

Mechanical damage to wheat seeds as affected by phosphorus and iron fertilisation rate

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RESEARCH ARTICLE

Abstract

The effects of phosphorus and iron fertilisers on the mechanical damage to wheat seed are unclear. The objectives were to determine the effect of different levels of phosphorus and iron fertilisation on the mechanical damage to wheat seed under impact. Phosphorus and iron treatments were combinations of four phosphorus rates (0, 75, 150 and 225 kg/ha P_2O_5) and three foliar iron rates (0, 1.2 and 2 l/ha Fusin) at three replications. The harvested seeds were then subjected to impact energies of 0.1 and 0.2 J, at moisture contents of 8.5 to 25% (wet basis). Phosphorus and iron fertility levels and the interaction between two variables significantly influenced the mechanical damage to seeds ($P < 0.01$). Resistance to breakage of wheat seeds increased following linear and polynomial relationships with increase in the phosphorus and iron rates, respectively. Increasing the rate of phosphorus from 0 to 225 kg/ha caused a significant decrease in the mean values of damage to seeds from 54.85 to 26.40% (by 2.07 times). The mean values of seeds damage decreased significantly from 52.39 to 24.07% (by 2.17 times) as the rate of foliar iron increased from 0 to 2 l/ha. As the moisture content of the seeds increased from 8.5 to 25%, the percentage breakage of seeds decreased, at all rates of the phosphorus and iron fertilisers.

Keywords: wheat, mechanical damage, harvesting, handling, fertilisation, phosphorus, iron

1. Introduction

Many of today's seed production environments are managed at very high application of chemical fertilisers to return plant nutrient to agricultural lands and ensure maximum yield potential. Consequently, it is important to understand the seed properties and resistance to impact damage in response to chemical fertilisers such as phosphorus and iron.

Cereal seeds such as wheat are subjected to a series of static and dynamic loads during harvesting, handling, processing, and storage. Such loadings cause external and internal damage in seeds, which lead to decreases in quality and can eliminate both viability and vigour (Khazaei *et al.*, 2008). The machinery and equipment for harvesting, transporting, storage and processing caused significant mechanical damage to seeds, i.e. skin rupture, seed fracture, etc. The damage resulted from mechanical interaction between biological material (seeds) and machineries material (steel, rubber, etc.). Most authors admit that the seeds damage

mainly occurs in the course of harvest and transport, where the seeds are damaged by impact forces.

The mechanical resistance to the impact damage of seeds among other mechanical and physical properties plays a very important role in the design and operational parameters of equipment relating to harvesting, threshing, handling and other processing of the seeds (Baryeh, 2002). It is very important to use injury minimising cropping and harvesting techniques and to further introduce varieties and agro technical methods that ensure the maximum resistance to injury (Niewczas, 1994). Resistance to impacts can be advantageous (storage, biological form). On the other hand, high impact resistance is an unfavourable trait in processing because of higher energy costs and less efficiency in size reduction (Szwed and Tys, 2002).

Among biological, physical and thermal factors, an important role in the resistance to damage is played by seed hardness and resilience. The higher the resilience, the better resistance to damage and therefore, the higher

their sowing value/potential. Particularly important here are the seed cover, its structure, position and chemical composition (Gorzalany, 1999). These factors are affected by the mineral fertilisation level (Szwed and Tys, 2002). Therefore, it is useful to determine the effects of various modes of fertilisation of wheat seed plantation on the mechanical damage of seeds.

Another highly important factor that has a significant effect on the resistance to damage of seeds is their water (moisture) content. Water content in seeds affects their anatomical-morphological structure only to a slight degree (Dziki and Laskowski, 2007), but plays a significant role in affecting their elastic properties. Dry biological material is little elastic and relatively brittle, and stress caused by external forces is more likely to disturb its inner structure. Higher moisture content increases the elasticity and deformability of seeds. There were some research approved a significant influence of moisture content upon the seed damage and affirm that the damage increases significantly as the moisture content decreases (Baryeh, 2002; Parde *et al.*, 2002; Shahbazi, 2011; Szwed and Lukaszuk, 2007). According to numerous studies, there is an optimum water content for each variety in which a seed is least vulnerable to injuries from outer mechanical loads (Niewczas, 1994). This feature may be important in the case of selecting the time of harvest and postharvest process, from the viewpoint of minimising yield losses due to the share of damaged seeds.

