Poisson's ratio of pumpkin seeds and their kernels as a function of variety, size, moisture content and loading rate

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Abstract: In this study, the Poisson's ratio of two varieties of Iranian pumpkin seeds and their kernels (namely Zaria and Gaboor) was determined as a function of moisture content (4%, 7.8%, 14% and 20% d.b.), size (small, medium, large) and loading rate (2, 5, 8 and 10 mm/min). Pumpkin seeds and their kernel were quasi-statically loaded in horizontal and vertical orientations. The results showed that Poisson's ratio of pumpkin seeds and their kernels decreased with increasing moisture content for the varieties under study while it increases with increasing loading rate. Average Poisson's ratio values decreased from 0.347 to 0.267 and from 0.421 to 0.348 when the moisture levels increased from 4% to 20%, for seeds of Zaria and Gaboor varieties, respectively. Poisson's ratio values for corresponding kernels ranged from 0.252 to 0.330 and 0.345 to 0.417. When the loading rate increased from 2 to 10 mm/min, average values of Poisson's ratio increased from 0.272 to 0.420 for seeds and from 0.26 to 0.41 for kernel, respectively. Investigating the effect of size revealed that Poisson's ratio of pumpkin seeds and its kernel increased as the average size of the samples increased. Finally, values of the studied parameters play a key role in minimizing losses during hulling of pumpkin seeds. Therefore, by applying the results of this study, the cost of hulling process is reduced, or the effectiveness of this industry will be increased.

Keywords: pumpkin seeds, elasticity theory, engineering properties, Poisson's ratio, hulling process

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1 Introduction

Recent activities in the mechanization of harvesting and handling of different types of seeds and grains have brought a significant increase in research on elastic properties of them. Moreover, 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. Also, these elastic properties could be used to compare the relative strengths of different biomaterials and investigating these engineering properties could aid in the design of crop processing machinery (Kiani, Maghsouldi and Minaei, 2009). The Poisson's ratio of an agricultural seed is a mechanical property which has been suggested as a measure of the textural attribute designated as firmness. It is also an important property for determination of the stress cracks in seeds.

On the other hand, Poisson's ratio of a material is of importance particularly from the point of view of specifying the loads which the material will safely sustain. Owing to the complex shape of most agricultural products and their associated complex structure, the determination of a reliable Poisson's ratio presents a number of problems. However, as other researchers have demonstrated, these problems can be overcome, to a certain extent, by using methods based on elasticity theory (Misra and Young, 1981; Balastreire et al., 1982; Jindal and Techasena, 1985; Bargale, Irudayaraj and Marquis, 1994; Bargale and Irudayaraj, 1995; Khazaei, 2002; Hicsasmaz and Rizvi, 2005; Burubai et al., 2008;

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Kiani, Maghsoudi and Minaei, 2009).

Pumpkin (*Cucurbita maxima*) seeds contain many valuable functional components and have been traditionally used for herbal, therapeutic as well as clinical applications. Pumpkin seeds have been used as safe deworming and diuretic agents, and the seed oil as a nerve tonic (Ghani, 2003; Younis, Ghirmay and Al-Shihry, 2000). Pumpkin seed oil has strong antioxidant properties (Stevenson et al., 2007) and has been recommended for several health benefits such as prevention of the growth and reduction of the size of prostate, retardation of the progression of hypertension, mitigation of hypercholesterolemia and arthritis, reduction of bladder and urethral pressure and improving bladder compliance, alleviation of diabetes by promoting hypoglycemic activity, and lowering levels of gastric, breast, lung, and colorectal cancer (Caili, Huan and Quanhong, 2006; Stevenson et al., 2007).

Many researchers have studied Poisson's ratio for agricultural produce. In a study on wheat that was done by Shelef and Mohsenin (1969), Poisson's ratio was assumed 0.4 and it was revealed that variation of Poisson's ratio of wheat was 0.3 to 0.5. Kiani, Maghsoudi and Minaei (2009) obtained Poisson's ratio values ranging from 0.267 to 0.322 and from 0.340 to 0.406 when the moisture content decreased from 15% to 5% for Goli and Akhtar varieties of red bean, respectively. Many researchers have also assumed a value of 0.4 for Poisson's ratio of agricultural produce (Misra and Young, 1981; Jindal and Techasena, 1985; Bargale and Irudayaraj, 1995; Khazaei, 2002).

