Table 8. Hypothetical premium payment and compensation benefit by a farmer (Rs)

				Total		Limited to 25 years	
Weather perils	DRC/WDI	ERC/ERI	CDD/DDI	Premium	Payout	Premium	Payout
Dharmapuri	14,231	4,433	2,800	8,750	21,464	8,750	21,464
Virudhunagar	25,509	2,223	1,200	9,100	28,932	8,750	27,819
Coimbatore	3,129	472	160	10,500	3,761	8,750	3,134
Theni	6,652	10,074	16,000	9,507	32,726	7,923	27,272
Tirunelveli	2,087	1,294	7,000	10,500	10,381	8,750	8,650

Tirunelveli, S_2 occurred five times while S_3 occurred three times (Figure 3).

On comparison of CDD/DDI, among the different companies, cumulative days of the strike event were considered by AIC and IFFCO–TOKYO, whereas the strike events between particular days in the phase were considered in the remaining companies. With respect to DDI, HDFC–ERGO provides good compensation between particular days in the phase and this increased the payout benefit of the farmer. For CDD, the water holding capacity of the soil and the daily ET must be taken into account for fixing the strike threshold values as well as compensation rates.

Table 8 provides an examination of five districts covered by four agricultural insurance companies on hypothetical premium payment and amount of compensation received over 25 years. To arrive a good comparison among the different companies, the period is limited uniformly to 25 years.

The hypothetical premium payment and compensation analysis showed that farmers at Virudhunagar and Dharmapuri districts followed by Theni district were highly benefitted. The farmers in Coimbatore and Tirunelveli did not get adequate compensation compared to the above-mentioned districts. This was due to lower compensation rate per mm of rainfall fixed by the company. In this study, the deficit rainfall risk was more pronounced in all the study districts, whereas the risk of excess rainfall impact could be clearly observed in Theni district.

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Zinc as an important factor determining resistance against *Helicoverpa armigera* herbivory in pigeon pea (*Cajanus cajan* L.)

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The potential of enzyme inhibitors against infestation of insects serves as attractive strategy for the management of devastating pests. In an effort to identify some effective and eco-friendly inhibitors of a damaging pest, *Helicoverpa armigera*, iron and zinc were found to be potent inhibitors of *H. armigera* α-amylase, which is an important digestive enzyme required for its survival. This observation motivated us to determine the status of iron and zinc in different pigeon pea genotypes in response to *H. armigera* herbivory. In general, there was significant decline in zinc content in developing seeds and pod wall after herbivory. However, zinc content was significantly higher in moderately resistant genotypes than moderately susceptible genotypes in infested developing seeds. Significant accumulation of iron was also observed in developing seeds of moderately resistant and intermediate genotypes after the pod borer attack. Higher content of zinc in pod wall of moderately resistant genotypes could determine their resistibility status against *H. armigera* herbivory.

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Keywords: *Helicoverpa armigera*, iron, pigeon pea, zinc.

PLANTS are the targets of biotic stress factors such as insects and pathogens. During this long course of host–parasite interactions, plants have acquired certain degree of resistance against insect pests through the accumulation of defensive compounds such as phenolics, enzyme inhibitors, enzymatic- and non-enzymatic antioxidants, etc. Despite such prevalence, plants remained susceptible to predation because insects too evolved several means of defeating plant defences during this co-evolution[1]. Insect survival is mainly dependent on the availability of starch which is required for its optimal growth and longevity. Amylase inhibitors are regarded as effective candidates for managing the insect infestation as they impede the digestion through their action on insect α-amylases, which play a key role in the digestion of plant starch. Non-proteinaceous inhibitors of *Rhyzopertha dominica* α-amylase such as salicylic acid, oxalic acid, etc. cause significant reduction in the multiplication of the destructive pest of stored grains[2].

Helicoverpa armigera is one of the most damaging pests of pigeon pea (*Cajanus cajan* L.). The pest mainly attacks the reproductive parts such as flowers and pods and causes heavy reduction in crop yield[3]. It has developed high level of resistance against conventional insecticides due to which it has become difficult to control the damaging effect of this pest on crop productivity. Therefore, the present work was focused on identifying effective and eco-friendly inhibitors of *H. armigera* α-amylase. The interaction of this pest α-amylase was studied with various compounds, and iron and zinc caused effective inhibition of *H. armigera* α-amylase. This observation propelled us to determine the status of Fe and Zn in different pigeon pea genotypes in response to *H. armigera* herbivory. Zn has been reported as an excellent protective agent against the oxidation of several vital cell components such as membrane lipids and proteins. It also provides tolerance to plants by being an important part of the zinc finger proteins which are expressed in response to various abiotic stresses[4]. Zn and Fe are metal cofactors of superoxide dismutase, an antioxidative enzyme which catalyses the dismutation of superoxide radical into H_2O_2 and is the first plant immune response which further upregulates various signalling pathways and the antioxidative defence system[5]. The present investigation was undertaken to study whether Zn and Fe status of pigeon pea could be related with *H. armigera* resistance.