Impact damage to seeds has been the subject of much research due to the loss in product quality incurred during harvesting, handling and processing. Many studies have been conducted to determine the mechanical damage to seeds, such as: Kim *et al.* (2002) on maize, Parde *et al.* (2002) on soybean seed, Sosnowski (2006) on bean seed, Szwed and Lukaszuk (2007) on rapeseed and wheat kernels, Khazaei *et al.* (2008) on wheat seed, Khazaei (2009) on white kindey bean, Shahbazi (2011) on chickpea seed, Shahbazi *et al.* (2011a) on pinto bean, Shahbazi *et al.* (2011b) on navy bean and Shahbazi (2012) on wheat seed.

There is little information in the published literature investigating the effects of phosphorus and foliar iron fertilisers rate on the resistance to impact of wheat seeds. Therefore, the objective of this study was to investigate the effects of different rates of phosphorus and iron fertilisers on the mechanical damage to wheat seeds under impact loading at moisture contents of 8.5 to 25% (wet basis).

2. Materials and methods

Wheat seeds of the *Chamran* cultivar were chosen to be used in this research. An experiment was conducted during 2013 growing season, at the experimental research station of Lorestan University, Iran. The cropping system used in the experiment was irrigated continuous corn rotation

under conventional tillage in the fall. The wheat plots were planted in a randomised complete block design with three replications. Wheat cultivar and planting dates were chosen based on the best recommendation for farmer's practices in the area of the study. Crop management practices (except phosphorus and iron fertilisation) varied among location depending on the requirements based on soil test results. Row spacing (six rows in each plot) was 0.2 m and plot length measured 4 m in length and 1.5 m in width.

The treatment methods were combinations of four phosphorus and three iron fertilisation rates. Fertilisation rates were 0, 75, 150 and 225 kg/ha of phosphorus fertiliser (P_2O_5) and 0, 1.2 and 2 l/ha foliar iron fertiliser (Fusin; Baharan Iron Chelate Co., Isfahan, Iran), respectively. Phosphorus treatments were applied to the soil by hand in the fall, after cropping, in a 25 mm-wide band placed 5 cm to the side and 5 cm below the seeds. Fertilisation doses of foliar iron were 0 (control), 3 and 5 ng/kg, using Fusin. The equivalent rates of foliar fertilisation were 0, 1.2 and 2 l/ha, respectively. Foliar spray was done according to experimental treatments at the tillering and heading stages.

After attaining optimum maturity, samples of seed were harvested by hand, from a central area of each plot, and cleaned in an air screen cleaner. The initial moisture content of seed treatments were about 8.5% (wet basis) determined with ASAE S352.2 (ASAE, 1988). The higher moisture content samples were prepared by adding calculated amounts of distilled water, then sealing in polyethylene bags, and storing at 5 °C for 15 days.

The laboratory apparatus used to impact seeds, operated in a way similar to the impacting energy instruments used by Asoegwu (1995), Kim *et al.* (2002), Oluwole *et al.* (2007), Shahbazi *et al.* (2012) and Shahbazi (2013). In this experiment, the impact energies on seeds were 0.1 and 0.2 J.