Owing to the fact that there was not enough information about Poisson's ratio of pumpkin seeds and their kernels needed for determination of other mechanical properties, the objective of this study was to determine the Poisson's ratio of pumpkin seeds and their kernels during applied compression load under various conditions such as moisture content, size, loading rate and variety.

2 Materials and methods

2.1 Sample preparation and moisture content determination

Zaria and Gaboor varieties of pumpkin seeds were obtained from different regions of Khorasan Razavi province (Northeast of Iran) during autumn in 2010 (Figure 1). A portion of seeds equal to 20 kg was also randomly selected from each variety. The seeds were manually cleaned to remove all foreign matters such as dust, dirt, stones, immature and broken seeds. To get whole kernels, the seeds were manually dehulled. The initial moisture content of seeds and kernels were determined by using the standard hot air oven method with a temperature setting of (105 ± 1)℃ for 24 h (Baryeh, 2002; Coskuner and Karababa, 2007; Khodabakhshian, Emadi and Abbaspour-Fard, 2010). The initial moisture content of the seeds of Zaria and Gaboor varieties was found 7.80% and 7.6% d.b., respectively. The similar level of moisture content for corresponding kernels were obtained to be 6.2% and 5.8% d.b., respectively. To investigate the effect of sample (seed and kernel) size on Poisson's ratio, the seeds of each variety were graded into three size categories (small, medium and large) using 5.5, 6.5 and 8.0 mm square mesh sieves (Khodabakhshian, Emadi and Abbaspour-Fard, 2010). The Poisson's ratio of pumpkin seed and its kernel was measured in four moisture content levels in the range of 4% to 20% (d.b.) that is a usual range since harvesting, transportation, storage and processing operations of pumpkin seeds. To get the seeds and kernels with the desired moisture contents, some samples of seeds and kernels of each variety and size category (small, medium and large), each weighing 0.5 kg, were drawn from the bulk samples and dried (by putting them in the oven at 75℃ for 2 h) or adding calculated amount of distilled water, through mixing and then sealing in separate polyethylene bags of 90 μm thickness. The samples were kept at 5℃ in a refrigerator for seven days to distribute the moisture uniformly throughout the sample. Before starting the tests, the required quantities of seeds and kernels were taken out of the refrigerator and allowed to warm up to room temperature for approximately 2 h (Gupta and Das, 1997; Joshi, 1993; Khodabakhshian, Emadi and Abbaspour-Fard, 2010).

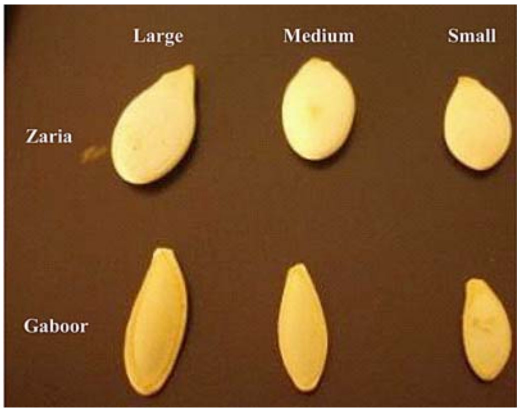

Figure 1 The size categories of two Iranian varieties of pumpkin seeds

2.2 Poisson's ratio measurement

The technique used here for the determination of Poisson's ratio was that described by Sitkei (1986). Poisson's ratio of both varieties were investigated at four moisture levels of 4%, 7.8%, 14% and 20% (d.b.) at loading rates of 2, 5, 8 and 10 mm/min. Prior to testing, both the original length and diameter of specimens were recorded by 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 as was shown in Figure 2. Whole samples (seeds or kernels) were used for this experiment because whole-grain data was more useful in the design of processing machinery. Axial displacement (strain) was measured and recorded by 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):

Figure 2 Universal test machine used in the compression test

$$\mu = \frac{d/D}{l/L} \qquad (1)$$

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

2.3 Statistical analysis

The experiments were conducted with four replications for each moisture contents, varieties, size categories, and loading rates, and the average values reported. Average and regression equations were computed by using Microsoft Excel software (2003). The analysis of variance (ANOVA) was carried out on a completely randomized design with factorial experiment using SPSS 16.0 software. The F test was used to determine the significance of independent treatments, and significant differences of means were compared by using the Duncan's multiple ranges test at 5% significant level.

