INTERNATIONAL
Agrophysics
www.international-agrophysics.org

*Int. Agrophys., 2023, 37, 41-49*
doi: 10.31545/intagr/156049

# Impact damage to chickpea seeds during free fall

*Farzad Delfan*[1], *Feizollah Shahbazi*[1]*, *and Hamid Reza Esvand*[2]

[1]Department of Biosystems Engineering, Lorestan University, Khorramabad, 6815144316, Iran
[2]Department of Agriculture and Plant Breeding, Lorestan University, Khorramabad, 6815144316, Iran

*Received July 1, 2022; accepted October 25, 2022*

A b s t r a c t. The study aimed to determine the extent of the percentage of mechanical damage (seed breakage) to chickpea seeds due to the impact caused by free fall. Three independent variables were used in the test, namely: impact surface (concrete, metal, plywood and seed-on-seed), drop height (3, 6, 9, and 12 m) and seed moisture content (10, 15, 20, and 25% w.b.). The results showed that all three independent variables significantly influenced the percentage breakage of chickpea seeds. The seeds dropped onto concrete and metal had by a significant margin the highest means of percentage breakage at 13.89 and 12.94%, respectively, in comparison with 10.64 and 8.34% on plywood and in the case of seed to seed impact, respectively. Increasing the drop height from 3 to 12 m caused a significant increase in the mean values of damage to seeds from 7.20 to 15.57%. Increasing the moisture levels caused a decreasing trend by a factor of two in the damage to the seeds due to free fall. Empirical models were developed to reveal the relationships between damage to chickpea seeds with various moisture contents that was due to the impact with different impact surfaces caused by free fall from the drop height.

K e y w o r d s: chickpea, mechanical damage, handling, drop height, contact surface

## INTRODUCTION

One of the most important factors that affects the grain quality of agricultural products is mechanical damage to the grains (seeds). Mechanical injuries can be caused by any type of physical and mechanical action, but injuries caused by the impact of the moving parts of machines during harvesting and postharvest processing are the most serious ones (Shahbazi, 2011; Mir and Shahbazi, 2022). The seeds of agricultural products are constantly subjected to impact forces from machines from the moment they are harvested to the time they are transferred into storage (Shahbazi *et al*., 2011a; 2011b; 2011c; Shahbazi *et al*., 2012). The improper design and performance of such machines at each of these stages can cause mechanical damage to seeds. Damage to seeds caused by impacts during these processes is a major problem in the grain industry. Symptoms of mechanical damage to seeds may take several different forms (Paulsen *et al*., 2019; Shahbazi, 2021; Chen *et al*., 2021; Shahbazi and Shahbazi, 2022a). External damage to the seeds is easily visible, this includes breakage and the cracking of the grain (seed), internal damage (such as the formation of internal cracks), microscopic fissures, and injuries to the embryo of the grain. All of these forms of damage reduce the value and shelf life of the product, create health problems, decrease production and processing costs, reduce the efficiency of nutrient extraction from the grains, and also reduce the germination rate and seed vigour. In addition, depending on the quality of the harvest and the postharvest process, the broken (fine) seeds may be affected by different types of spoilage that may adversely affect seed management in silo bins (Liu *et al*., 2012; Meyers and Hollinger,

*Corresponding authors e-mail: shahbazi.f@lu.ac.ir

2004). Mechanical damage to the seeds reduces their shelf life by producing carbon dioxide gas and reducing the dry mass of the seeds. Fractures, cracks and scratches on the seed cause air and moisture to penetrate it and also cause the rapid hydration of the living tissues of the seed, which adversely affects seed storage potential (DaSilva *et al.*, 2018). Another problem with mechanical damage to the seeds is the uneven distribution of broken particles inside the tank or silo. An uneven distribution of broken particles occurs when the seed is discharged from above into the silo. Since broken seeds do not have a uniform shape, or a smooth and uniform surface, compared to healthy seeds, they are not spread evenly inside the tank. The uneven distribution of these fine particles and their concentration in one part of the silo bin (mainly in the central part of the bin) causes the non-uniform distribution of airflow paths during aeration or the drying of the seeds and also results in the uneven distribution of moisture and heat inside the bin, which causes non-isothermal and humidity points and also increases the risk of fungal and insect growth (Guo, 2015; Fan *et al.*, 2017; Narendran *et al.*, 2019; Deng *et al.*, 2021).

Free fall is one of the most important stages in seed and fruit processing and handling, in which products are damaged by impact. Seeds are exposed to impact when free falling or being strewn onto a hard surface, such as when they are being unloaded from a combine harvester into a cart or filling a storage bin (Chen *et al.*, 2020). Depending on the type of operation being conducted, the seeds may fall freely from a few meters on the farm when unloaded using a combine harvester and truck transport bin, to a height of more than 50 m when unloaded and loaded into silo bins at seed transport and export terminals (Chen *et al.*, 2020; Shahbazi, 2021; Shahbazi and Shahbazi, 2022b). Also, during conditioning, the seeds may be stored in bins until they are ready to be processed. Loading seeds into bins may cause mechanical damage as the seeds are subjected to a free fall drop. During these processing stages, the seeds fall from different heights and impact various surfaces (concrete, metal, wood and there are also seed on the seed impacts), resulting in potential damage. The damage to the seeds during free fall depends on various factors, such as drop height, the condition of the seed (seed size, volume, mass, temperature and moisture content), and contact with the surface material (Delfan, 2020).

