Mechanical damage to wheat and triticale seeds related to moisture content and impact energy

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Abstract: The objective of this research was to determine the effects of moisture content and the impact energy on the breakage susceptibility of wheat and triticale seeds. The experiments were conducted at five moisture contents of 7.5%, 12%, 17%, 22% and 27% in wet basis (w.b.), and at the impact energies of 0.05 and 0.1 J. The percentage of breakage of both wheat and triticale seeds increased as the impact energy increased. The analysis of variance showed that the difference between breakage susceptibility of wheat and triticale seeds was significant at the 0.01% level (P<0.01). Triticale seeds had more breakage than wheat seeds. For both wheat and triticale seeds as the moisture content of the seeds increased, the amount of the percentage breakage of seeds decreased as a polynomial. The average values of percentage breakage of wheat seeds decreased from 43.81% to 19.88% as the moisture content increased from 7.5% to 27% (w.b.). Over the same moisture content range, the percentage breakage of triticale seeds varied from 81.34% to 37.77%. Below the moisture contents of 17% (w.b.) for the wheat and 22% (w.b.) for the triticale the percentage breakage of seeds increased obviously.

Keywords: wheat, triticale, mechanical damage, moisture content, impact energy, harvesting, handling, processing

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1 Introduction

For human nutrition, cereal grains supply the major portion of both protein and energy for the world population. The rapid increase in word population, especially in the developing nations, emphasizes urgency to the problem, particularly regarding wheat. Triticale, a hexaploid hybrid cereal produced by cross-bearing wheat rye, was found to have such qualification. Cereal seeds such as wheat and triticale are subjected to a series of static and dynamic loads during harvesting, handling, processing, and storage. Such loadings cause external and internal damage in seeds, which lead to decreases in quality and can eliminate both viability and vigor (Khazaei *et al*., 2008).

The harvesting and the postharvest operations negatively influenced the seeds quality. The machinery and equipment for harvesting, transporting, storage and processing caused significant mechanical damage to seeds i.e. skin rupture, seed fracture etc. The damage resulted from mechanical interaction between biological material (seeds) and machineries material (steel, rubber etc.). Most authors admit that the seeds damage mainly occurs in the course of harvest and transport, where the seeds are damaged by impact force.

The mechanical resistance to the impact damage of seeds among other mechanical and physical properties plays a very important role in the design and operational parameters of equipment relating to harvesting, threshing, handling and other processing of the seeds (Baryeh, 2002). The impact damage of the seeds depends on the variable factors as velocity of impact, seed structural features, seed variety, seed moisture content, stage of ripeness, fertilization level and the error of machinery re-assembly. According the above factors, the seed moisture content and the impact velocity are important factors influencing to the mechanical damage. There

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were some research approved a significant influence of the impact velocity and moisture content upon the seed damage and affirm that the damage increases significantly as the energy of the impact increases and as the moisture content decreases (Baryeh, 2002; Parde *et al*., 2002). Valentine and Hall (1990) reported that for oat seeds even at a low threshing speed (850 rpm), germination above 85% could not be guaranteed. The tests conducted by Bourgeois *et al*. (1995) on wheat seeds showed that with an increase in threshing speed from 17.5 to 35 m/s, the percentage of abnormal seedlings increased from 10 to 25%. Khazaei *et al*., (2008) reported that the loss in germination of wheat seeds threshed at 25 to 30 m/s impact velocity was in the range of 12.0 to 20.0%, depending on the moisture content and the loading quantity.

The impact damage on seeds has been the interested subject for research, due to the loss in product quality incurred during harvesting, handling and processing. Researchers have used the different impact damage assessment devices to conduct impact tests on seeds. Many studies have been conducted to determine the mechanical damage to seeds, such as: Fraczek and Slipek (1998) on wheat, Szwed and Lukaszuk (2007) on rapeseed and wheat kernels, Khazaei *et al*. (2008) on wheat seed, Shahbazi (2011) on chickpea seed, Shahbazi *et al*. (2011a) on pinto bean, Shahbazi *et al*. (2011b) on navy bean and Shahbazi (2012) on wheat seed.

