Mechanical Damage to Pinto Beans as Affected by Moisture Content and Impact Energy

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ABSTRACT

Mechanical damage of seeds due to harvest, handling and other process is an important factor that affects the quality of seeds. Seed damage results in lower grain value, storability problem, and reduces seed germination and seedling vigor and subsequent yield of crops. Tests were conducted to determine the extent of percentage of physical damage (PPD) and percentage of loss in germination (PLG) (physiological damage) of pinto beans due to impact. The effects of beans moisture content (9.25, 12.51, 15.02 and 17.50%, wet basis) and impact energy (0.09, 0.19 and 0.29J) were determined. The tests were conducted under laboratory conditions, using an impact test apparatus. Results showed that effects of moisture content and impact energy on seed damages were significant. PPD to beans was higher than PLG. It found that the total damage of beans increased from 54.45% (48.14 PPD and 6.31 PLG) to 73.20% (63.40 PPD and 9.80 PLG) as the impact energy increased from 0.9 to 0.29J, for all the moisture contents used. With increasing the moisture content from 9.25 to 17.50%, the mean values of the percentage of loss in germination of beans increased from 0.53 to 15.30%. However, by increasing in the moisture from 9.25 to 17.50%, the mean values of percentage of physical damage to beans decreased from 92.67 to 21.53%.

Keywords: Physical damage, reduce in germination, moisture content, impact energy, pinto bean.

1. INTRODUCTION

Legumes, such as pinto beans (*Phasaeolus vulgaris*), widely grown and consumed throughout the world, are excellent sources of proteins (20-25%) and carbohydrates (50-60%) and good sources of minerals and vitamins (Aykroyd and Doughty, 1977). Legumes are major food source for both human and animals, due to their nutritional benefits, such as high content in fibres and low content in fats, as well as being a cheap source of high protein content (Muzquiz *et al*., 1999; Sathe, 2002).

Beans seed quality is greatly affected by harvesting, cleaning, drying, handling and storage activities during the seed production process. In these operations, seeds are often subjected to impact forces repeatedly against metal surfaces predisposing them to mechanical damage. Pinto beans and other large seeded legumes are especially vulnerable to rough treatment. These seeds are particularly delicate because of their seed anatomy. The seed coat, or testa, of these seeds is very thin and easily cracked, making them susceptible to mechanical damage during handling and drying. In addition, the plumule and radicle, parts of the seed embryo, are just under the seed coat and can easily be bruised by rough handling. Because they are dicotyledons, these plants can easily be broken in two. The consequence of the mechanical damage is broken seeds and cracks, as well as invisible internal damages. The mechanical damage decreases the commercial values of seeds. It also decreases the biological values of seeds. The principal effect of the negative influence of the mechanical damage is the reduction of germination and yields. This is a serious problem for seed production (Grass and Tourkmani, 1999).

Moisture content is the most important factor following harvest, because it affects postharvest losses both in quantity and quality. Generally, mechanical injury occurs during harvesting when the pods are threshed, but injury can also occur any time when the seeds are processed or handled including during planting (Copeland and Saettler, 1982). Harvesting legumes at low moisture make them susceptible to mechanical injury. Depending on the operation, legume crops may experience free fall ranging from a few meters on the farm to a drop of over 50 m at certain grain terminals (Chawla *et al*., 1998).

The mechanical resistance to the impact damage of seeds, such as beans, among other mechanical and physical properties, plays a very important role in the design of harvesting and other processing machines (Baryeh, 2002). The Knowledge of this basic information is necessary, because during operations, in these sets of equipment, seeds are subjected to impact loads which may cause mechanical damage. Impact damage of seeds depends on a number factors such as velocity of impact, seed structural features, seed variety, seed moisture content, stage of ripeness, fertilization level and incorrect settings of the particular working subassemblies of the machines. These parameters must be considered during harvest, transport, storage, processing and other technological stages for seeds, in which the damage occurs. Among above factors, the seed moisture content and impact velocity (energy) are important factors influencing the damage. Khazaei (2009) indicated that increasing the impact velocity from 5 to 12 m/s caused an increase in the mean percent of physical damage of kidney beans from 3.25 to 37.5%. With increasing the moisture content from 5 to 15%, the mean values of percentage of damaged beans decreased by 1.4 times.

