DOI: 10.1515/cerce-2017-0031
Available online: www.uaiasi.ro/CERCET_AGROMOLD/
Print ISSN 0379-5837; Electronic ISSN 2067-1865

Original Article

Cercetări Agronomice în Moldova
Vol. L , No. 4 (172) / 2017: 5-16

CRUSHING SUSCEPTIBILITY OF VETCH SEEDS UNDER IMPACT LOADING

F. SHAHBAZI[1]*

*E-mail: shahbazi.f@lu.ac.ir

Received Jun. 02, 2017. Revised: Jul. 25, 2017. Accepted: Sep. 22, 2017. Published online: Dec. 27, 2017

ABSTRACT. Mechanical damage of seeds due to harvest, handling and other process is an important factor that affects the quality and quaintly of seeds. The objective of this research was to determine the effects of moisture content and the impact energy on the breakage susceptibility of vetch seeds. The experiments were conducted at moisture contents of 7.57 to 25% (wet basis) and at the impact energies of 0.1, 0.2 and 0.3 J, using an impact damage assessment device. The results showed that impact energy, moisture content, and the interaction effects of these two variables significantly influenced the percentage breakage in vetch seeds (*p*<0.01). Increasing the impact energy from 0.1 to 0.3 J caused a significant increase in the mean values of seeds breakage from 41.69 to 78.67%. It was found that the relation between vetch seeds moisture content and seeds breakage was non-linear, and the extent of damaged seeds decreased significantlyas a polynomial (from 92.47 to 33.56%) with increasing moisture (from 7.57 to 17.5%) and reached a minimum at moisture level of about 17.5%. Further increase in seed moisture, however, caused an increase in the amount of seeds breakage. Mathematical relationships composed of seed moisture content and impact energy, were developed for accurately description the percentage breakage of vetch seeds under impact loading. It was found that the models have provided satisfactory results over the whole set of values for the dependent variable.

Keywords: vetch seed, breakage susceptibility, moisture content, impact energy.

INTRODUCTION

Common vetch (*Vicia sativa* L.) is one of the most common fodder plants in Iran grown mainly for hay, green forage, silage and grain. The crude protein content of common vetch is 12-24% in hay and over 20% in grain (Yalçın & Özarslan, 2004).

The breakage resistance to the impact of seeds among other mechanical and physical properties

[1] Lorestan University, Faculty of Agriculture, Department of Biosystems Engineering, Khoram Abad 6815144316, Iran

plays a very important role in the design of harvesting and other processing machines (Baryeh, 2002). The value 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. Damaged seed have a lower price in the market and is vulnerable to attack by insects and mold. On the order hand, to design equipment and facilities for the shelling of vetch seeds, it is necessary to determine their breakage susceptibility as a function of moisture content.

Breakage susceptibility of seeds depends on a number factors, such as energy 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 (Shahbazi, 2011; Shahbazi *et al.*, 2011a). Among these factors, the seed moisture content and impact energy are important factors influencing the seed breakage. Some researchers found a significant influence of the impact energy and moisture content upon the seed breakage and found that the breakage increases significantly as the energy of the impact increases and as the moisture content decreases (Khazaei *et al.*, 2008; Khazaei, 2009; Shahbazi *et al.*, 2011a, b). Breakage susceptibility of seeds has been the subject of much research due to the loss in product quality incurred during harvesting, handling and processing. Researchers have used different impact damage assessment devices to conduct impact tests on seeds.

Because of the complex nature of breakage susceptibility of seeds, accurate designing, controlling and adjusting of threshers, harvesters, conveyors, and other processing systems is difficult. This necessitates the accurate design and the use of an automatic system for controlling and adjusting of harvesters and other processing systems. Automatic controlling of seeds processing systems needs to have practical data for those involved in equipments, which are used in harvesting, handling and other processing systems for seeds and a more powerful prediction model to be able to estimate the effects of several independent variables on several dependent ones.

During the last decade, various forms of multiple linear regression models have been widely considered to estimate the mechanical damage to seeds, based on the machine and crop parameters (Sosnowski & Kuzniar, 1999; Baryeh, 2002; Szwed & Lukaszuk, 2007; Khazaei, 2009; Shahbazi *et al.*, 2001a, b; Shahbazi, 2011).