In this study, the effects of phosphorus fertiliser rates (0, 75, 150 and 225 kg/ha), foliar iron fertiliser rate (0, 1.2 and 2 l/ha) and moisture content (8.5, 15, 20 and 25%) were studied on the percentage breakage of wheat seeds. The factorial experiment was conducted as a randomised 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, including 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. Sample mass was recorded with a digital electronic balance having an accuracy of 0.001 g. The percentage of seed breakage was calculated as (Shahbazi *et al.*, 2014):

$$\text{Seed breakage} = \frac{\text{weight of damaged seeds}}{\text{weight of total seeds}} \times 100 \quad (1)$$

Experimental data were analysed using analysis of variance (ANOVA) and the means were separated at the 5% probability level applying Duncan's multiple range tests in SPSS 17 (SPSS Inc., Armonk, NY, USA).

3. Results and discussion

Analysis of variance indicated that all the three independent variables, namely, phosphorus fertiliser rate, foliar iron fertiliser rate and seed moisture content, created a significant effect on the breakage susceptibility of wheat seeds at 1% probability level ($P < 0.01$). Iron rate had the most influence ($F = 723.11$) but, phosphorus rate ($F = 394.38$) and moisture content ($F = 134.11$) had the least, respectively, within the ranges studied for variables (Table 1). In addition, the interaction effect of the three independent variables significantly influenced the percentage breakage of wheat seeds at 1% probability level (Table 1).

Effect of phosphorus rate

The results of Duncan's multiple range tests for comparing the mean values of the percentage breakage of wheat seeds at different fertilisation levels of phosphorus is presented in Figure 1. It is evident from Figure 1 that the percentage breakage of seeds decreased with increase in phosphorus fertiliser rate. The result confirms, as the dose of chemical fertilisers has significant effects on the biological, physical and thermal properties of materials of plant origin, it also has a bearing on the effects of seed hardness and resilience of seeds, which play an important role in the resistance to damage. In addition, the result shows that the fertilisation rate of phosphorus had a significant effect on the chemical composition of wheat seed and increased its hardness and resilience therefore, caused the better resistance to impact damage. No reported results for the effect of fertilisation rate of phosphorus on the breakage susceptibility of wheat seeds were found to compare with the results obtained in

this study. However, the significant effect of fertiliser dose on the value of seed mechanical damage has also been noted for horse bean seeds by Gorzelany (1999). He reported that beans from the plot with a fertilisation dose of 40 kg/ha N, 120 kg/ha P_2O_5 and 70 kg/ha K_2O exhibited the highest resistance to cracking. Shahbazi *et al.* (2012) reported that the percentage breakage of triticale seeds decreased from 32.59 to 16.926% as the fertilisation level of zinc sulphate increased from 0 to 60 kg/ha.

With increasing the fertilisation rate of phosphorus from 0 to 255 kg/ha the mean values of the percentage breakage of seeds significantly decreased by 2.07 times. The average values for the percentage breakage of wheat seeds were found to be 54.85, 47.89, 34.97 and 26.41% for phosphorus fertiliser rates of 0, 75, 150 and 225 kg/ha, respectively. Moreover, according to Duncan's multiple range test results, the mean values of the percentage breakage of seeds at the different rates of phosphorus were statistically different from each other ($P < 0.05$) (Figure 1). Regression analysis was used to find and fit the best general model to the data of the percentage breakage of seeds at different phosphorus fertiliser rates. The result shows that, as the rate of phosphorus increased, the percentage breakage of

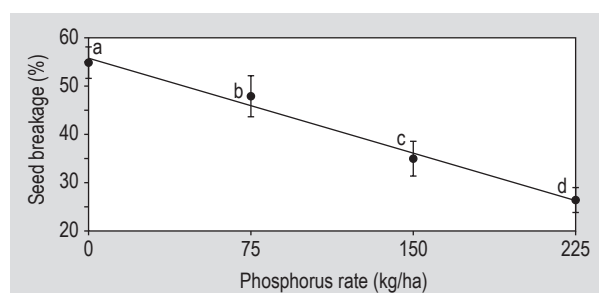


Figure 1. Effect of the phosphorus fertiliser rate on the percentage breakage of wheat seeds. Averages with the same letter have no significant difference at the 5% probability level.