However, studies conducted on the effect of moisture content and applied impact energy on the mechanical damage of pinto beans appears to have not been adequately attention. Technical information and data in the scientific literature concerning the physical and physiological damages of pinto beans under different impact energy at the different moisture contents are insufficient. In light of above facts, the objective of this research was to to evaluate the mechanical damage to pinto bean seed due to impact (PPD=percentage of physical damage and PLG=percentage of loss in germination) and determine the effects of moisture content and impact energy on the amount of damage.

2. MATERIALS AND METHODS

Samples of pinto bean (*cv. Cos-16*) at optimum maturity were harvested by hand in Lorestan province, Iran, in summer, 2010, and cleaned in an air screen cleaner. The initial moisture content was 9.25% (wet basis), determined with ASAE S352.2 for edible beans (ASAE, 1988). 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. Samples were warmed to room temperature before each test and moisture content was verified. Sample mass was recorded with a digital electronic balance having an accuracy of 0.001 g. To determine the average size of the beans, 100 beans were randomly picked and their three linear dimensions namely, length (*L*), width (*W*) and thickness (*T*) were measured using a digital micrometer with an accuracy of 0.01 mm. The average diameter of bean was calculated by using the arithmetic mean and geometric mean of the three axial dimensions. The arithmetic mean diameter D_a and geometric mean diameter D_g of the grain were calculated by using the following relationships (Mohsenin, 1970):

$$D_a = (L + W + T)/3 \quad (1)$$

$$D_g = (LWT)^{1/3} \quad (2)$$

Where: *L* is the length, *W* is the width, and *T* is the thicknes.

The tests were conducted under laboratory conditions. Each sample was impacted using an impact device shown in Figure 2.

For each sample of different moisture content, 100 beans were randomly selected (in three replicates) and each bean was subjected to impact by a specially constructed impact test apparatus. The laboratory apparatus used to impact beans, operated in a way similar to the impacting energy instruments used by Asoegwu (1995), Kim *et al*. (2002) and Oluwole *et al*. (2007) (Figure 2). An aluminium 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. The drop height of the aluminum bar was manually controlled by a pin inserted in the hole in the middle of a steel tube. The steel tube was clamped to a laboratory stand. Because the bean naturally lies on its radial diameter (Figure 2) and preliminary tests showed that impacts to the side of the seeds resulted in significantly more splits than impacts to top the bean seed was placed in the horizontal orientation on the base plate. The aluminum bar dropped, hitting the bean when the pin was manually removed at the given drop height. The impact energy on bean depends on the mass and drop height of the aluminum bar. The impact energy was determined using the following equation:

$$E_i \approx Mg(H - T) \quad (2)$$

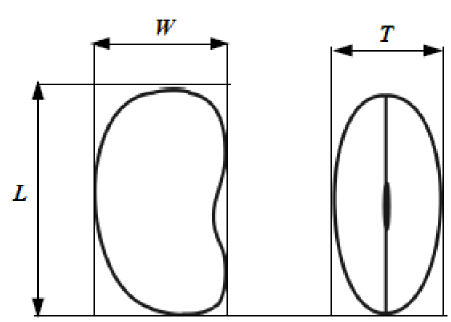

Figure 1. Typical dimensions of bean seeds: *L* – length, *W*– width, *T*– thickness.

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 T is the thickness (m) of the seed (Figure 2).

In practice, some of the impact (total) energy will be lost due to rebound, such that the absorbed impact energy E_a becomes more relevant to the cracking observed than total impact energy:

$$E_a \approx Mg(H_1 - H_2) \qquad (3)$$

Where: E_a is the absorbed impact energy (J), H_1 is the original drop height (m) and H_2 is the rebound height (m). However, it is assumed that H_2 is very small and negligible ($H_1 >> H_2$) and thus the rebound energy was ignored (Kim *et al*., 2002).

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

$$\frac{1}{2}mV^2 = E_i = Mg(H - T) \qquad (4)$$

$$V = \left[\frac{2E_i}{m}\right]^{1/2} = \left[\frac{2Mg(H - T)}{m}\right]^{1/2} \qquad (5)$$

The heights of fall used were 5, 10 and 15 cm from base plate. The average values of the temperature and relative humidity of the laboratory where the tests were carried out were 25±2°C and 50% ±10%, respectively.