In order to reduce the mechanical damage to the seeds caused by free fall, the condition of the seeds and the exact circumstances of their falling conditions should be adjusted so that the severity of the impact is reduced. Given that the condition of the seeds is somewhat uncontrollable during their movement and free fall, the only factor that can be managed and controlled is the falling conditions. The drop height and speed of the falling seeds must be reduced by as much as possible in order to prevent the seeds from impacting hard and hard surfaces. In order to reduce the drop height and speed of falling of the seeds when they leave the conveyors or during the unloading or loading of seeds storage bins, stepping falling systems (ladders) should be used (Shah *et al.*, 2001). Two kinds of such systems, known as the cushion box and closed let-down ladder (Gregg and Billups, 2016; Shahbazi and Shahbazi, 2022c) are commonly used. These types of equipment can be installed in the path of seed transfer pipes or in the center of seed storage bins in order to unload or load bins while preserving the desired seeds in a safe state, without damage (Gregg and Billups, 2016; Shahbazi and Shahbazi, 2022a).

Impact damage to seeds has been the subject of much research due to reduced crop quality during harvesting, handling and processing. Various test methods have been proposed to predict the crushing strength of seeds, including the compression method (Su *et al.*, 2019a and 2019b; Su *et al.*, 2020), the drop method (Li and Gao, 2009), the pendulum method (Srivastava *et al.*, 1976), and breakage sensibility (Bilanski, 1966). Many indexes and methods have been developed to determine seed susceptibility to breakage. The breakage susceptibility index is the most widely used and is defined as the likelihood of seed fragmentation occurring when seeds are subjected to impact forces during handling and transport. The methods for determining breakage susceptibility can be classified into four categories based on the different external forces applied to the seed and contact position. These include seed impacts against non-seed surfaces, seed-on-seed impacts, rubbing impacts, and centrifugal impacts. The instruments used to determine breakage susceptibility are typically the Wisconsin breakage tester and the Stein breakage tester (Shahbazi, 2021).

Various drop tests were performed with corn, soybean and wheat (Fiscus *et al.*, 1971; Foster and Holman, 1973). The results showed that mechanical damage to the seeds increased with drop height. Fiscus *et al.* (1971) reported that the damage to seeds caused by them falling more than 13 m, was higher than that caused by using either a seed thrower or a bucket elevator. When tested under the same conditions, the impact damage due to free fall depended on the type of seed. Wheat was found to be less susceptible to damage than soybeans (the percentage of damage was less than 0.4%) and soybeans were found to be less susceptible to impact damage than corn (Foster and Holman, 1973). Bergen *et al.* (1993) investigated damage to 'Trapper' peas and 'Laird' lentils in free fall and reported that seeds dropped from a greater height caused more seed damage on all three impact surfaces, namely metal, plywood, and concrete. Seeds with a lower moisture content reportedly incurred more damage. The results of various studies have shown that the degree of hardness and susceptibility to mechanical damage to the grain is affected by the application of fertilizers and, thus, soil fertility (Shahbazi *et al.*, 2015a; 2015b). Delfan (2020) used the electrical conductivity test to investigate the damage to chickpea seeds by free fall and reported that there was a linear relationship between the increase in the electrical conductivity of the seeds and their drop height.

Chickpea is one of the most important legumes which play an important role in providing the protein required by people in developing countries (Shahbazi, 2011). Chickpea seeds are highly susceptible to mechanical damage under impact loads because of their large size, mass, and also dicotyledonous characteristics, the germ tip being located at the protruding structure (Shahbazi, 2011). Information concerning mechanical damage to chickpea seeds due to free fall and relating the amount of damage to the drop height, impact surface and seed moisture content is limited. In light of the information mentioned above, this study was undertaken to: a) quantify the physical damage to chickpea seeds due to the impact caused by free fall from various heights at different sample moisture contents and against various impact surfaces, and b) to determine the velocities of seeds dropping from various heights and recommend safer heights for the design of handling equipment.

## MATERIALS AND METHODS

In this study, mechanical damage to chickpea seeds due to free fall was investigated. The chickpea seeds used in this study were of the Azad variety, they were manually harvested from a field located in Khorramabad at the commercial ripening stage and then transferred to the laboratory. The samples were stored during the experiment at 5°C and 85-90% humidity, until the time of the experiments.

The physical properties of the seed samples, including the length ($L$), width ($W$), and thickness ($T$), were measured using a digital micrometer, with an accuracy of 0.01 mm. Then the geometric mean diameter ($D_g$) and sphericity ($\varphi$) of the seeds were computed by using the following relationships between the length, width, and thickness parameters, respectively (Mohsenin, 1986):

$$D_g = (LWT)^{\frac{1}{3}} \ , \tag{1}$$

$$\varphi = \frac{(LWT)^{\frac{1}{3}}}{L} \ , \tag{2}$$

The mass of the seeds was measured using a digital scale with an accuracy of 0.01 g. A universal testing machine (Santam ST-1, Santam Company Tehran, Iran) was equipped with a 1000 N load cell that was used to determine the mechanical properties (rupture force and displacement (deformation)) at the rupture point following the test procedure described in the ASABE standard S368.3 (ASABE, 2008). The individual seeds were placed between parallel plates of the machine and compressed at a constant loading rate of 1.25 mm min$^{-1}$ until rupture occurred. The rupture force and displacement (deformation) at the rupture point for the seeds used in each experiment were obtained from the force-deformation curve plotted using machine software (Santam Company, Tehran, Iran). The physical and mechanical properties of the seeds were measured at the standard moisture content of 15% (Shahbazi, 2011). Before the impact test, the initial moisture content was measured. The moisture contents of the seeds were determined according to the ASABE standard S352.2 (ASABE, 2006) and calculated on a wet mass basis. The initial moisture content of the seeds was approximately 10%. Higher moisture levels of 15, 20, and 25% were obtained by spraying pre-calculated amounts of distilled water, and using the following rewetting formula (Jan *et al*., 2019):

$$Q = \frac{A(b-a)}{(100-b)} \ , \tag{3}$$

where: $Q$ is the mass of added water (kg), $A$ is the initial mass of the sample in (kg), $a$ is the initial and $b$ is the desired moisture content w.b. (%) of the sample.

