Elastic behavior of sunflower seed and its kernel

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Abstract: The objective of the present project was to investigate the elastic behavior (Elastic modulus and Poisson's ratio) of three common Iranian varieties of sunflower seeds and their kernels (Azargol, Fandoghi and Shahroodi) as a function of moisture content, size and loading rate. The obtained results showed that elastic modulus of sunflower seeds and their kernels decreased with increasing moisture content from 3% to 14% dry basis (d.b.), and also increasing loading rate from 2 to 10 mm/min for all studied varieties and size categories. Average Poisson's ratio values of Azargol, Fandoghi and Shahroodi seeds from 0.28 to 0.35, 0.31 to 0.38, 0.33 to 0.42, were obtained for moisture levels ranging from 3% to 14% (d.b.), respectively. Poisson's ratio increased from 0.281 to 0.357, 314 to 0.387 and 0.346 to 0.42 at loading rates of 2 to 10 mm/min, for Azargol, Fandoghi and Shahroodi seeds, respectively. The Poisson's ratio and elastic modulus of sunflower seed and its kernel also exhibit a positive relationship with size for all studied varieties, moisture content and loading rates.

Keywords: elastic modulus, Poisson's ratio, sunflower seed, kernel

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1 Introduction

Knowledge of apparent elastic properties such as Poisson's ratio and elastic modulus of agricultural materials are important for the prediction of their load-deformation behavior. These properties could be used to compare the relative strengths of different biomaterials and investigating these technological characteristics could aid in the design of processing machines. One of the agricultural materials is Sunflower (*Helianthus annuus* L.) seed that is considered to be an important oilseed crop because it contains highly nutritious oil in large quantity (Gupta and Das, 2000). In Iran, oil is mostly obtained by mechanical expression from sunflower seeds. However, this process suffers some disadvantages. The presence of a justly high percentage of hull in the seed 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, leads to high specific energy and yields cakes of lower food value (Khodabakhshian et al., 2010). Therefore, sunflower seeds should be hulled before they enter in the industrial process of oil extraction. So, information on the elastic properties of sunflower seed and its kernel under compressive loading is essential for a rational design of an efficient dehulling system and equipment for mechanical expression of oil and other processes.

Many studies have been conducted to determine the elastic modulus of agricultural produce from force-deformation curves, based on Hertz (Moshenin, 1986) theory. Khzaie (2002) studied the elastic modulus of pea pod, at loading rate of 5 mm/min and moisture content of 18% (w.b.) Kiani et al. (2009) determined elastic modulus of red bean grains as a function of moisture content and loading rate. Also, many researchers have studied Poisson's ratio for agricultural produce. In a study on wheat that was done by Molenda and Stasiak (2002), Poisson's ratio was assumed as 0.22. Molenda and Stasiak (2002) also investigated the effect of deformation and elastic modulus on Poisson's ratio of

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barley and found the variation to be 0.15 to 0.19. Kiani et al. (2009) obtained Poisson's ratio values of 0.322 to 0.267 and 0.406 to 0.340 for moisture levels ranging from 5% to 15%, for Goli and Akhtar varieties of red bean, respectively.

Due to the fact that there is not enough information about elastic properties of sunflower seed and its kernel which are needed for determining other mechanical properties, in this study, the elastic modulus and Poisson's ratio of sunflower seed and its kernel under compression load is determined for various conditions, such as moisture content, size, loading rate and variety.