In this study, the effects of seed moisture content (at: 9.25, 12.51, 15.01, and 17.50% wet basis) and impact energy (at: 0.09, 0.19 and o.29J) were studied on the mechanical damage of pinto bean seeds. The range of seeds moisture is from 7.5 to 17.50% as this includes the normal range of moisture levels during harvesting and post harvesting. The factorial experiment was conducted as a randomized design with three replicates. For each impact test 100 seeds were selected randomly from each sample and impacted by using the impact device.

Seed damage was evaluated using two different methods. The first method was by visual inspection of the physical damage to seeds including splits, cracks, or any seed coat penetration. Physical damage was quantified by removing damaged seeds from the sample and expressing this weight as a percent of the original sample weight (Khazaei *et al*., 2008). The second assessment method was to quantify hidden damage (physiological damage) to the seeds. Hidden damage was determined by subjecting the undamaged seeds from each combination of variables to germination tests. For germination tests, samples were placed in presoaked germination paper and then placed in a seed germinator at 20 ^{o}C for 7 days. After 7 days, the percentage of seeds, which were normally germinated, was recorded (Bourgeois *et al*., 1995; Khazaei *et al*., 2008).

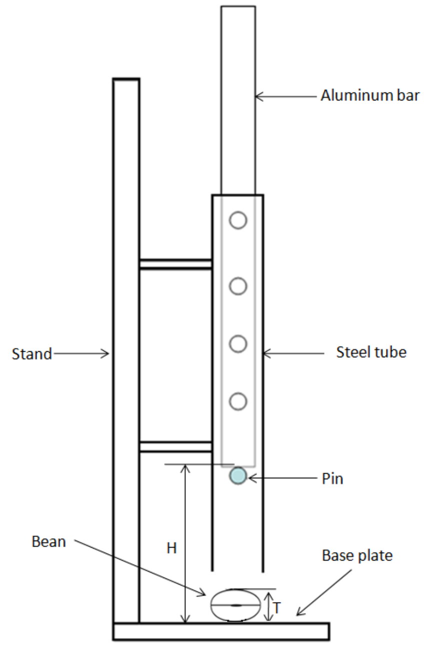

Figure 2. Schematic diagram of the impact test apparatus.

The loss of germination was determined based on the initial percentage of germination of the untreated (control) seeds (Table 1). Total damage was calculated as the sum of the PPD and PLG damages.

3. RESULTS AND DISCUSSION

Table 1 shows the mean, minimum, maximum, and standard deviation of the length, width, thickness, arithmetic and geometric mean diameter, weight and check germination of the beans at 9.25 % w.b. moisture content. Table 2 shows the analysis of variance (Mean square error) for the percentage of physical damage (PPD), percentage of loss in germination (PLG) and total damage to seeds as affected by moisture content and impact energy. From this table, it can be seen that the effects moisture content and impact energy are significant on the PPD, PLG and total damage to seeds at 1% probability level (Table 2). The interaction effects of two variables were not significant on the physical, physiological and total damages to seeds. Moisture content had the most influence on the both physical and physiological damages to seeds than impact energy, while impact energy had the most influence on the total damage than moisture content, within the ranges studied (Table 2).

Table 1. Some physical properties of studied beans at 9.25 % w.b. moisture content.

Parameters	Mean	Maximum	Minimum	Standard deviation
Length, mm	11.88	14.42	10.84	0.85
Width, mm	7.44	8.54	6.25	0.51
Thickness, mm	5.51	6.99	4.41	0.59
Arithmetic mean diameter, mm	8.27	9.54	7.42	0.53
Geometric mean diameter, mm	7.86	9.06	6.98	0.54
Weight, g	0.33	0.52	0.21	0.07
Initial (check) germination, %	96.80	99.12	94.25	3.41

Table 2. Analysis of variance (Mean square) for the percentage of physical damage, percentage of loss in germination and total damage to seeds as affected by moisture content and impact energy.