The information on the breakage susceptibility of wheat and triticale seeds which related to the moisture content and the impact energy is limited. Therefore, the objective of this study was to investigate the effects of moisture content on the breakage susceptibility of wheat and triticale seeds under impact loading.

2 Materials and methods

The wheat and triticale seeds used for the present study were obtained from a field in the Lorestan University that were cultivated in same condition, in 2011 cultivation season. After attaining an optimum maturity, the samples of the seeds were harvested by hand and cleaned in an air screen cleaner. The initial moisture content of wheat and triticale seeds were 7.5% and 6.8% (w.b.) respectively, determined with ASAE S352.2 (ASAE Standards, 1988). The higher moisture content samples were prepared by adding calculated amounts of distilled water, then sealing in polyethylene bags, and storing at 5ºC for 15 days. The samples were warmed to room temperature before each test and the moisture content was verified. The sample mass was recorded by using a 0.001 g accuracy digital electronic balance.

The laboratory apparatus used to impact seeds, operated in a way similar to the impacting energy instruments used by Asoegwu (1995), Kim *et al*. (2002) and Oluwole *et al*. (2007b) (Figure 1). An aluminum drop bar (800 mm length; 25 mm external diameter; 0.2 kg) was inserted into a steel tube (750 mm length; 27 mm internal diameter; 29 mm external diameter). The steel tube had 4 mm diameter holes drilled at 5 cm intervals from 5 to 60 cm. A pin inserted in the hole in the middle of a steel tube manually controlled the drop height of the aluminum bar. The steel tube was clamped by a laboratory stand. According to the seed, naturally lies on its length (Figure 1) and the preliminary tests showed that the impacts at the side of the seeds were significantly more splits than the impacts at the top, the test seed was placed in the horizontal orientation on the base plate. The aluminum bar was dropped, hit the seed when the pin was manually removed at the given drop height. The impact energy on the seed depends on the mass and drop height of the aluminum bar. The impact energy was determined using the following equation:

$$E_i \approx Mg(H - W) \tag{1}$$

where, E_i is the impact energy (J); M is the mass of the drop bar (0.2 kg); g is the acceleration due to gravity (9.8 m/s^2); H is the drop height from base plate (m); and W is the width (m) of seed (Figure 1).

However, considering the mass of the seed m (kg) that absorbs the impact energy in the systems that cause damage to seed, by the amount of damage done on the seed and dropping the seed from the height unto a hard surface or a mass (M), impact the seed to cause the same amount of damage, the impacting velocity V (m/s), could be determined:

$$\frac{1}{2}mV^2 = E_i = Mg(H - T) \tag{2}$$

$$V = \left[\frac{2E_i}{m}\right]^{1/2} = \left[\frac{2Mg(H-T)}{m}\right]^{1/2} \quad (3)$$

In this experiment, the optimum selected drop heights after preliminary experiment were used for the drop tester. The fixed drop heights of the aluminum bar were 2.5 and 5 cm, so the impact energies on seeds were 0.05 and 0.1 J.