It seems that there is not much published work relating to breakage susceptibility of vetch seed to energy of impact and seed moisture content and modeling the breakage susceptibility of seeds is limited. Hence, this study was conducted to: 1) investigate breakage susceptibility of vetch seed and determine the effects of impact energy and seed moisture content on the percentage breakage of seeds; 2) develop empirical models that explain the relationship between percentage of breakage and the experimental variables for vetch seeds and evaluate the predictive performance of the models.

MATERIALS AND METHODS

Samples of common vetch seeds at optimum maturity were harvested by hand in Lorestan Province, Iran, and cleaned in an air screen cleaner. The initial moisture content was 7.57% (wet basis), determined with ASAE S352.2 for edible beans (ASAE Standards, 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.

The laboratory apparatus used to impact seeds, operated in a way similar to the impacting energy instruments used by Kim *et al*. (2002), Oluwole *et al*. (2007), Shahbazi *et al*. (2012) and Shahbazi (2014). A schematic diagram of the impact test apparatus is shown in *Fig. 1*. An aluminum drop bar (800 mm length; 25 mm external diameter; 0.21 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. The aluminum bar dropped, hitting the seed when the pin was manually removed at the given drop height. The impact energy on seed depends on the mass and drop height of the aluminum bar. In this experiment the impact energies on seeds were 0.1, 0.2 and 0.3 J.

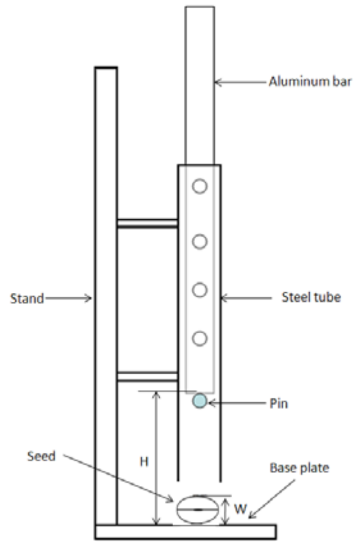

Figure 1 - Schematic diagram of the impact test apparatus

In this study, the effects of impact energy (at: 0.1, 0.2 and 0.3 J) and seed moisture content (at: 7.57, 10, 12.5, 15, 17.5, 20 and 25% wet basis) were studied on percentage breakage of vetch seeds. The range of seeds moisture is from 7.57 to 25% as this includes the normal range of moisture levels during harvesting and postharvest processing for seeds (Khazaei, 2009). The impact energy was ranged from 0.1, 0.2 and 0.3 J, including those happening in harvesters, separator, conveyors, storing system, and other processing systems (Shahbazi *et al*., 2014). 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. After each test, damaged seeds include the broken, cracked, and bruised seeds were accurately identified and sorted by visual inspection. A handheld magnifying glass was used to augment the visual inspection. The percentage of seed breakage was calculated as:

$$\text{Seed Breakage (SB)} = \frac{\text{Weight of damaged seeds}}{\text{Weight of total seeds}} \times 100 \quad (1)$$

Experimental data were analyzed using analysis of variance (ANOVA) and the means were separated at the 5% probability level applying Duncan's multiple range tests in SPSS 17 software. The nonlinear regression program of SAS (SAS, 2001) was used to find and fit the best general models to the data and develop empirical models, that explain the relationship between percentage of seed damage and the experimental variables.

RESULTS AND DISCUSSION

Table 1 shows the ANOVA (mean square) for the percentage of breakage of vetch seeds as affected by moisture content and impact energy. The breakage susceptibility of vetch seeds is affected by the moisture content, impact energy and interaction effects of two variables at 1% probability level (p<0.01). Impact energy had a larger influence (F=270.2) than moisture content (F=154.94) within the range studied.

Table 1 - ANOVA (Mean square error) for the percentage breakage of vetch seeds as affected by moisture content and impact energy.

