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RESEARCH ARTICLE

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Effects of Foliar Fe and Zn Application on Pod Shattering of Red Lentil Varieties in Semi-arid Region of Turkey

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ABSTRACT

Background: Reducing pod shatter is crucial for achieving high yields in lentils, a vital plant for dry lands. The selection of the right lentil variety is key to achieving this goal. While some varieties are highly productive, they may also suffer from shattering losses, which can significantly reduce profitability.

Methods: This study investigates the reduction of pod dehiscence in lentil pods through the foliar application of increasing rates of iron and zinc. A split-split-plot experiment was conducted with three lentil varieties ('Firat-87', 'Cagil' and 'Sanlibey'), two fertilizer types (zinc and iron sulphate) and three application rates (0-200-400 mg kg^{-1} and Zn rates are 0-150-250 mg kg^{-1}) as triplicates.

Result: The statistical analysis revealed that the fertilizer type had a significant effect (P<0.05) on pod shatter amounts, with iron sulphate being more effective than zinc in reducing pod shatter. The experiment found statistically significant (P<0.05) effects of foliar fertilizer rates on pod shatter. Increased Fe and Zn application rates resulted in the decreased pod shatter loss. The zinc and iron content of the leaf, pod and seed of lentils also increased with application rates for the two foliar fertilizers. The results indicate that foliar Fe and Zn application not only decreased pod shatter but also increased the mineral content (Fe and Zn) of the leaf, seed and pod of lentil varieties. The study revealed that Fe and Zn nutrient application to lentil plants increased the mineral Fe and Zn content of plant parts and decreaed the pod shatter loss in the semi-arid region of Turkey.

Key words: Foliar Fe application, Foliar Zn application, Lentil, Pod shatter.

INTRODUCTION

Lentil (*Lens culinaris* L.) is a cool season plant that moderately affected by high temperatures and drought. The most of the production of lentil done by in the developing world, approximately 75%. According to the report of Rawal and Navarro, (2019) and FAO (2021) Canada, India, Australia and Turkey are the biggest producer of the lentil, accounting for 68% of global lentil production. Lentil is a important protein and mineral source, such as iron, zinc and beta-carotene, not only for human consumption, but also for animal feeding. Straw of lentil is a valuable feed for animals (Erskine *et al*., 2016). However, pod shatter remains a significant cause of yield loss for lentil crops worldwide. According to Sosnowski *et al*. (1998), seed losses due to shedding can reach up to 20% of the crop. In a study on lentil cultivation in Slovakia, Sosnowski *et al*. (1993) found that mechanical multi-stage harvesting resulted in seed losses of 14.2%. Reported lentil seed losses in West Asia and North Africa can reach up to 55% due to pod shatter, which is the separation of cells in the pod of a lentil plant caused by the degradation of the middle lamella. Meakin and Roberts (1990) reported that this degradation is mainly due to the increased activity of hydrolytic enzymes which initiate the cell separation process. Pod shatter can occur before harvest due to adverse weather conditions or during harvest due to the impact of harvesting machinery. Pod shattering in lentils reduces grain yield and this grains result in growth of competing plants in next production season (Gülden *et al*., 2003). Factors affecting pod dehiscence can include biotic and abiotic stresses (Summers *et al*., 2003). The main reason of pod dehiscence is low moisture availability and high temperature stress in spring. At high altitudes, cold weather condion in winter can also be a limiting factor (Erskine *et al*., 2016).

Nleya *et al*. (2016) stated that in order to reduce pod shatter loss of lentil, cultivation of early-ripening and shatter-resistant species is an option. Lentil species with a thick replum should also be considered (Hu *et al*., 2015). Some of the different researches was conducted several field trial to solve this pod dehiscence problem. Erskine *et al*. (2016) studied on plant nutrients, Kandel *et al*., 2013 and Muehlbauer *et al*. (2016) on soil management techniques and Szot *et al*. (2005) on chemicals that reduce pod shattering. Latha *et al*. (2024) stated that soil moisture content affects the plant growth and pod yield in groundnut.