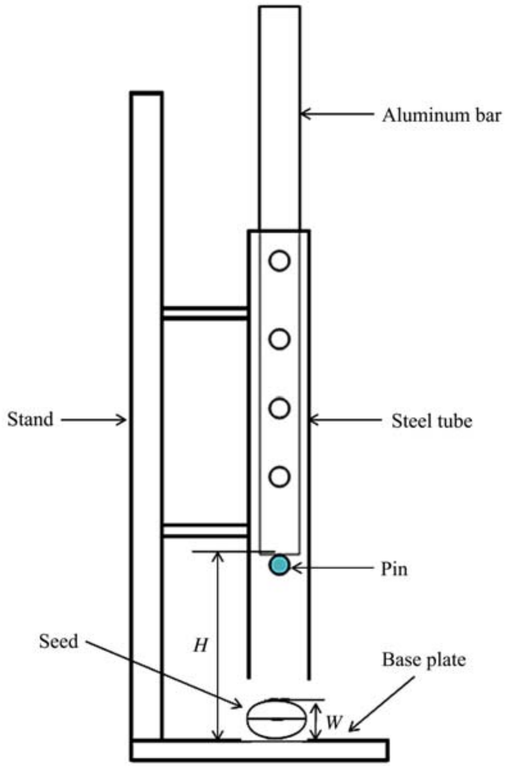

Figure 1 Schematic diagram of the impact test apparatus

In this study, the effects of seed moisture content (at: 7.5%, 12%, 17%, 22% and 27%, w.b.) and impact energy (at: 0.05 and 0.1 J) were studied on the percentage breakage of wheat and triticale seeds. The range of seeds moisture is from 7.5% to 27% as this includes the ordinary moisture levels during harvesting and postharvest processing for seeds (Khazaei *et al*., 2008). The factorial experiment was conducted as a randomized design with three replicates. For each impact test, 100 seeds were randomly selected from each sample and impacted by the impact device (Figure1). After each test, the damaged seeds include the broken, cracked, and bruised seeds were accurately identified and sorted by the visual inspection. A handheld magnifying glass was used. The percentage of the damaged seed was calculated as:

$$Seed\ breakage = \frac{(Weight\ of\ damaged\ seeds)}{(Weight\ of\ total\ seeds\,(damaged + undamaged))} \times 100\% \quad (4)$$

The experimental data were analyzed by using the analysis of variance (ANOVA) and the means were separated at the confidence interval 95% applying Duncan's multiple range tests in SPSS 17 software. The nonlinear regression program of SAS 2001 (SAS, 2001), was used to find and fit the best general models to the data and develop empirical models that explained the relationship between percentage of the damaged seed and the experimental variables.

3 Results and discussion

Analysis of variance indicated that there was a difference between the percentage breakage of wheat and triticale seeds of at the confidence interval 99.99% (P<0.01). In addition, the effects of the seed moisture content and the impact energy on this property were significant at the0.0l level (P<0.01). (Table 1). The seed type had the most influence (F=1679.58) but the impact energy (F=754.49) and the seed moisture content (F=407.27) had the least, respectively, within the studied boundary for the variables (Table 1). The interaction effects of the seed × moisture content, seed × impact energy, moisture content × impact energy and the interactions effect of the three independent variables significantly influenced the percentage breakage of seeds at the 0.01 level (P<0.01) (Table 1).

Table 1 Analysis of variance (mean square) for the percentage of seeds breakage as affected by crop type, the moisture content and the impact energy

Source	DF	Mean square	F
Seed (S)	1	13729.568	1679.580**
Moisture Content (MC)	4	3329.251	407.278**
S × MC	4	216.562	26.493**
Impact Energy (IE)	1	6167.554	754.496**
S × IE	1	292.693	35.806**
MC × IE	4	41.843	5.119**
S × MC × IE	4	64.812	7.929**
Error	40	8.174	

Note: **: Significant at the 0.01 level (P<0.01).

The percentage breakages of seeds at different test conditions are presented in Table 2. The greatest percentage breakage of seeds in Table 2 was obtained as 95.04% in the triticale seeds for the impact energy of 0.1 J at the moisture content of 7.5% (w.b.), while the lowest percentage breakage of seeds was found to be 10.58% in the wheat seeds for impact energy of 0.05 J at a moisture content of 27% (w.b.) (Table 2).

Table 2 Percentage of seeds breakage as a function of crop type, moisture content and impact energy

Crop	Moisture content /% w.b.	Percentage breakage of seeds Impact energy/J	
		0.05	0.1
Wheat	7.5	37.76 (1.29)*	57.87 (3.48)
	12	26.73 (3.38)	38.27 (2.94)
	17	16.32 (2.84)	30.73 (3.28)
	22	8.42 (0.96)	29.34 (1.96)
	27	10.58 (2.18)	21.17 (3.45)
	Mean	18.68 (9.78)	35.21 (11.72)
Triticale	7.5	81.63 (4.09)	95.04 (5.59)
	12	58.73 (6.63)	80.69 (4.56)
	17	40.55 (3.63)	70.25 (7.65)
	22	26.54 (3.78)	56.32 (3.050
	27	23.79 (2.63)	52.42 93.05)
	Mean	44.78 (12.69)	71.61 (20.13)
Total Mean		33.35 (20.88)	53.61 (22.79)

Note: *-Data in parentheses are standard deviation.