Source of variation	DF	Mean square	F
Moisture content (MC)	6	4101.588	151.945**
Impact energy (IE)	2	7293.769	270.200**
MC×IE	12	222.501	8.243**
Error	42	26.994	

** significant at % level

Effect of moisture content

The moisture content had a significant effect on the percent breakage of vetch seeds. The results of Duncan's multiple range tests for comparing the mean values of the percentage breakage of vetch seeds at the different moisture contents is presented in *Fig. 2*. As follows from the relation presented in this figure, the percentage breakage of vetch seeds decreases when the moisture content increases. These results show that the moisture content of the seeds has significant effects on their elastic properties. With increasing moisture content of seeds their elasticity and firmness will increase which causes to greater absorption of impact energy during impact loading so increases the resistance to impact 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 & 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. The mean values of seeds damage decreased significantly by a factor of 2.75 (from 92.47 to 33.57%) with increase in the moisture content from 7.57 to 17.5%. However, by a higher increase in the moisture from 17.5 to 25% caused an increase in the amount of seeds breakage from 33.57 to 55.95%. The average values for the percentage breakage were found to be 92.47, 77.40, 61.74, 47.83, 33.56, 39.84 and 55.95% for moisture contents of 7.57, 10, 12.5, 15, 17.5, 20 and 25% (w.b.), respectively (*Fig. 2*).

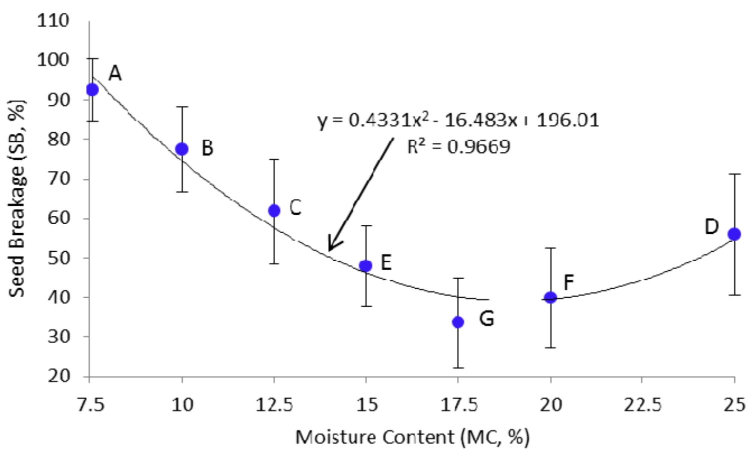

Figure 2 - Effects of moisture content on percentage breakage of vetch seeds

The relation of the percent breakage of vetch seeds rate, presented in the *Fig.* 2, is non-linear, and the appearance of minimum values of breakage rate at a certain moisture content range is a feature characteristic for the tested seeds. The shape of the graph in the figure show that the changes in seed breakage rate plots quadratic function for vetch seeds. Many researchers have also reported the similar results for the other crops (Tang *et al*., 1991; Parde *et al*., 2002; Szwed & Lukaszuk, 2007; Khazaei *et al*., 2008; Khazaei, 2009). The extent of breakage of impacted seeds decreased with increasing moisture and reached a minimum at moisture level of about 17.5%. Further increase in seed moisture, however, caused an increase in the amount of seeds breakage. According to numerous studies, there is a certain optimum level of moisture content for each variety, at which, under the effect of impact forces, there is minimum of damage (breakage) to the seeds (Szwed & Lukaszuk, 2007).

Therefore, in the case of vetch seeds, the optimum level of moisture is about 17.5%. The following best-fit regression equation was obtained for the relationship between vetch seed breakage (SB, %) and moisture content (MC, %):

$$SB=196.01-16.48\ MC+0.43\ MC^2 \quad R^2=0.9669 \qquad (2)$$

The above equation applies to moisture content between 7.57 and 25%. All the indexes are significant at the level of 99.95%.

Fig. 3 shows the vetch seed breakage variation with seed moisture content for various impact energies. As follows from the figure, for all the impact energies considered, the percentage of the seed breakage 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 plays an important role on the effect of resistance to impact. At higher moisture contents, the elasticity of seeds will increase, which causes that their firmness increase, thus, causes greater absorption of energy during impact and increases the resistance to damage. On the other hand, at lower moisture contents, the seeds are more brittle, thus, more prone to physical damage caused by impact (Khazaei *et al*., 2008; Khazaei, 2009).

As shown in *Fig. 3*, the rates of increase in percent damage to seeds by decreases in their moisture content are not the same for all the levels of impact energies. The effect of moisture content on the breakage is stronger at higher impact energies than at lower ones. As shown in figure for all the impact energies considered, the extent of the seed breakage decreased with increasing moisture and reached a minimum at moisture level of about 17.5%. Further increase in seed moisture, however, caused an increase in the amount of seed breakage, shown that for all the impact energies considered, the optimum level of moisture content there occur minimum of breakage of vetch seeds is about 17.5%.