3 Results and discussion

Table 1 showed the results of variance analysis which was carried out to examine the effect of treatments on Poisson's ratio for both seeds and kernels. As can be found from this table, the effects of variety, moisture content, loading rate and size of the seeds or kernels on the Poisson's ratio were significant at the 1% of probability level. The interaction effect of variety × size on the Poisson's ratio was not significant at 1% level for both seeds and kernels. Also, the interaction effects of variety × loading rate on the Poisson's ratio of pumpkin seeds were not significant at 1% level, while created a significant effect on Poisson's ratio for kernels ($p < 0.01$). All the three interaction effects of the treatments indicated significant effects at the 1% of probability level on Poisson's ratio of pumpkin kernels. However, the variance analysis of the data for seeds showed that all the three interaction effects of the treatments with the exception of interaction effects of moisture content × size × loading rate were not significant. So, Poisson's ratio of pumpkin seeds and their kernels are comeletly affected by studied parameters. Additionally, variance analysis of data for both seeds and kernels indicated an interaction effect level among variety, moisture content, size and loading rate ($p < 0.01$). In the following sections, the effects all treatments and their interactions on the Poisson's ratio of pumpkin seeds and their kernel were comprehensively discussed.

Table 1 Analysis of the variance of parameters considered on Poisson's ratio of pumpkin seed and its kernel

Variation source	df	Mean square	
		Seeds	Kernels
Treatment	95	11.351**	10.707**
Variety	1	0.137**	0.189**
Moisture content	3	0.025**	0.024**
Size	2	0.028**	0.037**
Loading rate	3	0.026**	0.026**
Variety × moisture content	3	0.01**	0.014**
Variety × size	2	0.0005 ns	0.0002ns
Variety × loading rate	3	0.0005ns	0.03**
Moisture content × size	6	0.01**	0.01**
Size× loading rate	6	0.02**	0.01**
Moisture content × loading rate	9	0.01**	0.01**
Variety × moisture content × size	6	0.0006ns	0.01**
Variety × moisture content × loading rate	9	0.0005ns	0.0007**
Variety × size × loading rate	6	0.0002 ns	0.0006**
Moisture content × size × loading rate	18	0.002**	0.002**
Variety × moisture content × size× loading rate	18	0.001 **	0.003**
Error	384	0.002	0.001

Note: * Significance at 5% level; ** Significance at 1% level; ns Non – significant.

3.1 Moisture content

The variation of Poisson's ratio at different moisture contents of the investigated varieties of pumpkin seeds and their kernels were shown in Table 2. As was shown in Table 2, as the moisture content increases from 4% to 20%, the Poisson ratio follows a decreasing trend for both seeds and kernels in the cases of variety. These conclusions is consistent with the findings of Kiani, Maghsoudi and Minaei, (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 addition, the results of this section were in agreement with the findings of many researchers who considered the effect of moisture content on mechanical properties of biological products (Liu et el., 1990; Joshi, 1993; Bay, Bourne and Taylor, 1996; Konak, Carman and Aydin, 2002; Altuntas and Yildiz, 2007; Saiedirad, Tabatabaeefar and Borghei, 2008; Khodabakhsina, Emadi and Abbaspour-Fard, 2010). 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 kernels may be attributed to a gradual change in the appropriate of the cellular matrix. As can be found from Table 2, the Gaboor variety exhibited a higher value of Poisson's ratio compared with the Zaria variety at all moisture contents, which indicated that Gaboor had a more porous texture than Zaria. According to Table 2, Poisson's ratio of Zaria variety of seed was 0.347 at 4% moisture. This is significantly more than the Poisson's ratio of Zaria variety of seed at 20% moisture (around 1.29 times). This value for Gaboor variety of seed was around 1.21. In the same way, the average Poisson's ratio of Zaria variety of kernels was about 1.31-fold of that of kernel at 20% moisture. Also this value for Gaboor variety of kernels was around 1.21.