Source of variation	DF	Mean square (MS)		
		PPD (Percentage of physical damage)	PLG (Percentage of loss in germination)	Total damage (PPD+PLG) (%)
Moisture Content (MC)	3	11847.277**	327.352**	8964.255**
Impact Energy (IE)	2	700.739**	36.524**	1056.617**
MC×IE	6	69.512^{ns}	10.730^{ns}	55.054^{ns}
Error	24	34.007	5.685	33.785

**: significant at the 0.01 probability level.
^{ns}: not significant.

Table 3 shows the Duncan's multiple range tests comparing the means of each independent variable. From Table 3 it is evident that moisture content had a decreasing effect on the PPD to bean seeds. With increasing the moisture content from 9.25 to 17.50%, the mean values of the PPD damage decreased by 4.3 times (from 92.67 to 21.53%), in all of the impact energy levels considered. A number of researchers have also reported similar results for other seeds (Liu *et al*., 1990; Bergen *et al*., 1993; Fraczek and Slipek, 1998; Sosnowski and Kuzniar, 1999; Parde *et al*., 2002; Khazaei *et al*., 2008; Khazaei, 2009; Shahbazi, 2011). Sosnowski (2006) concluded that PPD to bean seeds showed a decreased trend as moisture content increased from 15 to 25%. However, with further increase in moisture content, from 25 to 29%, an increasing trend in PPD was observed. Khazaei (2009) reported that with increasing the moisture content from 5 to 15%, the mean values of percentage of damaged beans decreased by 1.4 times. From the data in Table 3, it can be seen that for the PPD damage, the effect of moisture content is significantly different at 5% level. However, the data showed that moisture content had an increasing effect on PLG damage to bean seeds under impact tests (Table 3). The PLG increased from 0.53 to 15.30% as moisture content increased from 9.25 to 17.50%. However, some of the differences were not significant, especially at 12.51, and 15.01% moisture contents (Table 3). It was found that the seeds with lower moisture content could better withstand physiological damage than the seeds with higher moisture content. Chawla *et al*. (1998) also reported that moisture content, in the range of 12.8 to 20.4%, had an increasing effect on PLG to bean seeds, but it had no significant effect on PLG to peas. Kirkkari *et al*. (2001) concluded that, the greater the grain moisture content at harvest, the more damage was caused by the threshing unit. The total damage (PPD+PLG) to seeds decreased by 2.53 times (from 93.20 to 36.70%) as moisture content increased from 9.25 to 17.50% However the differences at 9.25 and 12.51 moisture contents were not significant (Table 3).

From Table 3 it is seen that, impact energy had a significant increasing effect on the PPD to bean seeds. With an increase in impact energy from 0.09 to 0.29 J, the mean value of PPD increased from 48.14 to 63.40%. For the PPD, the mean and the effect of all applied impact energy levels differed at 5% level of significance. The data in Table 3 showed that the impact energy also had a significant increasing effect on PLG to bean seeds under impact test. However, the effect of impact energy on PPD is significantly higher than that for PLG. The mean values of PLG increased from 6.31 to 9.80% with increasing in the impact energy from 0.09 to 0.29J.

From Table 3, it can be seen that for PLG, the effect of impact energy is significantly different at 5% level. Similar results have been reported for other grains by other investigators (Chawla *et al*., 1998; Kirkkari *et al*., 2001; Baryeh, 2002; Khazaei *et al*., 2008). Parde *et al*. (2002) concluded that an average germination loss of 10 and 31% was observed when soybean seeds fell from a height of 1 and 2 m, respectively, onto a cement floor. This drop in germination was 7.5 and 22% when the seeds dropped from the same heights on to galvanized iron floor. Baryeh (2002) observed that at 10% moisture content of bambara beans, PPD increased from 10% at 3 m/s impact velocity to 33% at 15 m/s velocity. 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%. Valentine and Hall (1990) reported that for oat seeds even at a low threshing speed (850 rpm), germination above 85% could not be guaranteed. Sosnowski (2006) found that with an increase in impact velocity from 7 to 27 m/s, the mean value of physically damaged beans seeds of Wiejska variety increased from about 0 to 35%. He found that the germination capacity of bean seeds was decreased from about 90% at impact velocity of 6.44 m/s to about 58% at impact velocity of 13 m/s. Khazaei *et al*., (2008) reported that the loss in germination of wheat seeds threshed at 25 to 30 m/s was in the range of 12.0 to 20.0%, depending on the moisture content and the number of loadings. Corresponding values for PPD were in the range of 21.9 to 35.8%. From data in Table 3 it is seen that the total damage to seeds increased by 1.34 times (from 54.45 to 73.20%) as impact energy increased from 0.09 to 0.29J.