The moisture in the seeds was allowed to equilibrate at a temperature of 4°C for at least 10 days. Each sample was mixed at 2-day intervals.

Laboratory tests were used to simulate free fall and to evaluate the effect of dropping the samples on to various impact surfaces from various heights at different moisture contents in terms of damage caused to the chickpea seeds. Four drop heights of 3, 6, 9, and 12 m were selected. These drop heights are typically indicative of circumstances which may occur on the farm, at a seed cleaning plant, or in a seed elevator. The four surfaces selected for the drop tests were concrete, metal, plywood and seeds on seeds. The tests were conducted at a temperature of 20°C. In order to conduct the test at a temperature of 20°C the experimental setup was placed inside a temperature-controlled building.

Seed samples of 500 g each were dropped from different heights inside a PVC pipe of 100 mm diameter. Three replications were made for each set of observations. 100 mm diameter PVC pipes were set up to obtain different drop heights. A hopper with a 40 mm-diameter opening was attached to the top of the pipe. The dropping rate of the seed samples was regulated using a gate attached to the bottom of the hopper. The flow rate of the seed samples was regulated at 0.25 kg s$^{-1}$. The bottom of the pipe was located in a specially-built wooden compartment. To prevent seeds from bouncing away, a foam core was placed in front of this compartment. The test surfaces were placed inside this compartment. The concrete, metal and plywood surfaces were placed at an inclination of 45° in order to simulate a drop in an empty hopper bottom bin. These surfaces had dimensions of about 500 × 400 mm. Two wooden flaps were placed just above the impact surfaces and channelled seeds into a bucket placed underneath. In order to conduct drop tests of seeds on seeds, a bucket containing seeds with similar moisture contents was used as a test surface. A very thin layer of saran wrap was placed on the test surface of the seeds to ease the separation of the test samples. The saran wrap was in contact with the seed surface at all times. The seed samples were collected and transferred into plastic bags for damage analysis.

After the free fall tests were completed, the tested seed samples were graded manually. The seeds were sorted into physically damaged and undamaged categories by visual inspection using a magnifying hand lens (Khazaei *et al*., 2008; Shahbazi, 2012). Seeds with splits and visibly cracked ones were considered to be physically damaged. By definition splits included broken pieces that were less than three-quarters of the whole seed and halves that were loosely held together. Cracked seeds included seeds with visibly cracked seed coats and seeds with less than one-fourth of the seed broken off. The percentage of physical damage to the chickpea seeds was quantified in terms of the percentage of the original sample mass and was computed by using Eq. (4) (Shahbazi *et al*., 2017):

$$PB = \frac{W_d}{W_t}\,, \tag{4}$$

where: $PB$ is the breakage percentage of chickpea seeds (%), $W_d$ is the mass of physically damaged seeds and $W_t$ is the total mass of the seeds (damaged + undamaged).

The velocities of the seeds were measured by dropping a single chickpea seed at a time and by dropping the seeds in mass flow. A video camera was used to record the velocity of the seeds just before they hit the floor of the chamber. A distance of approximately one metre was maintained between the bottom end of the desired drop system and the chamber floor in order to record the velocity of the seeds leaving the desired drop system. A set of horizontal lines were drawn at an interval of 5 cm and placed in the background to more easily observe the distance traveled by the seeds. Images of both the streams of seeds and the individual seeds were taken to observe the air resistance that affected their speed. Because tracking seeds in mass flow is difficult, the velocities of the seeds at the beginning and at the end of mass flow were recorded.

The factorial experiment was conducted as a randomized design. The main parameters were the impact surface (concrete, metal, plywood and seeds on seeds), moisture content (10, 15, 20, and 25%) and drop height (3, 6, 9 and 12 m). Three replications were performed to measure the percentage of physical damage. Thus, there were 192 (4×4×4×3) observations in all. The main treatments and their interactions were analysed with analysis of variance (ANOVA) by using SPSS software (version 19). For the graphs and tables, Microsoft Excel was used. The level of significance was shown in terms of * p<0.05 and ** p<0.01 by applying Duncan's multiple range tests.

## RESULTS AND DISCUSSION

In this study, mechanical damage to the chickpea seeds due to free fall during handling and the effects of the impact surface, drop height and seed moisture content were investigated. Table 1 describes the physical and mechanical properties of the chickpea seeds.

The results of the study illustrated that the percentage of physical damage to chickpea seeds was affected by the impact surface, drop height and moisture content. Table 2 shows the results of the analysis of variance in determining the percentage breakage of chickpea seeds due to free fall in different treatments with independent variables. The drop height, impact surface and seed moisture content appears to have significant effects on the percent breakage of chickpea seeds (p<0.01). However, the impact of the drop height on the percentage breakage of chickpea seeds was greater (F = 530.1 (F value of the analyses of variance)) this was followed by the moisture content (F = 349) and impact surface (F = 257.2) within the range of variables studied (Table 2). Furthermore, the relationship between drop height × impact surface, drop height × moisture content, impact surface × moisture content and the interaction between the three independent variables had significant effects (p<0.01) on the percentage breakage of chickpea seeds due to free fall (Table 2).