2 Materials and methods

Three varieties of sunflower seed, namely Shahroodi, Fandoghi and Azargol, were obtained from different regions in northeast of Iran during autumn season in 2008. Twenty kilograms of seeds of each variety were randomly selected and transported to the lab. At first, samples were manually dehulled and cleaned up to remove all foreign matters, broken and immature seeds. The initial moisture of the seeds was determined by using the standard hot air oven method with a temperature setting of 105 ± 1℃ for 24 h (Konak et al., 2002; Altuntas et al., 2005; Coskun et al., 2005; Saiedirad, 2008; Khodabakhshian et al., 2010). The initial moisture contents of seeds for Shahroodi, Fandoghi and Azargol were 7.9%, 6.8%, and 7.2% (d.b.), respectively. Also, in a similar way, the initial moisture contents of kernel for Shahroodi, Fandoghi and Azargol were measured as 5.9%, 5.6% and 5.4% (d.b.), respectively. To determine the effect of seed size and its kernel of each variety on studied elastic properties, the seeds of each variety were graded into three size categories (small, medium and large) using 5.5, 6.5 and 8 mesh sieves. The interested elastic properties of the seeds and their kernels were investigated for three levels of moisture content in the range of 3% to 14% (d.b.). The desired moisture content of the seed and kernel samples was achieved by weighing a mass of 0.5 kg of each variety and size category (small, medium and large) from the bulk of main sample and dried in the oven at 75℃ for 2 h. Subsequently, the calculated quantity of water was added to the sample (Coskun et al., 2005). Finally, the sub-samples were kept in double-layered low-density polyethylene bags of 90 μm thickness, sealed and stored at a low temperature (5℃ in a refrigerator) (Khodabakhshian et al., 2010). Before starting the tests, the required quantities of seed and kernel were taken out of the refrigerator and allowed to be warmed to room temperature for approximately 2 h (Gupta and Das, 2000; Ozarslan, 2002; Khodabakhshian et al., 2010).

The technique used here for the determination of Poisson's ratio was that explained by Sitkei (1986). Poisson's ratio of three studied varieties were investigated at three moisture levels of 3%, 7% and 14% (d.b.) and loading rates of 2, 5, 8 and 10 mm/min. Prior to testing, both the original length and diameter of specimens were recorded using a digital vernier caliper (Diamond, China). The specimens were axially loaded in a Instron Universal Testing Machine (Model H5KS, Tinius Olsen Company) equipped with a 500 N compression load cell and integrator and quasi-statically compressed at the preset condition until rupture occurred as is denoted by a bio–yield point in the force–deformation curve. Whole samples (seeds or kernels) were used for this experiment because whole-grain data is more useful in the design of processing machinery. Axial displacement (strain) was measured and recorded using the Instron Universal Testing Machine. Lateral deflections of the sample at the cracking limit of axial load were recorded again with the digital vernier caliper. Having axial and lateral deflection values of the samples, Poisson's ratio was then calculated using Equation (1) (Figura and Teixeira, 2007):

$$\mu = \frac{d/D}{l/L} \tag{1}$$

where, μ is Poisson's ratio (dimensionless); d is transverse deformation (mm); D is sample width (mm); l is axial deformation (mm) and L is sample length (mm).

For elastic modulus, individual seeds or kernels were loaded between two parallel plates of the machine, compressed at the preset condition until rupture occurred as was denoted by a bio–yield point in the force–

deformation curve. A typical obtained force–deformation curve for a sunflower seed was shown in Figure 1. As soon as the bio–yield point was detected, the loading was stopped. According to ASAE (2000), 108 series of tests (Three varieties: Shahroodi, Fandoghi and Azargol three levels of moisture content: 3%, 7% and 14%; and three size categories: small, medium and large; and four loading rates: 2, 5, 8 and 10 mm/min) were conducted. Data on the strength properties were automatically obtained from the integrator.

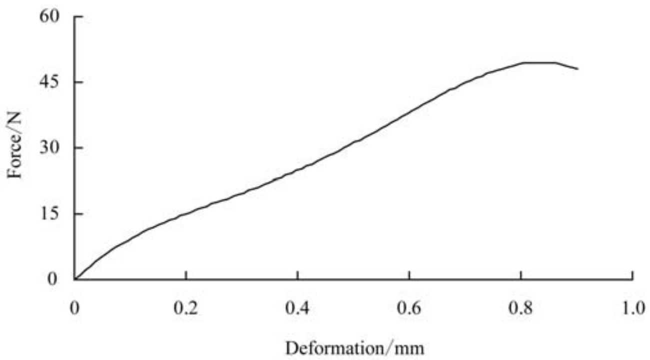

Figure 1 Typical force and deformation characteristics of sunflower seed

The experiments were conducted with four replications for each moisture contents, varieties, size categories, and loading rates, and the average values reported. Statistical analysis was done on completely randomized design with factorial experiment applying the analysis of variance (ANOVA) using SPSS software, version 16. The F test was used to determine significant effects of each variable, and Duncan's multiple ranges test was used to separate means at a 5% level of significance.

