 2. Universal test machine used in the compression test.

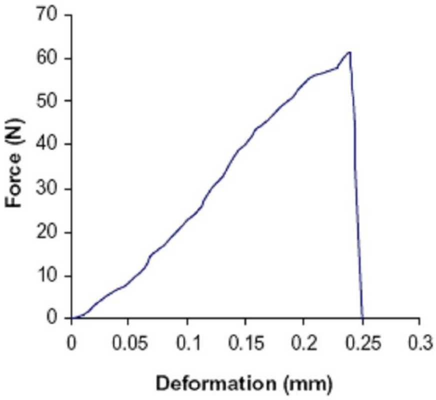

Fig. 3. Typical force – deformation Characteristics of safflower.

Statistical analysis

The experiments were conducted with four replications for each moisture contents, varieties and size categories, and the medium values reported. Average, minimum, maximum, standard deviations, correlation coefficients of dimensions and regression equations were computed using Microsoft Excel software (2003). The analysis of variance (ANOVA) was carried out on completely randomized design with factorial experiment using SPSS16 software. The F test was used to determine significant effects of each treatment, and significant differences of means were compared using the Duncan's multiple ranges test (LSD) at 5 % significant level.

Results and discussion

Modulus of elasticity

The variation trend of the *modulus of elasticity* over 96 test series was shown in Fig. 4. As it can be found from this figure, the *modulus of elasticity* of safflower seed had shown a decreasing trend as the moisture content increased from 4 to 20% d.b for all size categories and studied varieties. This could be owing to the fact that at higher moisture content, the seed became softer and demand less force. These conclusions is consistent with the findings of Kiani *et al.* (2009) and Burubai *et al.* (2008) who reported that *elastic modulus* of red bean and African nutmeg decreased linearly with the increase of moisture content, respectively. These results also agree with the results of Misra and Young (1981). They reported a functional relationship between the *modulus of elasticity* and moisture content of soybean. They reported that the *modulus of elasticity* decreased and approached a constant minimum, with the increase in moisture content of soybean. Among the studied varieties, *Golshid* had maximum *modulus of elasticity* for seed and the lowest range belonged to *Afshan* (Table 1). The differences in *modulus of elasticity* between the studied varieties could be the result of the individual cultivars properties and different environmental and growth conditions of cultivars. In agreement with these findins, Khodabakhsina *et al.* (2010) reported that variety has a significant influence on the mechanical properties of sunflower seed.

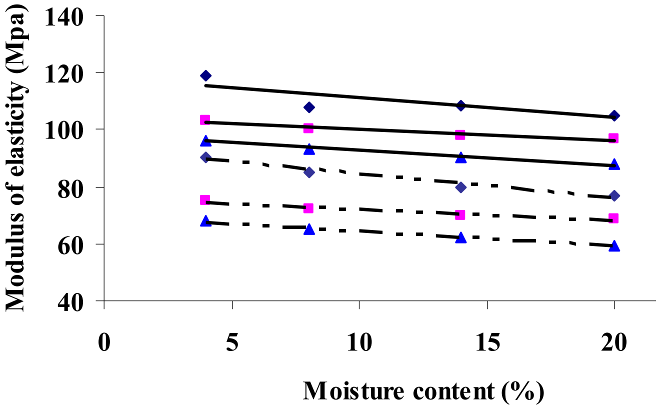

Fig. 4. Effect of moisture content, variety and size on modulus of elasticity of safflower seed (◊, large; □, medium; Δ, small; —, Golshid variety; - - -, Afshan variety).

It is apparent that either variation in size or variety (Table 1) had a significant effect on the *modulus of elasticity* of seed (p <0.95). The *modulus of elasticity* of seed increased as seed size increased so that the average *modulus of elasticity* of large seeds was about 1.19-fold of that of small ones for *Golshid* variety (This value for *Afshan* variety was around 1.3 times). This could be due to the fact that with increasing size, high contact area of the seed with the compressing plates results in the expansion of low stress. This is in agreement with the *Hertz theory* (Mohsenin, 1986) for compression test of food materials. This justification has been proved by Khodabakhsina *et al.* (2010) on engineering properties of sunflower seed and its kernel. The increasing trend of *elastic modulus* with increase of size was also observed for pea (Khazaei, 2002).