The means of the physical percentage breakage of chickpea seeds at various drop heights, impact surfaces and moisture contents (interaction between the three independent

**Table 1.** Physical and mechanical properties of the studied chickpea seeds

| Measured properties | | | | | | | |
|---|---|---|---|---|---|---|---|
| Deformation (mm) | Rupture force (N) | Mass (g) | Sphericity | Geometric mean diameter (mm) | Thickness (mm) | Width (mm) | Length (mm) |
| 0.35 (0.13) | 230.52 (80.52) | 0.25 (0.03) | 0.87 (0.09) | 7.32 (0.33) | 6.70 (0.82) | 6.95 (0.52) | 8.42 (1.05)* |

* Standard deviation.

**Table 2.** Analyses of variance for the percentage breakage of chickpea seeds as affected by the drop height, impact surface and moisture content

| Source | DF | Sum of squares | Mean square | F value |
|---|---|---|---|---|
| Drop height (*DH*) | 3 | 1827 | 609.1 | 530.1** |
| Impact surface (*IS*) | 3 | 886.8 | 295.6 | 257.2** |
| *DH* × IS | 9 | 33.39 | 3.710 | 3.228** |
| Moisture content (*MC*) | 3 | 1203 | 401.1 | 349.0** |
| *DH* × *MC* | 9 | 48.65 | 5.406 | 4.704** |
| *IS* × *MC* | 9 | 23.94 | 2.660 | 2.315* |
| *DH* × *IS* × *MC* | 27 | 72.71 | 2.693 | 2.344** |
| Error | 128 | 147.1 | 1.149 | |
| Total | 192 | 29418 | | |

* p<0.05, ** p<0.01.

**Table 3**. Percentage breakage of chickpea seeds when dropped as affected by the drop height, impact surface and moisture content

| Drop height (m) | Moisture content (%) | Impact surface | | | |
|---|---|---|---|---|---|
| | | Concrete | Metal | Plywood | Seed / seed |
| 3 | 10 | 12.28 | 11.50 | 7.67 | 7.49 |
| | 15 | 9.69 | 9.30 | 7.50 | 5.95 |
| | 20 | 7.28 | 8.19 | 5.88 | 4.47 |
| | 25 | 5.77 | 4.25 | 3.90 | 2.57 |
| 6 | 10 | 16.13 | 14.34 | 11.98 | 9.92 |
| | 15 | 15.32 | 13.23 | 9.41 | 7.66 |
| | 20 | 10.70 | 11.40 | 8.77 | 5.57 |
| | 25 | 9.59 | 9.27 | 7.58 | 3.66 |
| 9 | 10 | 18.08 | 18.53 | 16.54 | 13.34 |
| | 15 | 16.22 | 14.87 | 13.33 | 10.28 |
| | 20 | 15.55 | 13.43 | 10.55 | 8.18 |
| | 25 | 11.32 | 10.62 | 8.39 | 4.85 |
| 12 | 10 | 23.73 | 21.09 | 17.57 | 14.63 |
| | 15 | 21.21 | 19.91 | 16.50 | 12.78 |
| | 20 | 15.10 | 14.24 | 12.18 | 11.54 |
| | 25 | 13.72 | 12.85 | 11.50 | 10.53 |

variables) are shown in Table 3. From the data concerning the average percentage breakage of chickpea seeds after the drop tests conducted under various conditions in Table 3, it was observed that the percentage breakage of seeds was affected by the drop height, impact surface and moisture content. For all impact surfaces, increased drop height and decreased moisture content caused increasing trends in the mean values of damage to seeds due to free fall. Chickpea seeds dropped from the height of 12 m, averaged a percentage breakage of 13.72% on concrete, 12.85% on metal, 11.50% on plywood and 10.53% on seeds to seed, at a moisture content of 25%. While at a moisture content of 10% and at the same drop height of 12 m, the percentage breakage of the seeds was as high as 23.73% on concrete, 21.09% on metal, 17.57% on plywood and 14.63% on seed to seed.

Table 4 shows the means of the percentage breakage values for seed damage obtained from the drop tests. All three independent variables, namely, the drop height, impact surface and moisture content had a significant effect ($p = 0.05$) on the measured values.

The means of the percentage breakage which occurred as a result of damage to chickpea seeds colliding with an impact surface was highest on concrete, followed by metal, plywood and seed-on-seed (Table 4). This trend was reported previously by Evans *et al*. (1990) for soybeans. From the data shown in Table 4, it is evident that there are significant differences between the mean values of total damage to the seeds that collided with the different impact surfaces ($p<0.05$). In different test conditions, which include different levels of moisture content and drop height, the sample

**Table 4.** Duncan's multiple range tests compare the means (%) of the percentage breakage of chickpea seeds at different levels of dependent variables

| Independent variable | Dependent variable |
|---|---|
| | Percentage breakage of chickpea seeds |
| Drop height | |
| 3 m | 7.20 d |
| 6 m | 10.28 c |
| 9 m | 12.75 b |
| 12 m | 15.57 a |
| Impact surface | |
| Concrete | 13.89 a |
| Metal | 12.94 b |
| Plywood | 10.64 c |
| Seed/seed | 8.34 d |
| Moisture content | |
| 10% | 14.77 a |
| 15% | 12.70 b |
| 20% | 10.19 c |
| 25% | 8.15 d |

seeds that dropped on concrete had a significantly higher average percentage breakage of 13.89%. In the case of seeds that dropped on metal, the amount of damage inflicted was 12.93%, which was a decrease of about 7% lower than that inflicted by concrete. Sample seeds that were dropped on plywood had an average percentage breakage of 10.64%, which was about 23% lower than the value produced by contact with concrete and about 18% lower than that produced by metal. Sample seeds that were dropped on seeds had a significantly lower average damage of 8.34%, showing that the seed on seed impact surface helped to reduce the mechanical damage to the seeds by about 40% as compared to that of concrete, by about 34% compared to that of the metal and by about 22% compared to plywood, which effectively prevented damage to the seeds and reduced the resulting losses.