Table 2 Mean comparison of Poisson's ratio of pumpkin seed and kernel considering the interaction effect of moisture content and variety

Product	Moisture content/%	Variety	
		Zaria	Gaboor
Seeds	4	0.347 a	0.421 e
	7.8	0.317 b	0.387 f
	14	0.293 c	0.370 g
	20	0.267 d	0.348 h
Kernels	4	0.330 a	0.417 e
	7.8	0.300 b	0.384 f
	14	0.277 c	0.367 g
	20	0.252 d	0.345 h

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

3.2 Size

The Poisson's ratio of pumpkin seeds and their kernels at different size categories was shown in Table 3. As was given in this table, the Poisson's ratio of pumpkin seeds and their kernels increased as the size increased from small to large, so that the average Poisson's ratio of large seeds was about 1.19-fold of that of small ones. In the same way, the average Poisson's ratio of large kernels was about 1.22 times more than the small kernels. This trend could 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 agreed with the results of Khodabakhsina, Emadi and Abbaspour-Fard (2010) on engineering properties of sunflower seeds and their kernels. The increasing trend of Poisson's ratio with the increase of size was also observed for pea (Khazaei, 2002). It has been reported that the size of pea influenced its elastic properties significantly.

Table 3 Mean comparison of Poisson's ratio of pumpkin seeds and kernels considering the effect of size

Size	Product	
	Seeds	Kernels
Small	0.316 [a]	0.302 [d]
Medium	0.341 [b]	0.331 [e]
Large	0.375 [c]	0.370 [f]

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

Considering the interaction effect between moisture content and size category, the highest difference in Poisson's ratio for pumpkin seeds and kernels belonged to large category at 4% moisture content (Table 4). In addition, it is denoted from Table 4 that the least interaction effect of size category and moisture content on Poisson's ratio of seed and kernel belonged to small category at 20% moisture content.

Table 4 Mean comparison of Poisson's ratio of pumpkin seeds and their kernels considering interaction effect of moisture content and size

Product	Moisture content /%	Size category		
		Large	Medium	Small
Seeds	4	0.412 [a]	0.384 [b]	0.355 [h]
	7.8	0.380 [b]	0.349 [e]	0.328 [f]
	14	0.362 [c]	0.326 [f]	0.306 [g]
	20	0.344 [d]	0.305 [g]	0.275 [i]
Kernels	4	0.407 [a]	0.374 [b]	0.340 [d]
	7.8	0.375 [b]	0.339 [d]	0.312 [d]
	14	0.357 [c]	0.316 [e]	0.291 [f]
	20	0.339 [d]	0.294 [f]	0.262 [g]

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

3.3 Variety

Stepwise analysis of the obtained results revealed that among the studied variables including: variety, moisture content, size category and loading rate, the dominant factor on the Poisson's ratio of the seed and kernel was variety. The variation of Poisson's ratio of the investigated varieties of pumpkin seeds and their kernels are shown in Figure 3. As can be seen from Figure 3, the Poisson's ratio of Gaboor variety was significantly more than Zaria variety of pumpkin seeds (around 1.25 times). This value for corresponding kernels was around 1.30. 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. No reported results for Poisson's ratio of pumpkin seeds were found to compare with the results obtained in this study. However, in agreement with these results, a few results can be found in the literature for some grains with some way similarity. For instance, Kiani, Maghsoudi and Minaei (2009) found that the Poisson's ratio of red bean varied with different varieties. They reported the average values of 0.295 and 0.374 for the Goli and Akhtar variety of red bean, respectively. In addition, Khodabakhsina, Emadi and Abbaspour-Fard (2010) reported that variety has a significant influence on the mechanical properties of sunflower seeds and their kernels.