Fig. 3 indicates that for all the impact energies, relations of breakage rate are non-linear with seed moisture content. Regression analysis was used to find and fit the best general models to the data. Results showed that the percentage breakage of vetch seeds was a quadratic function of their moisture content, at all the impact energies considered. Szwed & Lukaszuk (2007) observed similar behavior for other crops. The equations representing the relationship between the percentage breakage of vetch seeds and moisture content at different impact energy and their coefficients of determination (R^2) are presented in *Table 2*. As follows from the relations, the effect of moisture is stronger for the higher levels of energy than in the case of the lower ones (higher values at variable MC^2).

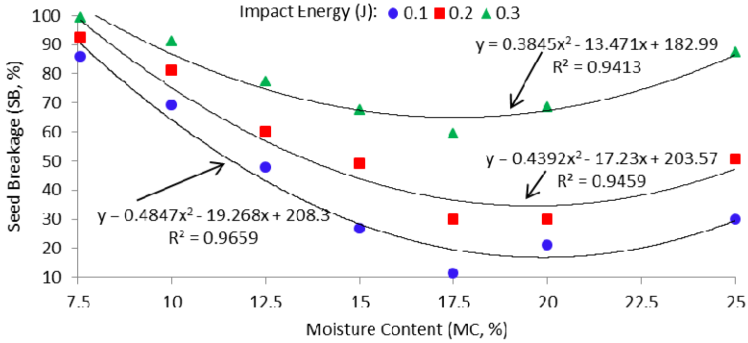

Figure 3 - Vetch seeds breakage variation with seed moisture content for different impact energies

Table 2 - Equations representing the relationship between the percentage breakage of vetch seeds (SB) and moisture content (MC) for each impact energy

Impact energy (J)	Equation	R^2
0.1	$SB = 208.3 - 19.268\ MC + 0.4847\ MC^2$	0.9659
0.2	$SB = 203.57 - 17.32\ MC + 0.4392\ MC^2$	0.9549
0.3	$SB = 182.99 - 13.471\ MC + 0.3847\ MC^2$	0.9613

All the indexes are significant at the level of 99.95%. SB= seed breakage (%); MC= moisture content (%).

Effect of impact energy

The impact energy had high effect on the percentage breakage of vetch seeds. The results of Duncan's multiple range tests for comparing the mean values of vetch seed breakage, in the moisture content between 7.57 and 25%, at different impact energies is shown in *Fig. 4*. It is evident that seed breakage increased, as a quadratic function, with increasing impact energy. For all the levels of impact energy, the differences between the mean values of the breakage percent are significant (p=0.05). When the impact energy was increased from 0.1 to 0.3 J, the mean value of the breakage percent increased about 36.97% (from 41.69 to 78.68%). The corresponding value for increasing the impact energy from 0.1 to 0.2 J and from 0.2 to 0.3 J, were about 14.41 and 22.56%, respectively. Similar results about incrasing the seeds damage with impact energy have been reported by other researchers (Khazaei *et al.*, 2008; Shahbazi, 2011; Shahbazi *et al.*, 2011a and b; Shahbazi *et al.*, 2017). Shahbazi *et al.* (2012) found that increasing 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. The vetch seed breakage (SB, %) was related to operation of impact energy (IE, J) for the the avearge values of moisturebetween

7.57 and 25%, by the following best-fit regression equation:

$$SB=35.436+21.82\ IE+407.46\ IE^2 \quad R^2=0.999 \qquad (3)$$

The above equation applies to impact energy 0.1 to 0.3 J. All the indexes are significant at the level of 99.95%.