In terms of drop height, damage to the chickpea seeds increased significantly with increases in this independent variable (Table 4). As expected according to the data in Table 4, the percentage breakage of chickpea seeds increased significantly with increasing drop height. Dropping seeds from 12 m caused the highest amount of damage at 15.57%, in comparison, damage values of 12.75, 10.28 and 7.64% were caused by drop heights of 9 m, 6 m and 3 m respectively. Furthermore, there are significant differences between the average damage to the seeds which occurs at different levels of drop heights ($p<0.05$). The adverse effect of increasing the drop height was similar to that which was reported by Bergen *et al*. (1993) using

'Laird' lentils. According to the well-known energy relationship (Eq. (5), it is predicted that, with increasing drop height, the amount of impact energy applied to the kernels will be increased:

$$E = mgh\,, \tag{5}$$

where: $E$ is the impact energy (J), $m$ is the kernel or sample mass (kg), $g$ is the acceleration due to gravity (9.81 m s$^{-2}$) and $h$ is the drop height (m).

As a result, the amount of damage will increase. This is due to the increasing seed velocity with drop height, which results in a larger impact force (Fiscus *et al*., 1971; Shahbazi and Shahbazi, 2022c). Foster and Holman (1973) reported that when the drop height was more than 15 m, the velocity of the seed stream could exceed the single kernel velocity because, when the seed stream was dropped as a whole, the drag forces on the individual seeds were not all the same. Foster and Holman (1973) suggested limiting the drop height to 12 m in order to reduce free fall damage. Therefore, it is necessary to reduce the drop height of the seeds as much as possible. Perry and Hall (1966) evaluated the mechanical damage to pea beans using drop tests and observed that the damage to pea beans was found to vary proportionately to the drop height. Furthermore, similar results were reported by Fiscus *et al*. (1971) concerning mechanical damage to corn, soybeans, and beans. Gatongi (1982) reported that mechanical damage during corn seed processing was affected by the drop height and moisture content. Asiedu (1986) reported a sharp decrease in the percentage germination of corn seeds with increasing drop height on hard surfaces.

At low moisture contents, the seeds were more brittle, thus, more prone to damage due to free fall which was also reported by Bergen *et al*. (1993) for 'Laird' lentils and Evans *et al*. (1990) for soybeans. At 10% moisture content, chickpea seeds had a higher means of percentage breakage of 14.77% compared with 12.70, 10.19 and 8.15%, for moisture contents of 15, 20 and 25%, respectively. Also, there are significant differences between the means of the percentage breakage of chickpea seeds at different levels of moisture contents ($p<0.05$). The adverse effect of decreasing the moisture content on mechanical damage to seeds was similar to the results reported by Frączek and Ślipek (1998) for wheat, Sosnowski and Kuźniar (1999) for soybean, Szwed and Łukaszuk (2007), Khazaei *et al*. (2008) for wheat, Shahbazi *et al*. (2011a) for Pinto beans, Shahbazi and Shahbazi (2019) for corn, Su *et al*. (2019a and b) and Gu *et al*. (2019) for corn seeds.

Figure 1 shows the interaction effect of the impact surface and drop heights on the percentage breakage of chickpea seeds. At all drop heights, the damage to the seeds was significantly higher when the seeds were dropped on either a concrete or metal surface than on plywood and seed to seed. This difference was greater at a height of 12 m as compared with heights of 9, 6 and 3 m. The dependency

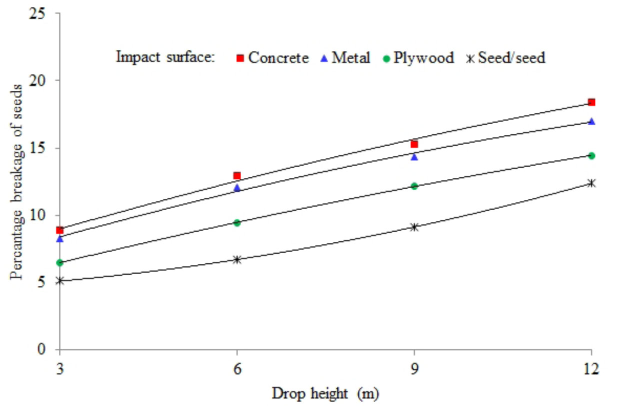


**Fig. 1.** Interaction effect of the impact surface and drop height on the percentage breakage of chickpea seeds.

of the percentage breakage of chickpea seeds ($PB$, %) on drop height ($DH$, m) was expressed by the following best-fit Eqs. (6-9) for the impact surfaces of concrete, metal, plywood and seeds on seeds respectively:

$$PB = 4.79 + 1.42DH - 0.03DH^2\,,\ R^2 = 0.994 \text{ at concrete,} \tag{6}$$

$$PB = 4.46 + 1.40DH - 0.03DH^2\,,\ R^2 = 0.996 \text{ at metal,} \tag{7}$$

$$PB = 3.13 + 1.18DH - 0.02DH^2\,,\ R^2 = 0.997 \text{ at plywood,} \tag{8}$$

$$PB = 4.32 + 0.13DH - 0.05DH^2\,,\ R^2 = 0.99 \text{ at seeds on seeds.} \tag{9}$$

The interaction effect between the impact surface and the moisture content on the percentage breakage of chickpea seeds is shown in Fig. 2. The difference in the means of the percentage breakage of chickpea seeds at the four moisture levels when seeds were dropped on seeds was significantly lower than it was for the seeds that were either dropped onto a concrete or metal surface. The mid-range damage data were produced by seeds that were dropped on plywood. On all of the impact surfaces, a decreased moisture level caused an increasing trend in the damage to the seeds due to free fall; however, the effect of the moisture level was less critical when seeds were dropped on seeds. The dependency of the percentage breakage of chickpea seeds ($PB$, %) on the moisture content ($MC$, %)