Table 1. Mean comparison of modulus of elasticity (Mpa) and rupture force (N) of safflower seed considering interaction effect of variety and size

Parameter	**Size**	**Variety**	
		Golshid	**Afshan**
Modulus of elasticity	Large	110.02 a	83.14 d
	Medium	99.68 b	71.4 e
	Small	91.93 c	63.65 f
Rupture force	Large	6.82 a	45 d
	Medium	34.05 b	32.05 e
	Small	22.7 c	21.05 f

The means with the same letter is not significant at 5% level according to Duncan's multiple ranges test

Rupture force

The force required for initiating seed rupture at different moisture content, variety and seed size is shown in Fig. 5. As it can be seen from this figure, the rupture force decreased with an increase in seed moisture content for each variety and size category. As given in this Fig, rupture force was 37.68 N at 4% moisture. This is significantly more than the force required to initiate seed rupture at 20% moisture (around 1.28 times). This may be due to the fact that at higher moisture content, the seed became softer and required less force (Khodabakhsina *et al*. (2010). This conclusion was consistent with the findings of Konak *et al*. (2002), who reported the highest rupture force of chick pea seeds was obtained as 210 N with a moisture content of 5.2% d.b. It was also stated that the seeds became more sensitive to cracking at higher moisture content; hence, they required less force to rupture. A similar decreasing trend of rupture force with moisture content has been reported by Joshi (1993), Gupta and Das (2000), Konak *et al*. (2002) and Saiedirad *et al*. (2008) for soybean, pumpkin seed, bean seeds, sunflower seed, chick pea seeds, faba bean grains and cumin seed, respectively.

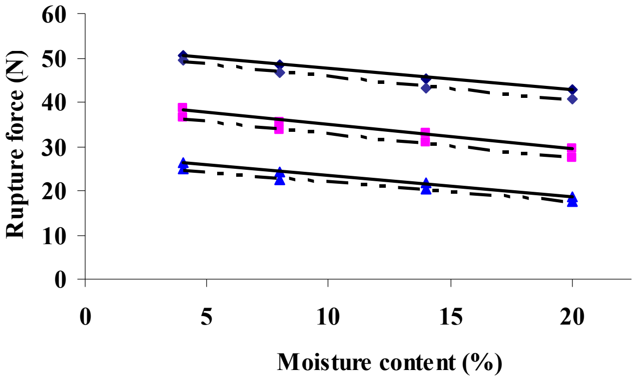

Fig. 5. Effect of moisture content, variety and size on rupture force of safflower seed (◊, large; □, medium; △, small; —, Golshid variety; - - -, Afshan variety).

The variation of rupture force for investigated varieties of safflower seed are shown in Table 1. According to this Table, the changes in variety influenced significantly the rupture force of seed (*p* <0.95). These differences in rupture force among studied varieties could be the result of the individual cultivars properties and different environmental and growth conditions of cultivars. No reported results for rupture force of safflower seed as a function of variety were found to compare with the results obtained in this study. However, in agreement with these results, Khodabakhsina *et al.* (2010) that variety has a significant influence on the mechanical properties of sunflower seed and its kernel. There was significant difference between small and large seed size (*p* <0.95) as shown in Table 1. The force required to initiate seed rupture increased as seed size increased so that the average rupture force of small seeds was about 2.06-fold of that of large ones for *Golshid* variety (This value for *Afshan* variety was around 2.13 times). This could be due to the fact that with increasing size, high contact area of the seed with the compressing plates results in the expansion of low stress. This is in agreement with the *Hertz theory* for compression test of food materials.

Deformation

Deformation of the seed at the bio-yield point as a function of moisture content, variety and size category is shown in Table 2. As given in this Table for all varieties and size categories of safflower seed, deformation occurring at hull rupture increased as the moisture content of the seed increased. This trend is attributed to the fact that at higher moistures, seeds become softened and tend to flatten easily under load and thus subjected to greater bruises (Gupta and Das, 2000). The similar trend was reported by Paulsen (1978) for soybean.