3 Results and discussion

Variance analysis of data indicated that the effects of variety, moisture content, loading rate and size of the seed or kernel on elastic modulus and Poisson's ratio were significant ($P<0.01$). Also, the interaction of variables on each other was significant for different combinations. Among the studied varieties, Azargol had maximum elastic modulus of the seed ranged from 157.84 to 61.15 MPa, and then Fandoghi in the range of 137.38 – 40.69 MPa and the lowest range belonged to Shahroodi ranged from 126.86 to 30.17 MPa. Also, the similar order was found among kernels, Azargol (139.91 – 47.28 MPa), Fandoghi (123.03 – 28.1 MPa) and Shahroodi (110.96 – 18.33 MPa). The Poisson's ratio of Azargol, Fandoghi and Shahroodi seeds varied from 0.28 to 0.35, 0.31 to 0.38, 0.33 to 0.42, while this property for the corresponding kernels varied from 0.25 to 0.32, 0.29 to 0.36 and 0.3 to 0.39, respectively, when the moisture content increased from 3% to 14% (d.b.) in each size category and loading rate. In the following sections, the effects of all variables and their interactions on elastic modulus and Poisson's ratio were comprehensively discussed.

Table 1 shows the variation of the elastic modulus of sunflower seed and its kernel at different moisture contents and loading rates for the investigated varieties. As it can be seen from this table, the elastic modulus of sunflower seed decreased as the moisture content increased from 3% to 14% (d.b.) for all loading rates and studied varieties. This may be due to the fact that at higher moisture content, the seed became softer and demanded less force. According to Table 1, the elastic modulus of sunflower kernel also decreased with the increase in moisture content. The trend of decreasing elastic modulus at higher kernel moisture contents may be attributed to a gradual change in the integrity of the cellular matrix. These are 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 agreed with the results of Misra and Young (1981) that reported a functional relationship between the modulus of elasticity and moisture content of soybean and that the modulus of elasticity decreased and approached a constant minimum, with the increase in moisture content of soybean. The comparison of the elastic modulus for both sunflower seed and its kernel revealed that the elastic modulus of seeds was significantly higher (30.17-157.84 MPa) than those for kernel (18.33-139.91 MPa) in all levels of moisture content, variety and loading rate. This might be attributed to cellular arrangement or structure of sunflower seed and its kernel.

Table 1 Mean comparison of elastic modulus (Mpa) of sunflower seed and kernel considering interaction effect of variety, moisture content and loading rate

Loading rate /mm · min^{-1}	Moisture content /%	Variety Shahroodi					
		Azargol		Fandoghi		Shahroodi	
		Seed	Kernel	Seed	Kernel	Seed	Kernel
2	3	199.33 a	101.54 d	98.87 g	85.93 j	88.35 h	72.59 o
	7	109.45 b	91.04 e	88.99 h	76.05 k	78.09 m	61.90 p
	14	102.47 c	83.71 f	82.01 i	67.80 l	70.82 n	54.59 q
5	3	116.11 A	98.46 D	95.67 G	82.73 J	85.15 M	69.51 P
	7	106.69 B	88.67 E	86.23 H	73.29 K	75.18 N	59.61 Q
	14	99.13 C	81.06 F	78.67 I	64.42 L	66.99 O	51.91 R
8	3	112.74 s	94.77 v	92.32 y	79.37 β	81.80 ε	65.82 θ
	7	104.87 t	87.27 w	84.41 z	71.46 γ	73.45 ζ	57.66 λ
	14	96.56 u	79.46 x	76.1 α	62.28 δ	64.07 η	50.05 κ
10	3	110.317 S	92.53 V	89.86 Y	76.91 ν	79.34 σ	63.58 ς
	7	103.25 T	85.43 W	82.79 Z	69.11 ξ	71.95 φ	55.76 Φ
	14	93.267 U	77.2 X	72.81 μ	59.55 τ	60.34 χ	47.21 Ч