The lentil is produced in the arid region of Turkey where the annual precipitation is less than 350 mm that is not enough for rainfed wheat production. This precipitation

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takes place in November to March at the early growth stage of the lentil plant. This precipitation pattern results in less solubility of Zn and Fe mineral in calcareous soil during the main growth stage of lentil during pod setting and ripening. Cakmak *et al*. (1996) stated that Zn deficiency of plants may occur in the upper soil layers which are drier compared to deeper soil layers and prohibit Zn transport to the plant roots by diffusion in arid and semi-arid regions. Hence, solubility of Zn in dry land is less and related with soil moisture content. Similarly, Latha *et al*. (2024) stated that soil moisture content affects the plant growth and pod yield in groundnut. Under water stress condition, pod yield, clorophyll content, total dry matter content, photosynthetic traits decreased.

The critical level of soils Zn and Fe are 0.5 mg kg^{-1} and 4.0 mg kg^{-1} for DTPA extraction, respecively. The DTPA extractable Zn and Fe content of lentil producing land are 0.235-0.89 mg kg^{-1} and 4.74-6.72 mg kg^{-1}, respectively. Therefore, the uptake of Fe and Zn is less than the lentil plant needs. As a result, the vegetative growth and yield of lentil is limited by these minerals. Some researchers have shown that 20-77% of soils in this arid region are below the critical level of Fe and Zn supply (Saracoglu *et al*. 2011, Karaalp, 2019, Ozturkmen *et al*. 2020).

In this situation, it has been suggested that limited solubility of these minerals may affect pod shattering and yield loss of lentil. In the current study, the effects of foliar application of Fe and Zn fertilizer rates on lentil pod shatter in the semi-arid region of Turkey were investigated.

MATERIALS AND METHODS

Features of lentils

In November 2020, three lentil varieties, namely ′Firat-87′, ′Cagil′ and ′Sanlibey′, were sown. The Firat-87 variety has a height of 40-50 cm and exhibits red cotyledons. The variety is resistant to both cold and water stress, with a thousand-kernel weight of 35-40 g and a yield of 1,750-2,250 kg ha^{-1}. The Cagil variety has a height of 26-33 cm and also exhibits red cotyledons. The thousand kernel weight and yield of this variety are 31-40 g and 1,650-2,370 kg ha^{-1}, respectively (Anonymous, 2024a). The Sanlibey variety is 31-45 cm tall and has red cotyledons. It is resistant to cold and water stress, with a thousand kernel weight of 39-45 g and a yield of 1,900-2,400 kg ha^{-1} (Anonymous, 2024b). Nleya *et al*. (2016) classified three species as Persian lentil varieties.

Soil oroperties and climate

The soil in the experimental plots exhibited alkaline and calcareous properties and organic matter content between 1.58-1.81%. The soil texture was classified as heavy, with a clay content of 55% (Karagöktas *et al*., 2014). DTPA extraactable Fe and Zn amount of experiement field soil is 2.402 and 0.302 mg/kg, respectively. The climate data for the experimental station were obtained from the General Directorate of Meteorology of Turkey (Fig 1).

Experimental design

An experiment was conducted in GAP Agricultural Institute Research Institute, Talat Demirören Research Statiton in 2020-2021 production calander to determine the effects of two types of foliar fertilizer (Fe and Zn sulphate) and three red lentil varieties (′Firat-87′, ′Sanlibey′ and ′Cagil′) on lentil pod shatter. The field trial stared at November 2020 with seed sowing and finished at June 2021 with harvest. The experiment used a split-split-plot design with triplicate plots and three application rates of Fe (0-200-400 mg kg^{-1}) and Zn (0-150-250 mg kg^{-1}) foliar fertilizer. The lentils were sown in November with a density of 120 kg ha^{-1} in a 6 m^2 plot (1.2 m × 5 m) with 20 cm row spacing and 5 cm distance between plants. The required fertilizer for lentil is 40 kg ha^{-1} of N and 70 kg ha^{-1} of P_2O_5 at sowing.

Foliar Fe and Zn application

Foliar Fe and Zn fertilizers were applied on the lentil plants tractor spraying machines at podset stage for all lentil varieties. The Fe fertilizer was applied at 0, 200, 400 mg kg^{-1} rates, the Zn foliar fertilizer was applied 0, 150, 250 mg kg^{-1} rate for each plot.