The moisture content had high effect on the percentage breakage of both wheat and triticale seeds. As follows from the data in Table 2, for all the impact energies considered, the percentage breakage of both wheat and triticale seeds decreases with increase in their moisture content. These results confirm that, as the moisture content has significant effects on the elastic properties of materials of plant origin, it also has a bearing on the effects of impact damage. At the higher moisture contents, the elasticity of seeds will increase, which causes that their firmness increase, effect to the greater absorption of energy during impact and increases the resistance to damage. On the other hand, at the lower moisture contents, the seeds are more brittle, thus, more prone to physical damage caused by impact. Similar decreasing trends for percentage breakage of seeds by increasing the moisture content were reported by Szwed and Lukaszuk (2007) for rapeseed and wheat, Khazaei *et al*. (2008) for wheat seed, Khazaei (2009) for white kindey bean, and Shahbazi (2011) for chickpea seed.

As follows the data in Table 2, considering all the moisture contents and impact energies that were studied at the same condition of impact tests, triticale seeds had more breakage than wheat seeds. The average value of the percentage breakage of wheat seeds at different test conditions in Table 2 was obtained 26.94% (data not shown) while its value for triticale seeds was obtained as 58.20%. These results show that triticale seeds are more brittle than wheat seeds. These features may be important in the case of selecting the time of harvesting and designing or adjusting the machinery for threshing, handling or processing the seeds. The values of the percentage breakage of seeds increased with increasing of impact energy. Increasing the impact energy from 0.05 to 0.1 J caused an increase in the percentage breakage from 18.68% to 35.21% and from 44.78% to 71.61% for wheat and triticale seeds, respectively. The mean values of the total percentage breakage of seeds at 0.05 J impact energy was 31.73% and its value for 0.1 J impact energy was 53.42% (Table 2).

The results of Duncan's multiple range tests for comparing the mean values of the percentage breakage of seeds (wheat and triticale seeds) at the different moisture contents is presented in Figure 2. It is evident that the percentage breakage of seeds decreased as a quadratic function, with increase in their moisture content (Figure 2). Many researchers have also reported the similar results for the other crops (Parde *et al*., 2002; Szwed and Lukaszuk, 2007; Khazaei *et al*., 2008; Khazaei, 2009). With increasing the moisture content from 7.5% to 27%, the mean values of the percentage breakage significantly decreased by 2.53 times. The average values for the percentage breakage were found to be 62.57%, 51.10%, 40.71%, 33.82% and 24.64% for moisture contents of 7.5%, 12%, 17%, 22% and 27% (w.b.), respectively. The mean values of the percentage breakage at the different moisture contents had significant differences at the 0.05 level (P<0.05) base on the Duncan's multiple range tests (Figure 2).

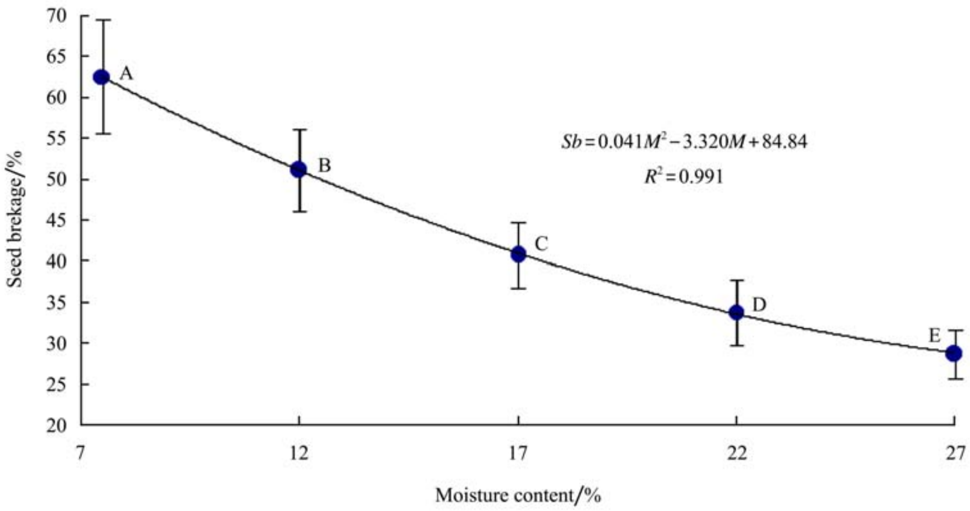

Figure 2 Effects of moisture content on the percentage breakage of seeds (wheat and triticale seeds). Averages with the same letter have no significant difference at the 0.05 level (P<0.05)