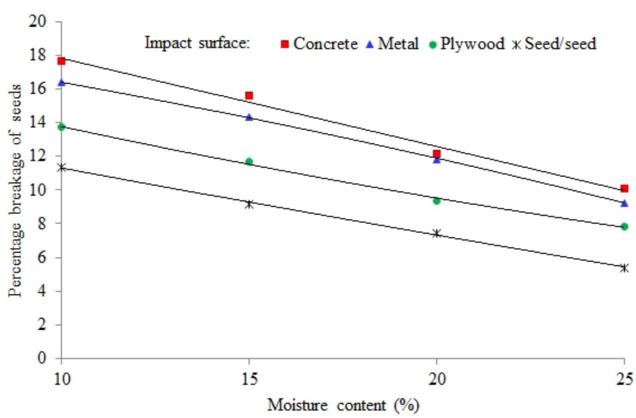


**Fig. 2.** Interaction effect of the impact surface and moisture content on the percentage breakage of chickpea seeds.

was expressed by the following best-fit Eqs (10-13) for the impact surfaces of concrete, metal, plywood and seeds on seeds respectively:

$$PB = 23.04 - 0.52MC,\ R^2 = 0.989 \text{ at concrete,} \quad (10)$$

$$PB = 19.82 - 0.29MC - 0.01MC^2,\ R^2 = 0.997 \text{ at metal,} \quad (11)$$

$$PB = 19.03 - 0.58DH - 0.01DH^2,\ R^2 = 0.999 \text{ at plywood,} \quad (12)$$

$$PB = 15.57 - 0.44MC - 0.01MC^2,\ R^2 = 0.999 \text{ at plywood.} \quad (13)$$

Figure 3 shows the interaction of the drop height and moisture content. As the moisture level decreased, the percentage breakage of chickpea seeds increased at a higher rate with the increase in drop height.

The velocities of the seeds were observed by dropping one seed at a time and by dropping the seeds in a mass flow. Table 5 shows the average velocities (single seed and mass flow) for chickpea seeds dropped from various heights. In the mass flow velocity measurement, the velocities were higher compared to those resulting from the seeds being dropped individually. The seeds dropped individually had lower velocity values which may be due to the effect of the air resistance encountered in the drop tubes. According to the data in Table 5, the mass velocity of the chickpea kernels increased significantly with increasing drop height. The average mass flow velocities of the seeds were 5.83, 8.02, 10.12 and 13.03 m s$^{-1}$ when they were dropped from heights of 3, 6, 9 and 13 m, respectively. At these velocities, the means of percentage breakage of the chickpea seeds were

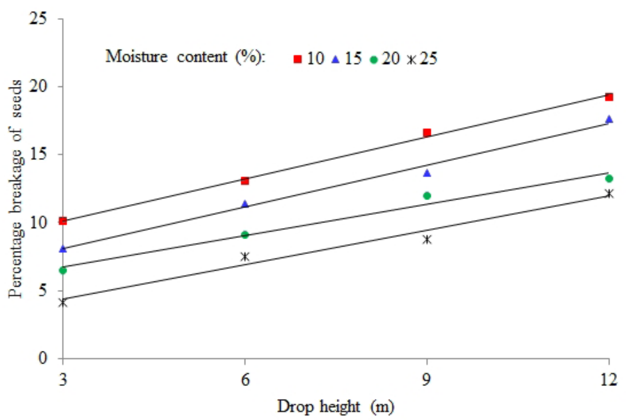


**Fig. 3.** Interaction effect of the drop height and moisture content on the percentage breakage of chickpea seeds.

**Table 5.** Average velocities for chickpea seeds dropped from various heights

| Drop height (m) | Velocity (m s$^{-1}$) | |
|---|---|---|
| | Mass flow | Single seed |
| 3 | 5.25 | 8.83 |
| 6 | 7.35 | 8.02 |
| 9 | 9.17 | 10.12 |
| 12 | 11.95 | 13.03 |

7.20, 10.28, 12.75 and 15.57%, respectively (Table 4). Seed damage increased as the impact velocity increased which was also the case for soybeans (Evans *et al*., 1990; Paulsen *et al*. 1981) and chickpeas (Shahbazi, 2011).

## CONCLUSIONS

Based on the results of this study, the following conclusions may be drawn:

1. The percentage breakage of chickpea seeds was significantly higher when the seeds were dropped on either a concrete or metal surface in comparison with the seeds being dropped on plywood and seeds. In most cases, greater damage resulted when the seeds were dropped on concrete rather than on a metal surface.

2. The drop height was a significant factor causing damage to the chickpea seeds. Increasing the drop height caused increased damage.

3. On striking a surface at speeds above 8 m s$^{-1}$, the percentage breakage of chickpea seeds was at least 10.28%. To reduce damage to seeds due to the impact caused by free fall, the drop height should be limited to about 5 m.

4. As the moisture level increased from 10 to 25%, the percentage breakage of chickpea seeds decreased from 17.77 to 8.15%.

**Conflict of Interest.** The authors declare that there are no conflicts of interest. Furthermore, the manuscript does not contain experiments using animals or humans.

## REFERENCES

**ASABE Standards, 2006**. S352. 2 Moisture measurement – Unground Grain and Seeds. American Society of Agricultural and Biological Engineers, Michigan, St. Joseph.

**ASABE Standards, 2008.** S368.3: Compression test of food materials of convex shape. American Society of Agricultural and Biological Engineers, Michigan, St. Joseph.