Plot harvest, pod shatter and mineral nutrient content determination

The pod dehiscence ratio for production plots were determined based on a randomised 625 cm^2 area with a 25 × 25 cm quadrate. The production yield of each plot was

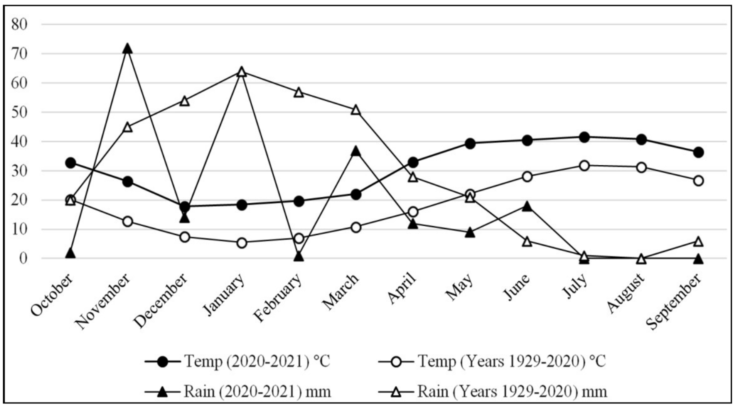

Fig 1: Annual temperature and precipitation of experiment field.

measured by harvester in mid of plot 0.8 m × 4 m (3.2 m^2) area and the pod shatter ratio was determined by counting the number of the shattered pods.

Mineral content of leaf, pod and seed of lentil varieties

Prior to harvest, the collected leaves, pods and seeds of lentil varieties were treated with an aqueous solution of nitric and perchloric acid. The zinc and iron content of the resulting solution was determined using an ICP-OES device in the laboratory.

Statistical analyses

The statistical evaluation of the results determined by the SPSS 17 software program with a split-split plot experimental design and the LSD test to determine the main effects of fertilizer type and lentil varieties on application rates. The experiment parameters, including variety and type of foliar fertilizer, were conducted as separate experiments using statistical programs to reveal the effects of application rates.

RESULTS AND DISCUSSION

Main effects of type foliar fertilizer on lentil yield, pod shatter and mineral content of plant parts

The statistical analysis revealed that the type of foliar fertilizer used had no significant effect on the harvest yield of lentil (Table 1). However, it did have a significant effect on the amount of pod shatter ($P<0.05$), with the application of Fe and Zn containing foliar fertilizers resulting in a decrease in pod shatter amounts. Applying Zn fertilizer from soil (Togay *et al.*, 2001, Öktem *et al*. 2016) to lentil plants and applying foliar Zn fertilizer increased lentil yield (Karacil, 2023). Similarly, Dhaliwal *et al*. (2021) stated that application of Fe and Zn foliar fertilizer increased the grain and straw yield compared with 0 rate parcel. However, effects of Fe fertilizer more than Zn fertilizer application.

The Fe and Zn content of the plant parts were also significantly affected by the two fertilizer types. The application of Fe and Zn containing foliar fertilizers resulted in an increase in the Zn and Fe content of leaves, seeds and pods. Additionally, the Fe-containing foliar fertilizer was found to be more effective than the Zn foliar fertilizer in reducing pod shatter (Fig 2). There was a statistically significant negative correlation between the Fe content of plant leaves, seeds and pods and the amount of pod shatter (Table 4). An increase in the Fe content of the plant led to a decrease in the amount of pod shatter. In contrast, there is no significant correlation between the Zn content of plant parts and pod shatter amounts. Karacil (2023) found that foliar application of Fe to lentil plants increased the Fe content of lentil seeds but didn't affect the Zn content of the seeds. In addition, foliar application of Zn to lentil plants increased the Fe and Zn contents of lentil seeds.

Main effects of varieties on lentil yield, pod shatter and mineral content of plant parts

The statistical analysis revealed that the main effects of lentil varieties on harvest yield and pod shatter amounts

Table 1: Pairwise comparison of main effects of fertilizer type by harvest yield, pod shatter, leaf Fe, leaf Zn, seed Fe, seed Zn, pod Fe and pod Zn.