Table 1. Analysis of variance (mean square) results for the percentage breakage of wheat seeds as affected by phosphorus and iron fertilisers rate and moisture content.

Source of variation	DF	Mean square	F-value ¹
Iron rate (IR)	2	14,341.431	723.116**
Phosphorus rate (PR)	3	7,821.803	394.387**
IR × PR	6	121.152	6.109**
Moisture content (MC)	3	2,659.786	134.110**
IR × MC	6	401.475	20.243**
PR × MC	9	99.443	5.014**
IR × PR × MC	18	75.918	3.828**
Error	144	19.833	

¹ ** = significant at the 0.01 probability level.

DF = degrees of freedom.

seeds decreased linearly. So the dependence of percentage breakage of wheat seeds (S_b , %) on the rate of phosphorus fertiliser (P, kg/ha) was expressed best by Equation 2:

$$S_b = -0.131P + 55.77 \quad R^2=0.987 \quad (2)$$

Statistical analysis showed that the effect of the interaction between phosphorus rate and iron rate on breakage of wheat seeds was highly significant ($P<0.01$) (Table 1). The values of the percentage of the breakage of seeds in the interaction between fertilisation rate of phosphorus and rate of foliar iron are presented in Figure 2. The data of the percentage breakage of seeds in Figure 2 varied from 10.37 to 66.19%. The minimum value (10.37%) was obtained for the 225 kg/ha phosphorus with 2 l/ha iron rate. The maximum value (66.19%) was obtained for the interaction of 0 (control treatments) rates of phosphorus and iron fertilisation. As follows from Figure 2, the percentage breakage of seeds decreases with an increase in the rate of phosphorus, at all foliar iron rates. The rate of decrease in breakage of seeds from an increase in the rate of phosphorus is not the same for all the levels of iron fertiliser. The effect of fertilisation level of phosphorus on reducing of the seeds breakage is stronger at higher iron rates than at lower ones. At 0 l/ha iron rate, the percentage breakage of seeds decreased from 66.19 to 35.80% (by 1.84 times) with an increase in the phosphorus rate from 0 to 225 kg/ha. Corresponding percentage damages were from 61.69 to 33.04% (by 1.86 times) and from 36.67 to 10.37% (by 3.53 times) for the same phosphorus rate, at 1.2 l/ha and 20 l/ha iron rates, respectively. The wheat seeds breakage was related to the phosphorus fertiliser rate in the range of 0 to 225 kg/ha, at different foliar iron fertiliser rates, by regression analysis. The results show that percentage breakage of seeds decreased linearly with an increase in the rate of phosphorus, at all the iron rates considered. The equations representing the relationship between the percentage breakage of seeds and phosphorus rate, at different iron rates, and their coefficients of determination are presented in Table 2.

The interaction between phosphorus fertiliser rate and seed moisture content on breakage of wheat seeds was significant

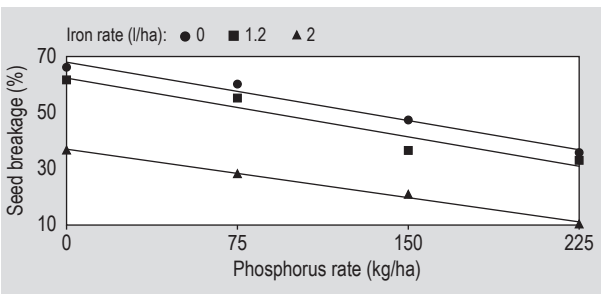


Figure 2. Wheat seed breakage variation with phosphorus fertiliser rate at different foliar iron fertiliser rates.