**Asiedu E.A., 1986.** Influence of delayed harvest, chilling and mechanical injury on quality of stored seed corn (*Zea mays* L.) (No. CIMMYT.). M.S. Thesis, Mississippi State University, Mississippi State.

**Bergen G.A., Jayas D.S., and White N.D.G., 1993**. Physical damage to peas and lentils due to free fall. Can. Agric. Eng., 35(2),151-155.

**Bilanski W.K., 1966**. Damage resistance of seed grains. Trans. ASABE, 9, 360-0363, https://doi.org/10.13031/2013.39978

**Chen Z., Wassgren C., and Ambrose K., 2020.** A review of grain kernel damage: mechanisms, modeling, and testing procedures. Trans. ASABE, 63, 455-475, https://doi.org/10.13031/trans.13643

**Chen Z., Wassgren C., and Ambrose R.K., 2021.** Measured damage resistance of corn and wheat kernels to compression, friction, and repeated impacts. Powder Technol., 380, 638-648, https://doi.org/10.1016/j.powtec.2020.11.012

**DaSilva A.B.P., Scatolini T.B., Danao M.G.C., Gates R.S., and Rausch K.D., 2018.** Effects of splits content on dry matter loss rates of soybeans measured using a static grain respiration measurement system. Proc. ASABE Annual Int. Meeting, July 9-12, Portland, OR, USA.

**Delfan F., 2020.** Investigation of mechanical damage to chickpea seeds due to free fall using electrical conductivity tests accelerated aging and storage capacity changes (in Farsi). M.S. Thesis, Faculty of Agriculture. Lorestan University, Khorram Abad, Iran.

**Deng T., Garg V., Salehi H., and Bradley M.S., 2021.** Correlations between segregation intensity and material properties such as particle sizes and adhesions and novel methods for assessment. Powder Technol., 387, 215-226, https://doi.org/10.1016/j.powtec.2021.04.023

**Evans M.D., Homes R.G., and McDonald M.B., 1990.** Impact damage to soybean seed as affected by surface hardness and seed orientation. Trans. ASABE, 33(1), 234-240, https://doi.org/10.13031/2013.31321

**Fan Y., Jacob K.V., Freireich B., and Lueptow R.M., 2017.** Segregation of granular materials in bounded heap flow: A review. Powder Technol., 312, 67-88, https://doi.org/10.1016/j.powtec.2017.02.026

**Fiscus D.E., Foster G.H., and Kaufmami H.H., 1971.** Physical damage of grain caused by various handling techniques. Trans. ASABE., 14(3), 480-0485, https://doi.org/10.13031/2013.38319

**Foster G.H. and Holman L.E., 1973.** Grain breakage caused by commercial handling methods. Marketing Research Report No. 968. Washington, DC: USDA-ARS. Retrieved from https://archive.org/details/grainbreakagecau968fost

**Frączek J. and Ślipek Z., 1998.** Influence of moisture content and number of loading of mechanical impacts, upon the energy and sprouting capacity of wheat grains. Int. Agrophys., 12(2), 97-101.

**Gatongi I.N., 1982.** Effects of mechanical injury upon corn (*Zea mays* L.) seed quality. M.S. Thesis, Mississippi State University. Mississippi State.

**Gregg B. and Billups G., 2016.** Seed Conditioning, Volume 2: Technology-Parts A & B. CRC Press, https://doi.org/10.1201/b10312

**Gu R.L., Huang R., JIA G.Y., Yuan Z.P., Ren L.S., Li L., and Wang J.H., 2019.** Effect of mechanical threshing on damage and vigor of maize seed threshed at different moisture contents. J. Integr. Agric., 18(7), 1571-1578, https://doi.org/10.1016/S2095-3119(18)62026-X

**Guo D., 2015.** Kernel and bulk density changes due to moisture content, mechanical damage, and insect damage (Doctoral dissertation), Purdue University.

**Jan K.N., Panesar P.S., and Singh S., 2019.** Effect of moisture content on the physical and mechanical properties of quinoa seeds. Int. Agrophys., 33(1), 41-48, https://doi.org/10.31545/intagr/104374

**Khazaei J., Shahbazi F., Massah J., Nikravesh M., and Kianmehr M.H., 2008.** Evaluation and modeling of physical and physiological damage to wheat seeds under successive impact loadings: mathematical and neural networks modeling. Crop Sci., 48, 1532-1544, https://doi.org/10.2135/cropsci2007.04.0187

**Li X., Ma F., and Gao L., 2009.** Dropping impact experiment on corn seeds. Trans. Chin Soci. Agri. Eng., 25(1), 113-116.

**Liu S., Song F., Liu F., Zhu X., and Xu H., 2012.** Effect of planting density on root lodging resistance and its relationship to nodal root growth characteristics in maize (*Zea mays* L.). J. Agric. Sci., 4(12), 182-189, https://doi.org/10.5539/jas.v4n12p182

**Meyers T.P. and Hollinger S.E., 2004.** An assessment of storage terms in the surface energy balance of maize and soybean. Agric. For. Meteorol., 125(1-2), 105-115, https://doi.org/10.1016/j.agrformet.2004.03.001

**Mir H. and Shahbazi F., 2022.** Simulated transit vibration effects on the postharvest quality of persimmon during storage. Postharvest Biol. Technol., 189, 111918, https://doi.org/10.1016/j.postharvbio.2022.111918

**Mohsenin N.N., 1986.** Physical properties of plant and animal materials. New York, Gordon and Breach Science Publishers.