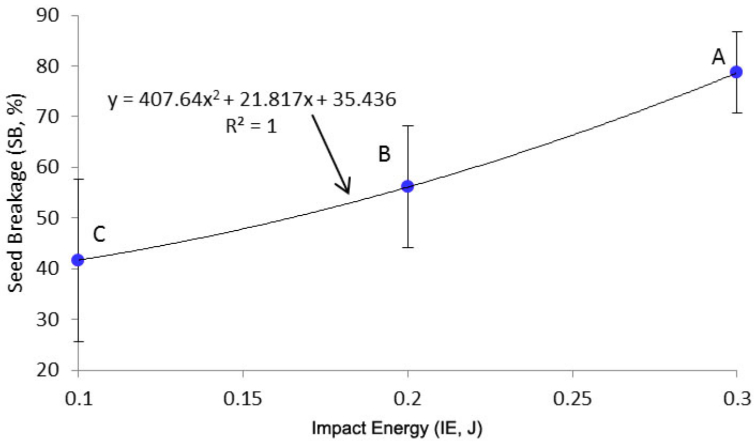

Figure 4 - Effects of impact energy on percentage breakage of seeds

In *Fig. 5*, the vetch seed breakage is plotted against the energy of impact for various seed moisture contents. The figure shows that, at all the seed moisture contents considered, the seed damage increases as the impact energy increases. Due to the significant interaction effect between impact energy and moisture content, the rates of increase in damage are not the same for all levels of moisture contents. The effect of impact energy on the damage is more significant at lower moisture contents than at higher ones. In *Fig. 5*, the lowest damage among the combinations was found to be 11.42% occurred in the 0. 1J impact energy with the moisture content of 17.5%, while the greatest damage was obtained as 99.33%, occurred in the impact energy of 0.3 J with the moisture content of 7.57%. At 7.57% seed moisture content, percentage breakage increased from 85.80 to 99.33% with the increase of the impact energy from 0.1 to 0.3 J. Corresponding percent breakages were from 69.23 to 80.96%, 47.66 to 77.44%, 26.86 to 67.56%, 11.42 to 59.38%, 20.97 to 68.64% and from 29.93 to 77.33% for the same energy range, at 10, 12.5, 15, 17.5, 20 and 25% moisture contents, respectively. The seed damage was related to the energy of impact in the range of 0.1 to 0.3 J by regression analysis. The results showed that the percentage breakage of seeds was a quadratic function of the energy of impact, at all the moisture contents considered. The equations representing the relationship between the percentage seed breakage (SB, %) and impact energy (IE, J) for each moisture content and their coefficients of determination (R^2) are presented in *Table 3*.

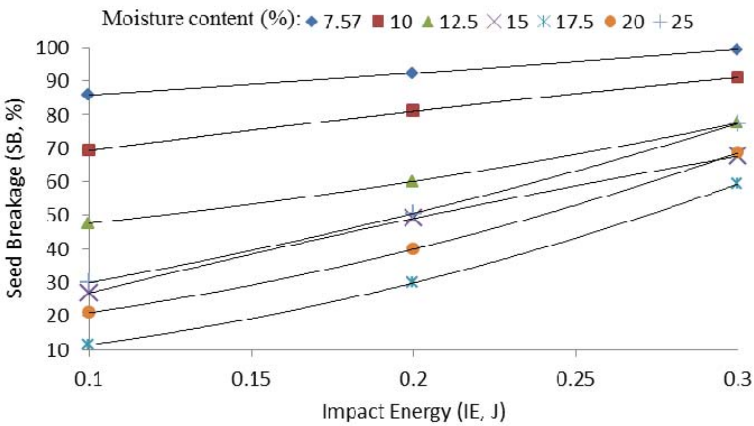

Figure 5 - Vetch seeds breakage variation with impact energy for different seed moisture contents

Table 3 - Equations representing the relationship between the percentage breakage (SB) of vetch seeds and impact energy (IE) at different moisture contents

Moisture content (%)	Equation	R^2
7.56	$SB = 79.843 + 56.817\ IE + 27.167\ IE^2$	1
10	$SB = 55.81 + 142.68\ IE - 84.5\ IE^2$	1
12.5	$SB = 40.153 + 50.4\ IE + 246.33\ IE^2$	1
15	$SB = 1.0167 + 276.7\ IE – 183\ IE^2$	1
17.5	$SB = 4 + 18.95\ IE + 552.17\ IE^2$	1
20	$SB = 11.853 + 42.15\ IE + 490.5\ IE^2$	1
25	$SB = 15.377 + 115.05\ IE + 304.83\ IE^2$	1

All the indexes are significant at the level of 99.95%. SB= seed breakage (%), MC= moisture content (%).