($P<0.01$) (Table 1). Figure 3 shows the variation of the seed breakage with the fertilisation rate of phosphorus, at different moisture contents. As follows from the relations presented in the Figure 3, for all the moisture contents considered, the breakage of seeds decreased with an increase in rate of phosphorus. In addition, the damage decreased with increase in the moisture content, for all the phosphorus rates. Similar results for reducing seed breakage with increasing in the seed moisture content were also reported by Parde *et al.* (2002), Szwed and Lukaszuk (2007) Khazaei *et al.* (2008) and Khazaei (2009). The highest seed breakage value was obtained as 64.75% in the 0 phosphorus rate at a moisture content of 8.5%, while the lowest value was found to be 20.71% in the 225 kg/ha phosphorus rate at a moisture content of 25%. As shown in Figure 3, the rate of decrease in for breakage of seeds by increasing in the rate of phosphorus is not the same for all the levels of moisture contents. The effect of fertilisation level of phosphorus on the reduction of seeds breakage is stronger at higher moisture contents than at lower ones. At 8.5% seed moisture content, the percentage breakage of seeds decreased from 64.75 to 34.87% (by 1.85 times)

Table 2. Equations representing the relationship between the percentage breakage of wheat seeds and phosphorus fertiliser rate at different foliar iron rates and moisture contents. All the indexes are significant at the level of 99.99%.

	Equation ¹	R ²
Foliar iron rate (l/ha)		
0	$S_b = -0.138P + 67.98$	0.989
1.2	$S_b = -0.139P + 62.31$	0.983
2	$S_b = -0.115P + 37.01$	0.992
Moisture content (%)		
8.5	$S_b = -0.141P + 66.18$	0.980
15	$S_b = -0.160P + 61.66$	0.998
20	$S_b = -0.109P + 48.65$	0.982
25	$S_b = -0.113P + 46.58$	0.964

¹ R² = coefficients of determination; S_b = percentage seed breakage; P = phosphorus rate (kg/ha).

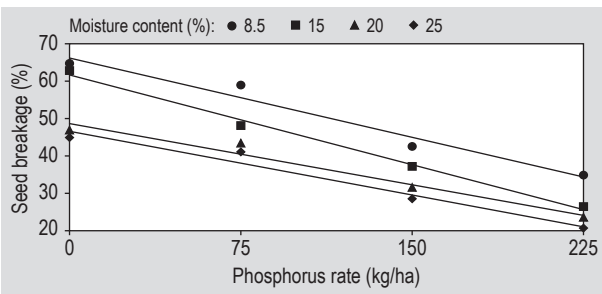


Figure 3. Wheat seed breakage variation with phosphorus fertiliser rate at different seed moisture contents.

with increases in the phosphorus rate from 0 to 225 kg/ha. Corresponding percentage damages were from 62.83 to 26.46% (by 2.37 times), 46.92 to 23.58% (by 1.98 times) and from 44.92 to 20.71% (by 2.16 times) for the same phosphorus rate, at 15, 20 and 25% moisture contents, respectively. Regression analysis showed that wheat seed breakage decreased linearly with increasing phosphorus rate, at all moisture contents considered. The equations representing the relationship between the percentage breakage of wheat seeds and phosphorus fertiliser rate, at different moisture contents, and their coefficients of determination are presented in Table 2.

Effect of foliar iron rate

The results of Duncan's multiple range tests for comparing the mean values of the percentage breakage of wheat seeds at different fertilisation levels of foliar iron presented in Figure 4. It is evident from Figure 4 that the percentage breakage of seeds decreased with an increase in iron rate, indicating that the iron fertiliser had a significant effect on the chemical composition of wheat seed and increased its hardness, resilience, and reduced the brittleness of the seed, therefore exhibited the highest resistance to cracking due to impact. No reported results for the effect of fertilisation rate of iron on the breakage susceptibility of seeds were found to compare with the results obtained in this study. With increasing the fertilisation rate of iron from 0 to 2 l/ha the mean values of the percentage breakage of seeds significantly decreased by 2.17 times. The average values for the percentage breakage of seeds were found to be 52.39, 46.63 and 24.07% for iron fertiliser rates of 0, 1.2 and 2 l/ha, respectively. Moreover, according to Duncan's multiple range test results, the mean values of the percentage breakage of seeds at the different iron fertiliser rates were statistically different from each other ($P<0.05$) (Figure 4). Regression analysis showed that percentage breakage of wheat seeds decreased as a polynomial function with increase in the rate of iron fertiliser. The following best-fitting equation was obtained for the relationship between percentage breakage of wheat seeds (S_b , %) and the rate of iron fertiliser (Fe, l/ha):