Fertilizer type		Mean difference (i-j)							
(i)	(j)	Yield (kg ha^{-1})	Pod shatter (kg ha^{-1})	Leaf-Fe (mg kg^{-1})	Leaf-Zn (mg kg^{-1})	Seed-Fe (mg kg^{-1})	Seed-Zn (mg kg^{-1})	Pod-Fe (mg kg^{-1})	Pod-Zn (mg kg^{-1})
Foliar Fe	Foliar Zn	3.615	-25.444*	121.464*	-83.717*	25.847*	-5.772*	68.963*	-17.692*
Foliar Zn	Foliar Fe	-3.615	25.444*	-121.464*	83.717*	-25.847*	5.772*	-68.963*	17.692*
$LSD_{0.05}$		125.767	49.558	12.027	4.011	3.848	1.989	6.904	1.336

* is statistically important at 5% level.

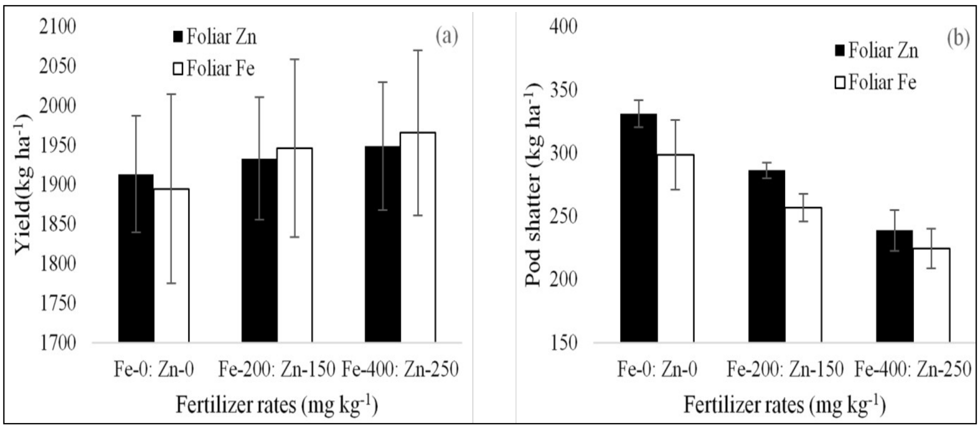

Fig 2: The effects of foliar Fe and Zn application rates on lentil yield (a) and pod shatter (b) of plant parts.

were significant (P<0.05) (Table 2). There were differences in harvest yield among the varieties, with Sanlibey having the highest yield and Firat-87 having the lowest. Similarly, the pod shatter amount varied among the lentil varieties. The Sanlibey variety exhibited the highest pod shatter amount, while the Firat-87 variety had the lowest. This suggests that high-yield lentil varieties are more prone to pod shattering than low-yield ones (Table 4).

The Fe and Zn content of the leaves, seeds and pods varied significantly among the lentil varieties (P<0.05). The content of Zn and Fe in the leaves and seeds of lentil varieties is higher than that in the pods. The Sanlýbey variety has the highest Fe content, while the Cagil variety has the highest Zn content. Toklu *et al*. (2017) stated that mineral Fe content of different lentil cultivar changed between 29.8-185.7 mg kg^{-1}, Erbaş Köse *et al*. (2019) revealed that mineral Fe content of different lentil cultivar changed between 77.0 - 108.0 mg kg^{-1} and Düzgün *et al*. (2022) found that mineral Fe content of different lentil line and cultivar changed between 70.3 - 96.4 mg kg^{-1}. Toklu *et al*. (2017) stated that mineral Zn content of different cultivar changed between 30.6 - 96.7 mg kg^{-1}, Erbaş (Köse *et al*., 2019) revealed that mineral Zn content of different cultivar changed between 32.7-34.3 mg kg^{-1} and Düzgün *et al*. (2022) found that mineral Zn content of different cultivar changed between 32.4-40.8 mg kg^{-1}.

Main effects of fertilizer rates on lentil yield, pod shatter and mineral content of plant parts

The statistical analysis shows that the foliar fertilizer rates have no significant effect on the harvest yield of lentil but have a significant effect on pod shatter amounts (P<0.05) (Table 3). The lentil harvest yield remained unchanged when treated with foliar fertilizer containing Zn and Fe. However, the amount of lentil pod shatter decreased with the application of foliar fertilizers containing Zn and Fe (Fig 3). Szpunar-Krok *et al*. (2021) revealed that foliar application of Fe and Zn fertilizer on common pea increased the mechanical resistance of seed. Saha *et al*. (2024) showed that foliar application of nanoparticles of Zn to the lentil plant increased the Zn content of seeds and stover, which resulted in additional benefits for the yield of lentil seeds and stover. Singh and Bhatt (2013) stated that application of foliar Zn on late sown lentil plant increased the plant vegetative growth and harvest yield.