For the optimum level of moisture content of 17.5%, in *Figs. 3 and 5*, the percentage breakage of seeds are 11.42, 29.88 and 59.38% at impact energies of 0.1, 0.2 and 0.3 J, respectively, shown that at impact energies lower than 0.1 J, the seed breakage is lower than 10%.

Based on the above fact, the limitation of impact energy to 0.1 J could be considered in the case of designing or adjusting the threshing and other mechanisms for handling or processing the vetch seeds.

It suggests that the radius and speed of the machine parts should be such that will not allow the impact energy of 0.1 J to be exceeded; higher energy than 0.1 J will damage seeds. However, considering the mass of the seed, m (kg), which absorbs the impact energy, then the impact velocity, V (m s^{-1}), which cause the same amount of energy, could be estimated as:

$$\tfrac{1}{2} mV^2 = IE \Rightarrow \quad (4)$$

In this study, the limited impact energy was found to be *IE*=0.1J, thus the velocity of the machine parts, that subject the seed with the mass of *m* (kg) to the required impact energy, could be determined:

$$V = \left[\frac{0.2}{m}\right]^{1/2} \quad (5)$$

Based on above results, the best conditions for harvesting and other processing for vetch seeds, in which seeds are subjected to impact loads, will be at moisture contents of about 17.5% with impact energy and velocity limited to about 0.1 J. 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, to limit the impact energy of machine parts to 0.1 J, from the viewpoint of minimizing yield losses due to the share of damaged seeds.

Modeling

An empirical relationship was developed utilizing the dependence of the vetch seeds percentage breakage (SB, %) on parameters, such as seed moisture content (MC, %), impact energy (IE, J), and M×IE as independent variables, with the help of regression techniques. The relationship is given as follows:

$$SB = 2140126 - 19.21\,MC - 174.31\,IE + 12.77\,MCIE + 0.44\,MC^2 + 407.64\,IE^2 \quad R^2=0.95 \quad (6)$$

The regression statistics for the model indicated that all terms were significant effects (at the 99.95% level) on the accuracy of the model. The p-value of predicting equation was lower than 0.0001. The performance of the selected relationship for the prediction percentage breakage of vetch seeds due to impact is shown in *Fig. 6*. This figure shows the predicted percentage breakage data versus the same set of measured data. The scatter plot showed no tendency for the model to under- or over-estimate the predicted percentage of damage data. It is observed that the predictive capability was good and data points were well compressed about the ideal of unity-slope line selected. The linear adjustment between the observed and estimated values gives a slope practically equal to 1 (Y=0.9477X +1.4723). The resulting correlation coefficient and the p-value were 0.9477 and <0.0001, respectively, for the regression between observed and estimated values *(Fig. 6)*, indicating that the model provided satisfactory results over the whole set of values for the dependent variable.

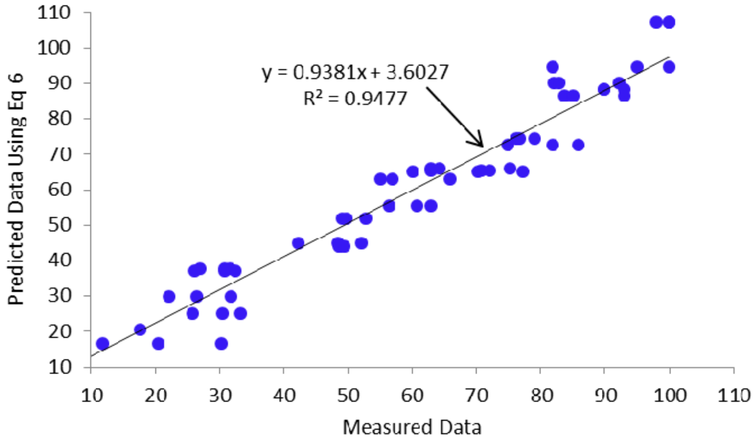

Figure 6 - Correlation between the experimental SB and the predicted data by the mathematical model (Eq. 6)

CONCLUSIONS

The data obtained from this study showed that the significant differences in the breakage susceptibility of vetch seeds to impact load were revealed at different levels of seed moisture content and impact energy.

Impact energy, moisture content, and the interaction effects of these two variables significantly influenced the percentage breakage of vetch seeds (p<0.01).