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

It is apparent that either variation in size or loading rate (Table 2) had a significant effect on the elastic modulus of seed and kernel ($p < 0.05$). The elastic modulus of seed and kernel increased as seed size increased so that the average elastic modulus of large seeds was about 2.15-fold of that of small ones. In the same way, the average elastic modulus of large kernels was about 2.60-fold of that of small ones. This could be due to the fact that with increasing size, high contact area of the seed (or kernel) with the compressing plates resulted in the expansion of low stress. This was 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 the increase of size was also observed for pea (Khazaei, 2002). The elastic modulus of sunflower seed and also its kernel decreased as the loading rate increased (Tables 1 and 2). Burubai et al. (2008) observed a negative trend for elastic modulus of African nutmeg with the loading rate. They reported the average value of 135.51 and 120.46 MPa at 1 and 7 mm/min, respectively. However, Kiani et al. (2009) observed that elastic modulus of red bean grain increased with the increasing loading rate from 3 to 15 mm/min, for two varieties named Goli and Akhtar. The discrepancies in observed behaviors could be related to the differences in surface roughness of grains or seeds.

Table 2 Mean comparison of elastic modulus (MPa) of sunflower seed and its kernel in different size categories and loading rates

Size category	Seed	Kernel
Size category		
Large	122.97 a	106.85 d
Medium	87.27 b	72.74 e
Small	57.21 b	41.15 f
Loading rate/mm · min^{-1}		
2	93.15 g	77.24 k
5	89.98 h	74.4 m
8	87.37 i	72.02 n
10	87.21 j	71.8

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

Figures 2 to 4 depicted the Poisson's ratio of sunflower seed and its kernel as a function of loading orientation for all studied varieties. It can be found that for all varieties when the loading rate increased from 2 to 10 mm/min, average values of Poisson's ratio of Azargol, Fandoghi and Shahroodi seeds increased from 0.281 to 0.357, 314 to 0.387 and 0.346 to 0.42. This property for the corresponding kernels varied from 0.254 to 0.33, 0.294 to 0.367 and 0.317 to 0.39, respectively when the loading rate increased. It was thus observed that

Poisson's ratio increased with the increasing loading rate. Finney and Hall (1967) reported a similar effect for loading rate. No reported results for Poisson's ratio of sunflower seed and its kernel were found to compare with the results obtained in this study. However, Burubai et al. (2008) also observed a positive trend for Poisson's ratio of African nutmeg with the loading rate. They reported the average value of 0.136 and 0.334 at 1 and 7 mm/min, respectively. In addition, in agreement with these results, Kiani et al. (2009) observed that Poisson's ratio of red bean grain increased with the increasing loading rate from 3 to 15 mm/min, for two varieties named Goli and Akhtar. Among the studied varieties, Shahroodi had maximum Poisson's ratio for both seed and kernel then Fandoghi and the lowest range belonged to Azargol. The differences in Poisson's ratio between the studied varieties could be the result of the individual cultivars properties and different environmental and growth conditions of cultivars. Also, in agreement with these results, Khodabakhsina et al. (2010) reported that variety has a significant influence on the mechanical properties of sunflower seed and its kernel.

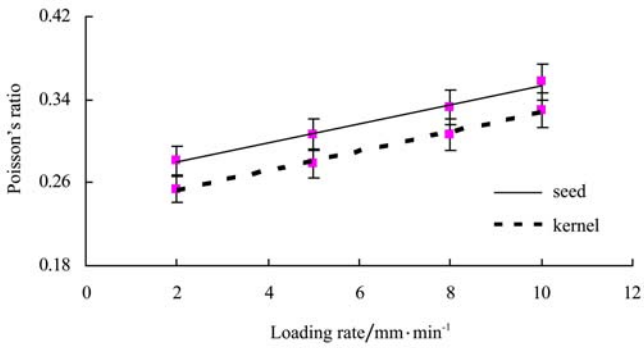

Figure 2 Effect of loading rate on Poisson's ratio of Azargol variety of sunflower seed and kernel