**Narendran RB., Jian F., Jayas D.S., Fields P.G., and White N.D., 2019.** Segregation of canola, kidney bean, and soybean in wheat bulks during bin loading. Powder Technol., 344, 307-313, https://doi.org/10.1016/j.powtec.2018.12.042

**Paulsen M.R., Nave W.R., and Gray L.E., 1981.** Soybean seed quality as affected by the impact damage. Trans. ASABE 24(6),1577-1582, https://doi.org/10.13031/2013.34493

**Paulsen M.R., Singh M., and Singh V., 2019.** Measurement and maintenance of corn quality. In: Corn (Ed. S.O. Serna-Saldivar). 165-211. AACC International Press, https://doi.org/10.1016/B978-0-12-811971-6.00007-3

**Perry J.S. and Hall C.W., 1966.** Evaluating and reducing mechanical-handling damage to pea beans. Trans. ASABE, 9(5), 696-0701, https://doi.org/10.13031/2013.40076

**Shah F.S., Watson C.E., Meredith N.D., Bohn P.A., and Marti B., 2001.** Effect of bean ladder usage on mechanical damage during soybean seed conditioning. Seed Technol., 23, 92-97.

**Shahbazi F., 2011**. Impact damage to chickpea seeds as affected by moisture content and impact velocity. Appl. Eng. Agric., 27(5), 771-775, https://doi.org/10.13031/2013.39557

**Shahbazi F., 2012.** A study on the seed susceptibility of wheat (*Triticum aestivum* L.) cultivars to impact damage. J. Agric. Sci. Technol., 14(3), 505-512.

**Shahbazi F., 2021.** Mechanical damage to agricultural grains (Causes and solutions) (in Farsi). Lorestan University Press, Khorram Abad, Iran.

**Shahbazi F., Saffar A., and Analooei M., 2011a**. Mechanical damage to pinto beans as affected by moisture content and impact energy. Agric. Eng. Int.: CIGR J., 13(2), Manuscript No.1867.

**Shahbazi F., Saffar A., and Analooei M., 2011b.** Mechanical damage to navy beans as affected by moisture content, impact velocity and seed orientation. Qual. Assur. Saf., 3, 205-211,https://doi.org/10.1111/j.1757-837X.2011.00114.x

**Shahbazi F., Valizadeh S., and Dolatshaie A., 2011c.** Correlating the data on the mechanical damage to mung bean seeds under impact loading. Int. J. Food Eng., 7(6), Article 10, https://doi.org/10.1515/1556-3758.2649

**Shahbazi F., Sharafi R., Moomevandi S.J., and Daneshvar M., 2015a.** Influence of foliar iron fertilization rate on the breakage susceptibility of wheat seeds. J. Plant Nutr., 38(14), 2204-2216, https://doi.org/10.1080/01904167.2015.1043379

**Shahbazi F., Sharafi R., Moomevandi S.J., and Daneshvar M., 2015b.** Mechanical damage to wheat seeds as affected by phosphorus and iron fertilization rate. Qual. Assur. Saf., 7(3), 385-391, https://doi.org/10.3920/QAS2013.0356

**Shahbazi F., Valizadeh S., and Dowlatshah A., 2012.** Mechanical damage to wheat and triticale seeds related to moisture content and impact energy. Agric. Eng. Int.: CIGR J., 14(4), 150-155.

**Shahbazi F., Valizade S., and Dowlatshah A., 2017.** Mechanical damage to green and red lentil seeds. Food Sci. Nutr., 5(4), 943-947, https://doi.org/10.1002/fsn3.480

**Shahbazi F. and Shahbazi R., 2019.** Mechanical damage to corn seeds. Cercetari Agronomice in Moldova, 51(3), 1-12, https://doi.org/10.2478/cerce-2018-0021

**Shahbazi R. and Shahbazi F., 2022a.** Effects of cushion box and closed let-down ladder usage on mechanical damage during corn kernel handling: Cracking. J. Stored Prod. Res., 99, 102006, https://doi.org/10.1016/j.jspr.2022.102006

**Shahbazi R. and Shahbazi F., 2022b.** Effects of cushion box and closed let-down ladder usage on mechanical damage during corn kernel handling: Cracking. Food Sci. Nutr., 00, 1-11, https://doi.org/10.1002/fsn3.3137

**Shahbazi R. and Shahbazi F., 2022c.** Effects of cushion box and closed let-down ladder usage on mechanical damage during corn kernel handling: Cracking. Plant Methods, 18(142), 1-11, https://doi.org/10.1186/s13007-022-00975-y

**Sosnowski S., and Kuźniar P., 1999.** Effect of dynamic loading on the quality of soybean. Int. Agrophys., 13(1), 125-132.

**Srivastava A.K., Herum F.L., and Stevens K.K., 1976.** Impact parameters related to physical damage to corn kernel. Trans. ASABE, 19(6), 1147-1151, https://doi.org/10.13031/2013.36191

**Su Y., Cui T., Zhang D., Xia G., Gao X., He X., and Xu Y., 2019a.** MLR and experimental testing for characterization and classification of damage resistance of maize hybrids based on mechanical properties. J. Food Process Eng., 42(7), e13262, https://doi.org/10.1111/jfpe.13262

**Su Y., Cui T., Zhang D., Xia G., Gao X., He X., and Xu Y., 2019b.** Damage resistance and compressive properties of bulk maize kernels at varying pressing factors: Experiments and modeling. J. Food Process Eng., 42(7), e13267, https://doi.org/10.1111/jfpe.13267

**Su Y., Cui T., Zhang D., Xia G., Gao X., He X., and XuY., 2020.** Effects of shape feature on compression characteristics and crack rules of maize kernel. J. Food Process. Preserv., 44(1), e14307, https://doi.org/10.1111/jfpp.14307

**Szwed G. and Łukaszuk J., 2007.** Effect of rapeseed and wheat kernel moisture on impact damage. Int. Agrophys., 21(3), 299-304.