Figure 3 shows the interaction effects of moisture content and impact energy on the PPD to seeds. From Figure 3 it can be seen that, increasing of impact energy for each moisture content increased the PPD. The effects of impact energy on PPD were more pronounced at the lower moisture content levels. The average value for the PPD, to bean seeds, in Figure 3 found to be 56.01 %. In Figure 3, the greatest PPD value obtained as 96.94%, occurred in the 0.29J energy for the 9.25% moisture content. The lowest value found to be 13.79% occurred in the 0.09J energy for the 17.50% moisture content.

Table 3. The Duncan's multiple range tests comparing the means of each independent variable.

Independent variable	PPD	PLG	Total damage (PPD+PLG, %)
Moisture content (%)			
9.25	92.67 a	0.53 c	93.20 a
12.51	81.51 b	8.02 b	89.53 a
15.01	28.33 c	8.37 b	36.83 b
17.50	21.53 d	15.30 a	36.70 b
Impact energy (J)			
0.09	48.14 c	6.31 c	54.45 c
0.19	56.50 b	8.04 b	64.54 b
0.29	63.40 a	9.80 a	73.20 a

Means followed by the same letter for columns (a, b, c and d) are not significantly different (P= 0.01).

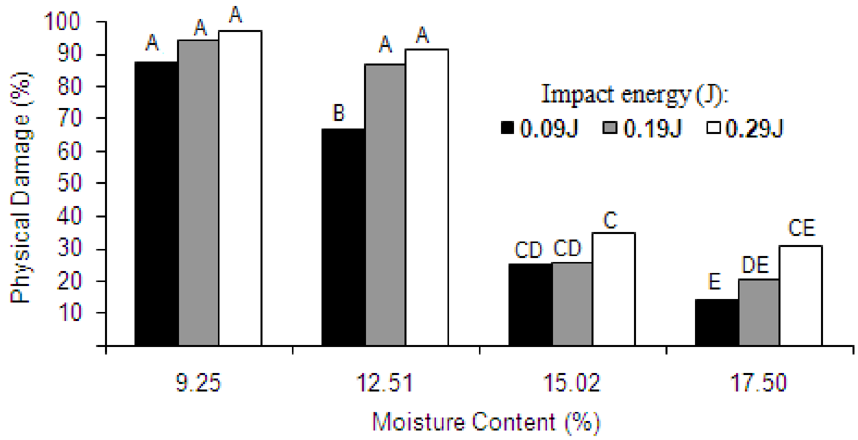

Figure 3. Effect of moisture content and impact energy interactions on percentage of physical damage of beans.

The means of the PLG due to different treatments are given in Figure 4. Increased impact energy from 0.09 to 0.29J caused an increase in the physiological damage to bean seeds for all moisture contents. In addition, the physiological damage to bean seeds increased as moisture content increased for all impact energies used. In Figure 4 the lowest physiological damage among the combinations was found to be 0% occurred in the 0.09J impact energy with the moisture content of 9.25%, while the greatest physiological damage was obtained as 17.74%, occurred in the 0.29J impact energy with the moisture content of 17.50%. The average value for the PLG damage to bean seeds in Figure 4 was found to be 8.16%. In comparison to the average values for the PPD in Figure 3 (56.01%), it was found that the percentage of physical damage to bean seeds was 6.86 times higher than that of the percentage of physiological damage. This data shows that the effect of impact energy on PPD to pinto bean seed was more important than that for PLG.

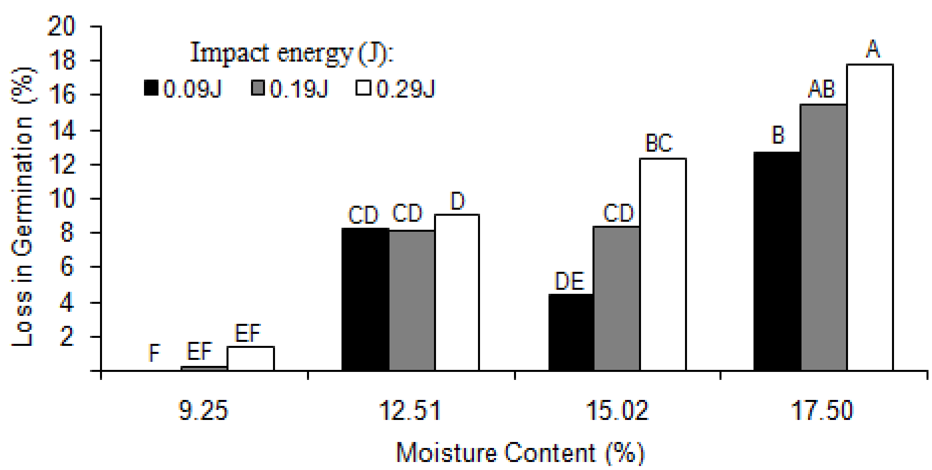

Figure 4. Effect of moisture content and impact energy interactions on the percentage of loss in germination of beans.