Figure 3 shows the relationship between seeds breakage and moisture content of wheat and triticale seeds. The average values for the percentage breakage of wheat seeds were found to be 43.81%, 32.49%, 23.52%, 19.88% and 15.51% for moisture contents of 7.5%, 12%, 17%, 22% and 27% (w.b.), respectively. There is an exponential relationship between breakage and moisture content of wheat seeds with an R^2 value of 0.994. The slope of the curve distinctly changes at about 17% moisture content, with little breakage above that moisture and greatly increasing breakage below that moisture, indicating that the optimal harvesting, the handling and the processing of wheat seeds would be above this moisture content. According to numerous studies, there exists a certain optimum level of moisture content for each variety at which, under the effect of impact forces, there occurs a minimum of damage to the seeds (Szwed and Lukaszuk, 2007). Therefore, in the current study the optimum level of moisture for wheat seeds was about 17% (w.b.).

The average values for the percentage breakage of triticale seeds, in Figure 3, were found to be 81.34%, 69.71%, 55.40%, 44.77% and 37.74% for the moisture contents of 7.5%, 12%, 17%, 22% and 27% (w.b.), respectively. There is an exponential relationship between the breakage and the moisture content of triticale seeds with an R^2 value of 0.991. The curve slope decreases at about 22% moisture content, indicating that the optimum level of moisture for triticale seeds would be above this moisture content.

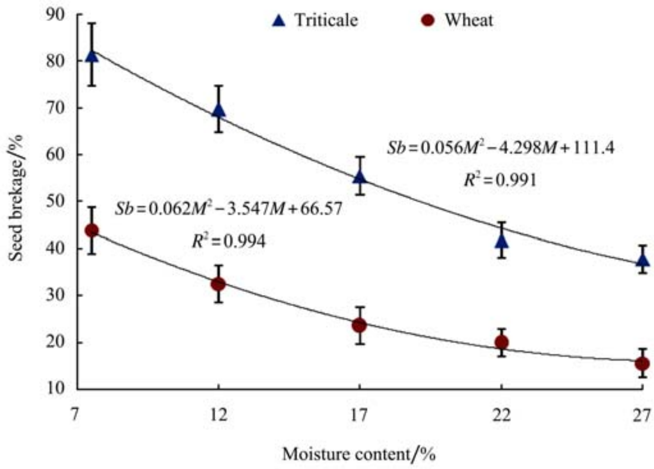

Figure 3 Percentage breakage of wheat and triticale seeds at different moisture contents

4 Conclusions

According the results of this study, the following conclusions can be drawn:

1) There was a significant difference between the percentage breakage of wheat and triticale seeds with different moisture contents at the 0.01 level (P<0.01).

2) It was found that the percentage breakage of wheat and triticale seeds was increased with impact energy. The increase of the impact energy from 0.05 to 0.1 J caused an increase in the percentage breakage of seeds from 18.68% to 35.21% and from 44.78% to 71.61% for

wheat and triticale seeds, respectively.

3) The results showed that an increase in moisture content of both wheat and triticale seeds led to a decrease in the percentage breakage of seeds as a quadratic function.

4) The average values of the percentage breakage of wheat and triticale seeds varied from 43.81% to 19.88%, and 81.34% to 37.77%, respectively, as the moisture content increased from 7.5% to 27% (w.b.).

5) For all moisture contents and impact energies that were studied, triticale seeds had more breakage than wheat seeds.

6) The optimum level of moisture, where the impact damage was minimized, for wheat seeds was about 17% and for triticale seeds was about 22%.

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