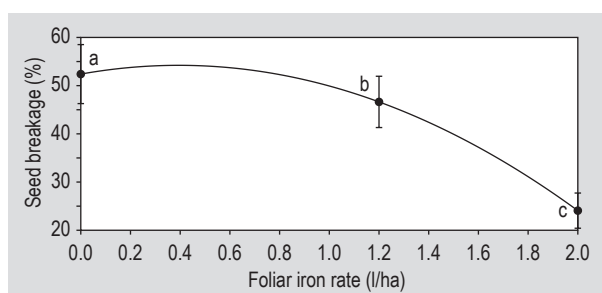


Figure 4. Effect of the iron fertiliser rate on the percentage breakage of wheat seeds. Averages with the same letter have no significant difference at the 5% probability level.

$$S_b = -11.69Fe^2 + 9.226Fe + 52.39 \quad R^2=0.999 \quad (3)$$

Figure 5 shows the percentage breakage of wheat seeds according to the rate of iron fertiliser at different fertilisation rates of phosphorus. Figure 5 shows that the percentage breakage of seeds decreases with increase in the rate of foliar iron rates, at all the phosphorus rates. However, the rate of decrease in breakage of seeds from an increase in the rate of foliar iron is not the same for all the levels of phosphorus fertiliser. The effect of the iron rate on reducing the wheat seeds breakage is stronger at higher phosphorus rates than at lower ones. At 0 phosphorus rate, the percentage breakage of seeds decreased from 66.19 to 36.69% (by 1.8 times) with an increase in the iron rate from 0 to 2 l/ha. Corresponding percentage damages were from 60.19 to 28.28% (2.12 times), 47.41 to 20.94% (2.26 times) and from 35.80 to 10.37% (3.45 times) for the same iron rate, at 75, 150 and 225 kg/ha phosphorus rates, respectively. The wheat seed breakage was related to the foliar iron fertilisation rate in the range of 0 to 2 l/ha, at different phosphorus fertiliser rates, by regression analysis. The results show that percentage breakage of seeds decreased as polynomial functions with increase in the rate of iron fertiliser, at all the phosphorus rates considered. The equations representing the relationship between the percentage breakage of wheat seeds and iron fertiliser rate, at different phosphorus rates, and their coefficients of determination are presented in Table 3.

The interaction between iron fertiliser rate and seed moisture content on breakage of wheat seeds was significant ($P<0.01$) (Table 1). Figure 6 shows that the percentage breakage of seeds decreases with increasing iron rate, at all employed moisture contents. In addition, the damage decreased with increasing seed moisture content, for all iron rates. The data of the percentage breakage of wheat seeds in Figure 6 varied from 11.69 to 59.56%. The minimum value (11.69%) was obtained for the 2 l/ha iron rate with 25% moisture content. The maximum value (59.56%) obtained for the interactions of 0 rates of iron and 8.5% moisture content. As shown in Figure 6, the effect of the fertilisation rate of iron on the reduction in seed breakage is stronger

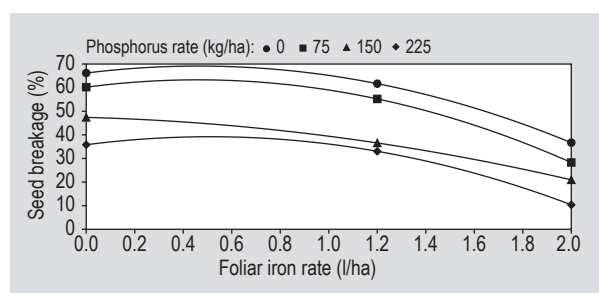


Figure 5. Wheat seed breakage variation with foliar iron fertiliser rate at different phosphorus fertiliser rates.