Figure 5 shows the total damage (sum of the PPD and PLG) to pinto bean seeds at different moisture contents and impact energies used. From this figure, it can be seen that at four moisture contents, 0.29J impact energy had the highest levels of damage than other energies. The percentage of the total damage to seeds in this energy was found to be 98.35, 99.13, 47.11, and 48.23 %, at moisture contents of 9.25, 12.51, 15.02 and 17.50%, respectively. The lowest total damage among the combinations was found to be 26.46% occurred in the 0.09J impact energy with the moisture content of 17.50%, while the greatest damage was obtained as 99.13%, occurred in the 0.29J impact energy with the moisture content of 12.51%.

These results indicate that if producers do not pay close attention to the combine settings and great care is not taken during handling and processing of pinto beans, a large amount of physical and physiological damage to the seed can occur. Bases on these results, the best conditions for harvesting and other processing for pinto bean seeds, in which seeds are subjected to impact loads, will be recommended the moisture content about 17.5% and impact energy limited to 0.09J. These features may be important in the case of selecting the time of harvesting and designing or adjusting the threshing and other mechanisms for handling or processing the seeds, in order to limit the impact energy of machine parts to 0.09J from the viewpoint of minimizing yield losses due to the share of damaged seeds.

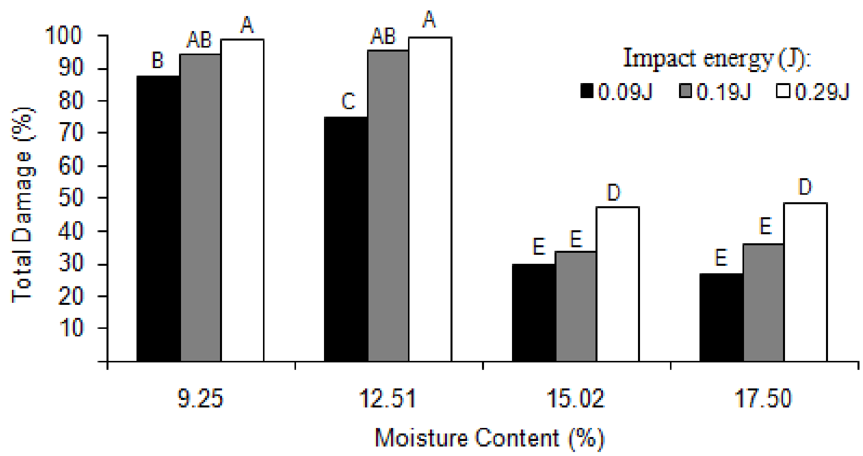

Figure 5. Interaction effects of moisture content and impact energy on the total damage to beans.

4. CONCLUSION

From this study, the following conclusions were drawn:

1. The results indicated that all of the two independent variables, namely, moisture content and impact energy significantly ($P = 0.01$) influenced the PPD, PLG and total damage of pinto bean seeds.
2. Increasing the impact energy from 0.09 to 0.29J caused an increase in PPD and PLG from 48.14 to 63.40% and from 3.31 to 9.80%, respectively. Impact energies of 0.19 and 0.29J caused the highest levels of PPD, PLG and total damage.
3. Physical damage to pinto bean seeds due to impact, was approximately 6.86 times higher than physiological damage to that.

4. Moisture content was a significant factor that causing the physical and physiological damages to bean seeds. The seeds with higher moisture content could better withstand physical damage rather than those with lower moisture content.
5. As the seed moisture level increased from 9.25 to 17.5%, the mean values of the PPD decreased from 92.67 to 21.53%, however, the mean values of PLG increased from 0.53 to 15.30%.
6. There exists a certain optimum level of moisture content at which, under the effect of impact forces, there occurs a minimum of damage to the seeds. In the case of pinto bean seeds, that optimum level of moisture was about 17.5%.

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