It was found that the percentage breakage of vetch seeds was a quadratic function of impact energy. Increasing the impact energy from 0.1 to 0. 3 J caused an increase in the mean percent breakage of seeds from 41.69 to 78.68%. To minimize physical damage to seeds, the impact energy should be limited to 0.1 J.

The mean values of seeds damage decreased significantly by a factor of 2.75, (from 92.47 to 33.57%) with increase in the moisture content from 7.57 to 17.5%. However, by a higher increase in the moisture from 17.5 to 25% caused an increase in the amount of seeds breakage from 33.57 to 55.95%. The optimum level of moisture, where impact damage to vetch seeds was minimized, was about 17.5%.

Empirical models were developed to explain the relationship between percentage of breakage of vetch seeds and the experimental variables. It was found that the models have provided satisfactory results over the whole set of values for the dependent variable.

REFERENCES

ASAE(1998). ASAE Standards. St. Joseph, MI, USA.

Baryeh, E.A. (2002). A simple grain impact damage assessment device for developing countries. *J. Food Eng.*, 56, 37-42.

Khazaei, J. (2009). Influence of impact velocity and moisture content on mechanical damage of white kindey beans under impact loadings. *Cercetari Agronomice in Moldova*, 1(137), 5-18.

Khazaei, J., Shahbazi, F., Massah, J., Nikravesh, M. & Kianmehr, M.H. (2008). Evaluation and modeling of physical and physiological damage to wheat seeds under successive impact loadings: mathematical and neural networks modeling. *J. Crop Sci.*, 48,1532-1544.

Kim, T.H., Opara L.U., Hampton, J.G., Hardacre, A.K. & MacKay B.R. (2002). The effects of grain temperature on breakage susceptibility in maize. *Biosystems Eng.,*82(4), 415-421.

Oluwole, F.A., Aviara, N.A. & Haque, M.A. (2007). Effect of moisture content and impact energy on the crackability of sheanut. *Agric.Eng.Int.,* CIGR Journal, Vol. 9.

Parde, S.R., Kausalb, R.T., Jayasa, D.S. & White, N.D.G. (2002). Mechanical damage to soybean seed during processing*. J. Stored Product.Res.,* 38: 385-394.

SAS. (2001). SAS User's Guide: Statistics. Ver.6a. Cary, N.C.: SAS Institute, Inc

Shahbazi, F. (2011). Impact damage to chickpea seeds as affected by moisture content and impact velocity. *Appl. Eng.Agric.,*25(7), 771-775.

Shahbazi, F. (2014). Effects of moisture content and impact energy on the cracking characteristics of walnuts. *Int.J. Food Eng.,* 10(1),149–56.

Shahbazi, F., Analooei, M. & Saffar, A., (2011a). Mechanical damage to pinto bean seeds as affected by moisture content, impact velocity and seed orientation. *Int.J.Food Eng.*, *7*(6), p.8.

Shahbazi, F., Dolatshah, A. & Valizadeh, S. (2014). Evaluation and modeling the mechanical damage to cowpea seeds under impact loading. *Qual. Assur. Saf. Crop.*, 6(4)., 453-458.

Shahbazi, F., Dowlatshah, A. & Valizadeh, S. (2012). Breakage susceptibility of wheat and triticale seeds related to moisture content and impact energy. *Cercetari Agronomice in Moldova*, 45(3), 5-13.

Shahbazi, F., Saffar, A. & Analooei, M. (2011b). Mechanical damage to navy beans as affected by moisture content, impact velocity and seed orientation. *Qual. Assur. Saf. Crop*., *3*(4), 205-211.

Sosnowski, S. & Kuzniar, P. (1999). Effect of dynamic loading on the quality of soybean. *Int.Agrophys.,* 13: 125-132.

Szwed, G. & Lukaszuk, J. (2007). Effect of rapeseed and wheat kernel moisture on impact damage. *Int.Agrophys.,* 21, 299-304.

Tang, J., Sokhansanj, S. & Sosulski, F. (1991). Determination of the breakage susceptibility of lentil seed. *Cereal Chem.,* 68(6): 647-650.

Yalçın, I. & Özarslan, C. (2004). Physical properties of vetch seed. *Biosyst.Eng.,* 88(4), 507-512.