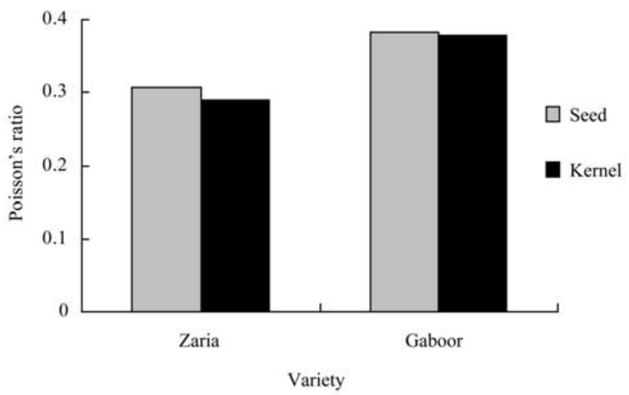

Figure 3 Effect of variety on Poisson's ratio of pumpkin seeds and their kernels

3.4 Loading rate

Variation of the Poisson's ratio of pumpkin seeds and their kernels as a function of loading rate at different moisture contents was shown in Table 5. According to this Table, when the loading rate increased from 2 to 10 mm/min, average values of Poisson's ratio increased from 0.272 to 0.420 for seeds and from 0.260 to 0.410 for kernels, respectively. It was thus observed that Poisson's ratio increased with the increasing loading rate. 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, Maghsoudi and Minaei (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. Investigating the interaction effect of loading rate and moisture content on Poisson's ratio of both seeds and kernels of pumpkin, Table 5 showed that the most differences belongs to 4% moisture content and 10 mm/min loading rate. Also, it was denoted that the least differences belonged to 20% moisture content and 2 mm/min loading rate.

Table 5 Mean comparison of Poisson's ratio of pumpkin seed and its kernel considering interaction effect of loading rate and moisture content

Product	Moisture content /%	Loading rate/mm • min^{-1}			
		2	5	8	10
Seeds	4	0.347^{a}	0.375^{e}	0.395^{h}	0.420^{l}
	7.8	0.313^{b}	0.333^{f}	0.363^{i}	0.398^{h}
	14	0.297^{c}	0.320^{g}	0.345^{j}	0.365^{i}
	20	0.272^{d}	0.290^{c}	0.323^{k}	0.347^{a}
Kernels	4	0.330^{a}	0.364^{e}	0.384^{h}	0.400^{1}
	7.8	0.302^{b}	0.321^{f}	0.352^{i}	0.387^{m}
	14	0.286^{c}	0.310^{g}	0.334^{j}	0.353^{i}
	20	0.26^{d}	0.283^{c}	0.314^{k}	0.336^{a}

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

4 Conclusion

Knowledge of apparent elastic properties such as Poisson's ratio of agricultural seeds is important for the prediction of their load-deformation behavior and subsequently design of processing machines for pumpkin seeds and kernels. In this sudy, Poisson's ratio of two varieties of pumpkin seeds and their kernels including Zaria and Gaboor were determined as a function of moisture contents ranging from 4% to 20% d.b., size category in three levels: small, medium and large; and four loading rates: 2, 5, 8 and 10 mm/min. The results of this study were summarized as below:

1) Poisson's ratio for both pumpkin seeds and their kernels decreased with the increasing moisture content from 4% to 20% d.b. for all varieties and size categories. The Gaboor variety exhibited a higher value of Poisson's ratio compared with the Zaria variety at all moisture contents, which indicated that Gaboor had a more porous texture than Zaria.

2) The Poisson's ratio of pumpkin seeds and their kernels increased as size increased from small to large, so that the average Poisson's ratio of large seeds was about 1.19-fold of that of small ones. In the same way, the average Poisson's ratio of large kernels was about 1.22 times more than the small kernels.

3) Stepwise analysis of the obtained results revealed that among the studied variables including: variety, moisture content, size category and loading rate, the dominant factor on the Poisson's ratio of the seed and also kernel was the variety. Also, obtained results showed that the Poisson's ratio of Gaboor variety was significantly more than Zaria variety of pumpkin seeds (around 1.25 times). This value for corresponding kernel was around 1.30.

4) When the loading rate increased from 2 to 10 mm/min, average values of Poisson's ratio increased from 0.272 to 0.420 for seed and from 0.260 to 0.410 for kernel, respectively. It was thus observed that Poisson's ratio increases with the increasing loading rate.

5) Values of the studied parameters played a key role in minimizing losses during hulling of pumpkin seeds. Therefore, by applying the results of this study, the cost of hulling process would be reduced, or the effectiveness of this industry would be increased. Values of studied parameters in each size category and studied varieties are useful for determining the possibility of developing a similar or alternative mechanical hulling process that may reduce the risk of kernel breakage during mechanical hulling.

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