The application rates of Zn containing fertilizer have a statistically significant effect on the Zn and Fe content of plant parts (P<0.05) (Table 3). The zinc content of the leaf, seed and pod increased with the application of zinc foliar fertilizer. However, the iron content of the lentil plant did not show a regular change with the application of zinc foliar fertilizer.

Table 2: Pairwise comparison of main effects of lentil varieties by harvest yield, pod shatter, leaf Fe, leaf Zn, seed Fe, seed Zn, pod Fe and pod Zn.

Lentil varieties		Mean difference (i-j)							
(i)	(j)	Yield (kg ha^{-1})	Pod Shatter (kg ha^{-1})	Leaf-Fe (mg kg^{-1})	Leaf-Zn (mg kg^{-1})	Seed-Fe (mg kg^{-1})	Seed-Zn (mg kg^{-1})	Pod-Fe (mg kg^{-1})	Pod-Zn (mg kg^{-1})
Cagil	Firat-87	382.161*	25.017	32.404*	47.635*	2.593*	-5.570*	0.653	1.482*
	Sanlibey	-229.272*	-33.000*	-10.753*	6.274*	-3.128*	0.519	-3.303	1.757*
Firat-87	Cagil	-382.161*	-25.017	-32.404*	-47.635*	-2.593*	5.570*	-0.653	-1.482*
	Sanlibey	-611.433*	-58.017*	-43.157*	-41.361*	-5.720*	6.089*	-3.956	0.275
Sanlibey	Cagil	229.272*	33.000*	10.753*	-6.274*	3.128*	-0.519	3.303	-1.757*
	Firat-87	611.433*	58.017*	43.157*	41.361*	5.720*	-6.089*	3.956	-0.275
$LSD_{0.05}$	154.032		60.696	14.73	4.912	4.713	2.436	8.456	1.636

*Is statistically important at 5% level.

Table 3: Pairwise comparison of main effects of fertilizer rates on harvest yield, pod shatter, leaf Fe, leaf Zn, seed Fe, seed Zn, pod Fe and pod Zn.

Fertilizer rates		Mean difference (i-j)							
(i)	(j)	Yield (kg ha^{-1})	Pod Shatter (kg ha^{-1})	Leaf-Fe (mg kg^{-1})	Leaf-Zn (mg kg^{-1})	Seed-Fe (mg kg^{-1})	Seed-Zn (mg kg^{-1})	Pod-Fe (mg kg^{-1})	Pod-Zn (mg kg^{-1})
0	Medium	-53,411	83,017*	-50.249*	-15.265*	-6.415*	-6.822*	-30.979*	-12.548*
	High	-35,8	43,283*	-90.710*	-25.595*	-22.080*	-14.518*	-63.811*	-12.213*
Medium	0	53,411	-83,017*	50.249*	15.265*	6.415*	6.822*	30.979*	12.548*
	High	17,611	-39,733*	-40.460*	-10.330*	-15.665*	-7.696*	-32.831*	0.335
High	0	35,8	-43,283*	90.710*	25.595*	22.080*	14.518*	63.811*	12.213*
	Medium	-17,611	39,733*	40.460*	10.330*	15.665*	7.696*	32.831*	-0.335
$LSD_{0.05}$	154.032		60.696	14.73	4.912	4.713	2.436	8.456	1.636

*Is statistically important at 5% level.