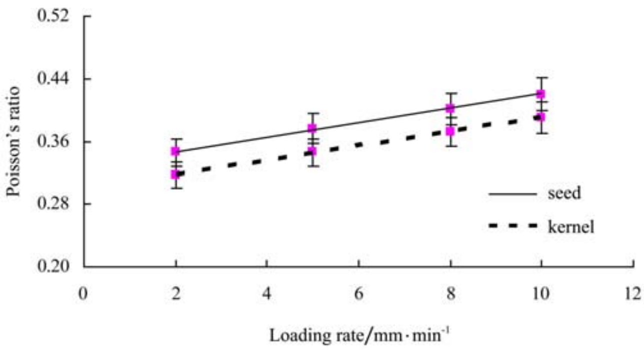

Figure 3 Effect of loading rate on Poisson's ratio of Shahroodi variety of sunflower seed and kernel

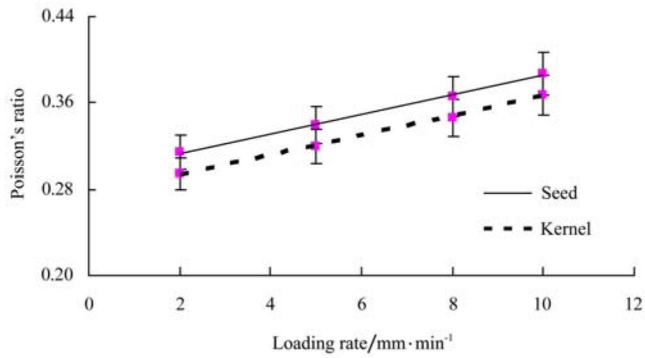

Figure 4 Effect of loading rate on Poisson's ratio of Azargol variety of sunflower seed and kernel

The interaction effect of moisture content and size category on Poisson's ratio of sunflower seed and kernel were shown in Table 3. As was shown in the table, rising in moisture content from 3% to 14% (d.b.) showed a decreasing trend in the Poisson's ratio for both seed and kernel in the cases of size. These were consistent with the findings of Kiani et al. (2009) and Burubai et al. (2008) who reported that Poisson's ratio of red bean and African nutmeg decreased linearly with the increase of moisture content. These results also agreed with the results of Mohsenin (1986) and Peleg (1987). In fact, at higher moisture content, the seeds become softer and demand less force. Also, the trend of decreasing Poisson's ratio at higher moisture contents of kernel may be attributed to a gradual change in the integrity of the cellular matrix. According to Table 3, the Poisson's ratio of sunflower seed and its kernel increased as size increased from small to large for all moisture contents, so that the average Poisson's ratio of large seeds was about 1.32-fold of that of small ones. In the same way, the average Poisson's ratio of large kernels was about 1.2 times more than the small kernels. This trend can be related to the geometric mean diameter of sample (seed or kernel). On the other hand, the discrepancies between the Poisson's ratio of seeds and their kernels can be related to the cell structure and the variation of physical properties in seeds and kernels when size was changed. This justification has been proved by Khodabakhsina et al. (2010) on engineering properties of sunflower seed and its kernel. Khazaei (2002) also observed the increasing trend of Poisson's ratio with the increase of size for pea and concluded that the size of pea influenced its elastic properties significantly.

Table 3 Mean comparison of Poisson's ratio of sunflower seed and its kernel considering interaction effect of moisture content and size

Product	Moisture content/%	Size category		
		Large	Medium	Small
Seed	3	0.412 a	0.357 c	0.349 f
	7	0.375 b	0.343 d	0.295 g
	14	0.355 c	0.326 e	0.222 h
Kernel	3	0.385 a	0.354 d	0.322 g
	7	0.349 b	0.319 e	0.295 h
	14	0.328 c	0.302 f	0.268 i

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

4 Conclusions

Negative correlations were observed between elastic modulus of sunflower seed and its kernel with moisture content as well as loading rate. This implies their elastic modulus decreased with the increasing moisture content from 3% to 14% (d.b.), and also decreased with the increase of loading rate from 2 to 10 mm/min for all studied varieties and size categories. The results also showed that Poisson's ratio of sunflower seed and its kernel decreased with the increasing moisture content for the varieties under study while it increased with the increasing loading rate. The Poisson's ratio and elastic modulus of sunflower seed and its kernel exhibit a positive relationship with size for all studied varieties, moisture content and loading rates. The elastic modulus and also Poisson's ratio of seeds was significantly higher than that of kernels in all levels of moisture content, variety, loading rate and size category.

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