Table 3. Equations representing the relationship between the percentage breakage of wheat seeds and foliar iron fertiliser rate at different phosphorus rates and moisture contents. All the indexes are significant at the level of 99.99%.

	Equation ¹	R ²
Phosphorus rate (kg/ha)		
0	$S_b = -13.75Fe^2 + 12.75Fe + 66.18$	1
75	$S_b = -14.76Fe^2 + 13.58Fe + 60.18$	1
150	$S_b = -5.24Fe^2 - 2.739Fe + 47.40$	1
225	$S_b = -13.01Fe^2 + 3.31Fe + 35.80$	1
Moisture content (%)		
8.5	$S_b = -4.694Fe^2 - 0.487Fe + 59.31$	1
15	$S_b = -8.679Fe^2 + 5.936Fe + 53.06$	1
20	$S_b = -16.26Fe^2 + 15.00Fe + 49.86$	1
25	$S_b = -17.14Fe^2 + 16.45Fe + 47.34$	1

¹ R² = coefficients of determination; S_b = percentage seed breakage; Fe = iron rate (l/ha).

at higher moisture contents than at lower ones. At 8.5% seed moisture content, the percentage breakage of seeds decreased from 59.31 to 39.56% (1.49 times) with increasing iron rate from 0 to 2 l/ha. Corresponding percentage damages were from 53.06 to 30.22% (1.75 times), 49.87 to 14.81% (3.36 times) and from 47.34 to 11.69% (4.05 times) for the same iron rate, at 15, 20 and 25% moisture contents, respectively. The seed breakage was related to the foliar iron rate in the range of 0 to 2 l/ha, at different moisture contents, by regression analysis. The results showed that percentage breakage of seeds decreased, as a polynomial function, with increase in the rate of iron, at all the moisture contents considered. The equations representing the relationship between the percentage breakage of wheat seeds and iron fertiliser rate at different seed moisture contents and their coefficients of determination are presented in Table 3.

4. Conclusions

The results of this study indicate that the phosphorus and iron fertilisers had significant effects on the chemical composition of wheat seed and increased its hardness, resilience, and reduced the brittleness of the seed, therefore exhibited the highest resistance to cracking due to impact. The effect of iron fertiliser rate on reducing seed breakage due to impact was higher than the effect of phosphorus fertiliser rate. Increasing the phosphorus fertiliser rate from 0 to 225 kg/ha caused significant decreases in the mean values of damage, in a linear relationship, from 54.85 to 26.41% (by 2.07 times). With an increase in the fertilisation rate of iron from 0 to 2 l/ha the mean values of the percentage breakage of seeds significantly decreased, as a polynomial function, by 2.17 times (from 52.39 to

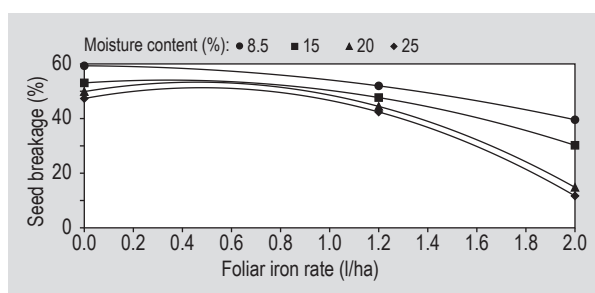


Figure 6. Wheat seed breakage variation with foliar iron fertiliser rate at different seed moisture contents.

24.07%). As the moisture content of the seeds increased from 8.5 to 25%, the amount of the percentage breakage of seeds decreased. The maximum rates of decrease in the damage to seeds, with increasing moisture content, were obtained at higher rates of phosphorus and iron fertilisers.

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