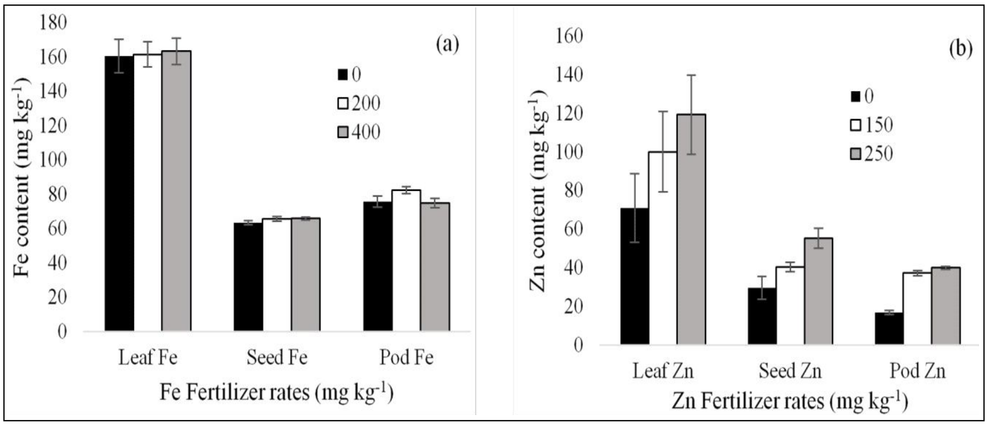

Fig 3: The effects of foliar Zn application rates on Fe (a) and Zn (b) content of plant parts.

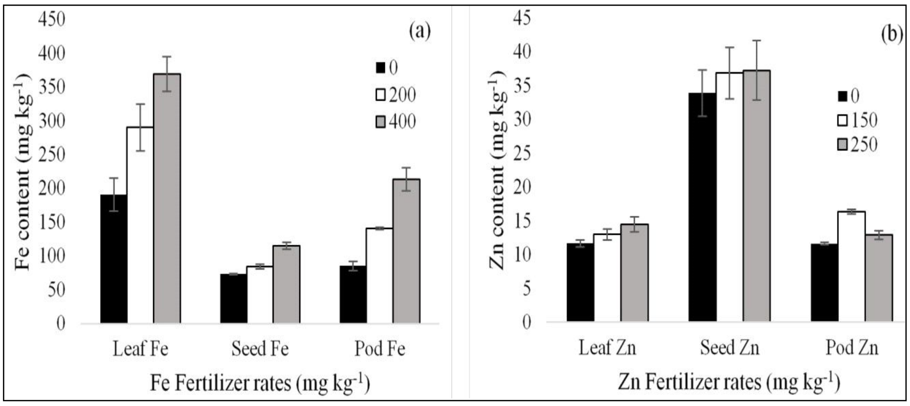

Fig 4: The effects of foliar Fe application rates on Fe (a) and Zn (b) content of plant parts.

Table 4: The correlation between lentil yield, pod shatter and mineral Fe an Zn content of plant parts (N=36).

	Yield	Leaf Fe	Leaf Zn	Seed Fe	Seed Zn	Pod Fe	Pod Zn
Pod shatter	0,359*	-0,378*	0.232	-,433**	-0.158	-0,458**	-0.034
Yield	1	0.293	0.3	0.115	-0.057	0.059	0.047
Leaf Fe		1	-0,539**	0,858**	0.041	0,884**	-0,476**
Leaf Zn			1	-0,524**	0.246	-0,496**	0,778**
Seed Fe				1	-0.052	0,953**	-0,497**
Seed Zn					1	-0.011	0,529**
Pod Fe						1	-0,464**

*Significant at the 0.05 level (2-tailed), **Significant at the 0.01 level (2-tailed).

The iron and zinc content of the leaf, seed and pod increased with the application of iron foliar fertilizer (Fig 4). However, there is a significant negative correlation between the iron and zinc content of all parts of the lentil plant (Table 4). As the iron content of the plant parts increased, the zinc content of the plant parts decreased. Karacil (2023) found that foliar application of Fe to lentil plants increased the Fe content of lentil seeds but didn't affect the Zn content of the seeds.

CONCLUSION

The impact of foliar Fe and Zn fertilizers on lentil plant harvest yield, pod shatter and mineral Fe and Zn content varied depending on the fertilizer type, variety and rate.

a) The application of foliar fertilizers containing Fe and Zn reduced the amount of pod shatter in lentil plants.
b) Fe-containing foliar fertilizer was found to be more effective than Zn-containing fertilizer in reducing pod shatter.
c) Although there were differences in harvest yield and pod shatter, the application of foliar Fe and Zn fertilizers had similar effects in reducing pod shatter.
d) Additionally, the mineral content of Fe and Zn in the leaf, seed and pod increased with the application of foliar fertilizers.

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Conflict of interest

All authors declare that they have no conflict of interest.

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