Similar trends in variation of deformation with moisture content under compressive loading were also observed for melon seed (Makanjuola, 1972); pumpkin seeds (Joshi, 1993); African nutmeg (Burubai *et al*., 2007) and cumin seed (Saiedirad *et al*., 2008). According to Table 2, the changes in variety influenced significantly the deformation of seed (p <0.95). As it can be found from this Table, the deformation of *Afshan* variety was about 1.10-fold of *Golshid* variety of safflower seed. As shown in Table 2, there was a significant difference among size categories on seed deformation. The most and least differences between size categories were found to be at 14% and 8% moisture contents for both studied varieties, respectively.

Table 2. Mean comparison of deformation (mm) of safflower seed considering interaction effect of moisture content, variety and size

Variety	Size	Moisture content (% d.b.)			
		4	8	14	20
Golshid	Large	1.18 a	1.245 d	1.38 g	1.479 j
	Medium	1.002 b	1.233 e	1.26 h	1.32 k
	Small	0.915 c	0.978 f	1.105 i	1.21 m
Afshan	Large	1.226 n	1.352 o	1.44 q	1.52 s
	Medium	1.15 a	1.336 k	1.36 o	1.45 q
	Small	1.08 i	1.14 p	1.289 r	1.33 k

All data are means of 10 replications

Rupture energy

Energy absorbed at seed rupture increased from 131.85 to 322.06 Jm^{-3} with the increasing moisture content from 4% to 20% d.b for all varieties and size categories (Table 3). Energy absorbed at seed rupture was a function of both force and deformation up to rupture point. At low moisture content, the seed requires high force to be ruptured and its deformation was low but at high moisture content, the rupture force was low and the deformation was high. This fact showed that energy absorbed at seed rupture increases as the moisture content of the seed increases indicating high resistance to seed rupture during compressive loading. The latter result has been documented by Khazaei (2002), who investigated rupture energy in pea rupture under quasi-statistically loading and reported that with an increase in seed moisture content, the rupture energy increases significantly. The increasing trend of rupture energy with increase of moisture content was also observed for some other seeds, such as pumpkin seed, sunflower seed and cumin seed by joshi (1993), Gupta and Das (2000), Saiedirad (2008), respectively. Conversely, Singh and Goswami (1996) found that rupture energy for cumin seed decreased with increase in moisture content in both horizontal and vertical loading orientations. They observed that the rupture energy for cumin seed at rupture point decreased from 14.8 to 9.4 mJ with the increase in moisture content from 7 to 13% d.b. According to Table 3, there was a significant difference among two varieties on rupture energy of the safflower seed at different levels of moisture content and size categories. As it can be found from this table, among the studied varieties *Afshan* had the most rupture energy. Also, there was a significant difference between small and large sizes ($p < 0.95$) and the rupture energy of seed increased with the increase of size from small to large. This agrees with the results of Gupta and Das (2000) for sunflower seed and kernel.

Table 3. Mean comparison of rupture energy (Jm^{-3}) of safflower seed considering interaction effect of moisture content, variety and size

Varieties	**Size**	**Moisture content (% d.b.)**			
		4	**8**	**14**	**20**
Golshid	Large	220.24 a	232.05 d	245.43 g	259.14 j
	Medium	180.55 b	200.25 e	213.04 h	227.5 k
	Small	131.85 c	149.5 f	158.1 i	172.53 m
Afshan	Large	276.72 n	290.04 q	305.31 t	322.06 v
	Medium	262.07 o	287.81 r	295.11 u	309.15 w
	Small	255.82 p	269.74 s	287.85 r	298.26 x

All data are means of 10 replications.

Conclusion

Mechanical aspects of Iranian cultivated safflower seeds were investigated in the range of moisture contents (4% to 20%), variety (Golshid and Afshan) and size category (Small, medium and large). The obtained results show that the compressive force needed to initiate rupture of safflower seed hulls decreased with an increase in moisture content while the deformation at rupture increased. 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. Rupture energy per unit volume increases with an increase in moisture content of the seed. The required force to rupture the hull of seed, rupture energy and deformation for safflower seed increased as seed size increased. Assuming that the behavior for impact loading is the same as in the quasi-static loading used in these experiments, a higher percentage of safflower seeds will be dehulled, with lower consumption of energy, when the seeds are low in moisture content and small size.

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