Fourth instar larvae of *H. armigera* were collected from pigeon pea fields at the Pulses Research Area, Punjab Agricultural University, Ludhiana, India. For the estimation of Fe and Zn contents, nine pigeon pea genotypes – four moderately resistant (AL 1495, AL 1735, AL 1747, AL 1770), three intermediate (AL 1753, AL 1755, AL 201) and two moderately susceptible (AL 1677 and AL 15) were sown by following the recommended agronomic practices in the University. These genotypes were classified on the basis of per cent pod damage and each genotype was sown in paired rows with a plot size of 2 m^2 in randomized block design with three replications[6,7]. At pod formation stage, one row of each genotype was selected for artificially confining two larvae of *H. armigera* (fourth instar) per plant using nylon mesh cloth cage. The other row sown alongside separately served as uninfested control. The controls as well as the infested rows were sown inside a nylon net house to prevent any other pest infestation. The larvae were allowed to feed on pods for a period of seven days.

Developing seeds and pod wall from each of three replications were then collected randomly from uninfested and infested plants, dried at 60°C till constant weight, digested with 10 ml concentrated nitric acid and perchloric acid (4 : 1) solution and analysed for Fe and Zn using atomic absorption spectrophotometer (AA240 Varian).

Helicoverpa armigera α-amylase was extracted by homogenizing fourth instar larvae in 0.02 M phosphate buffer (pH 6.9) containing 10 mM NaCl. The homogenate was centrifuged at 10,000 *g* for 30 min at 4°C. The supernatant obtained was used as an enzyme extract. Enzyme (100 μl) along with 0.5 ml of 1% soluble starch in 0.05 M phosphate buffer (pH 9.5) was incubated at 37°C for 60 min and the reducing sugars formed were determined[8]. The activity was expressed as nmoles of reducing sugars formed min^{-1} ml^{-1} of enzyme.

Fe and Zn were found to be potent inhibitors of *H. armigera* α-amylase. The percentage of inhibition increased with increase in iron (0.5–3 mM) and zinc (1.5–6 mM) concentration (Figure 1). *H. armigera* infestation caused significant decrease in Zn content in developing seeds and pod wall of tested genotypes (Figure 2). However, the relative decline was less in moderately resistant genotypes (AL 1495, AL 1735, AL 1747, AL 1770) in comparison with moderately susceptible genotypes (AL 1677, AL 15), leading to higher status of Zn in moderately resistant genotypes after infestation (Figure 2). The mean Zn content in infested developing seeds and pod wall was significantly higher in moderately resistant (10.2 and 1.1 μg g^{-1} DW respectively) and intermediate genotypes (11.0 and 0.6 μg g^{-1} DW respectively) compared to moderately susceptible genotypes (4.1 and 0.3 μg g^{-1} DW respectively).

Herbivory by pod borer resulted in significant increase in Fe content in developing seeds of moderately resistant and intermediate genotypes (Figure 3). However, no significant change in Fe content of developing seeds was observed in moderately susceptible genotypes (AL 1677, AL 15) after pod borer infestation. The mean Fe content was higher in infested developing seeds of moderately resistant (64.7 μg g^{-1} DW) and intermediate (64.9 μg g^{-1} DW) genotypes than moderately susceptible genotypes (49.2 μg g^{-1} DW). No significant change in Fe

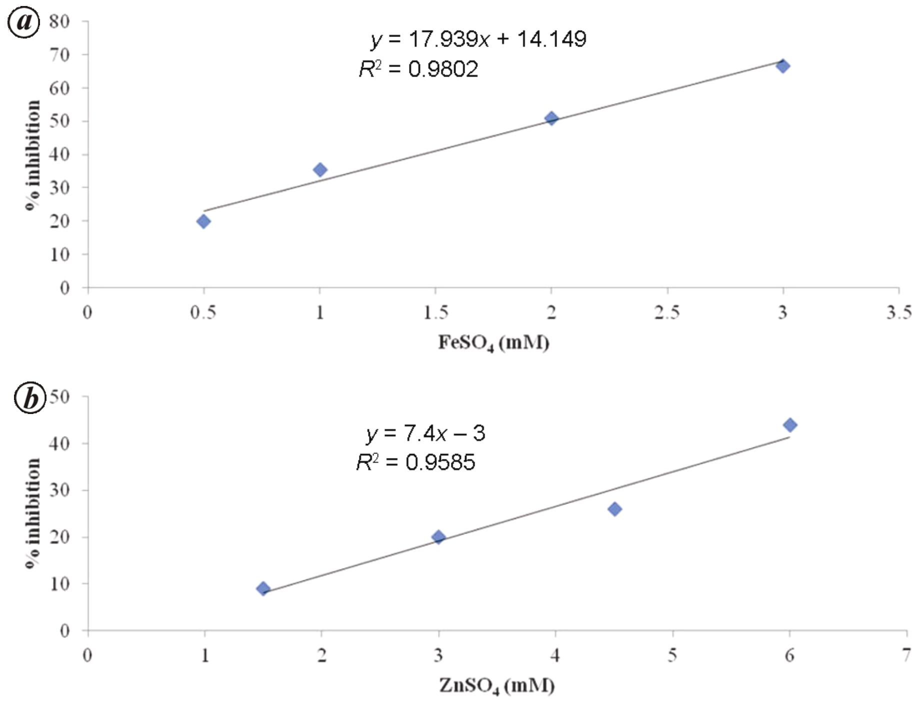

Figure 1. Inhibition of *Helicoverpa armigera* α-amylase by ferrous sulphate and zinc sulphate. The graph shows the increase in percentage of inhibition with increase in concentration of (***a***) ferrous sulphate and (***b***) zinc sulphate.

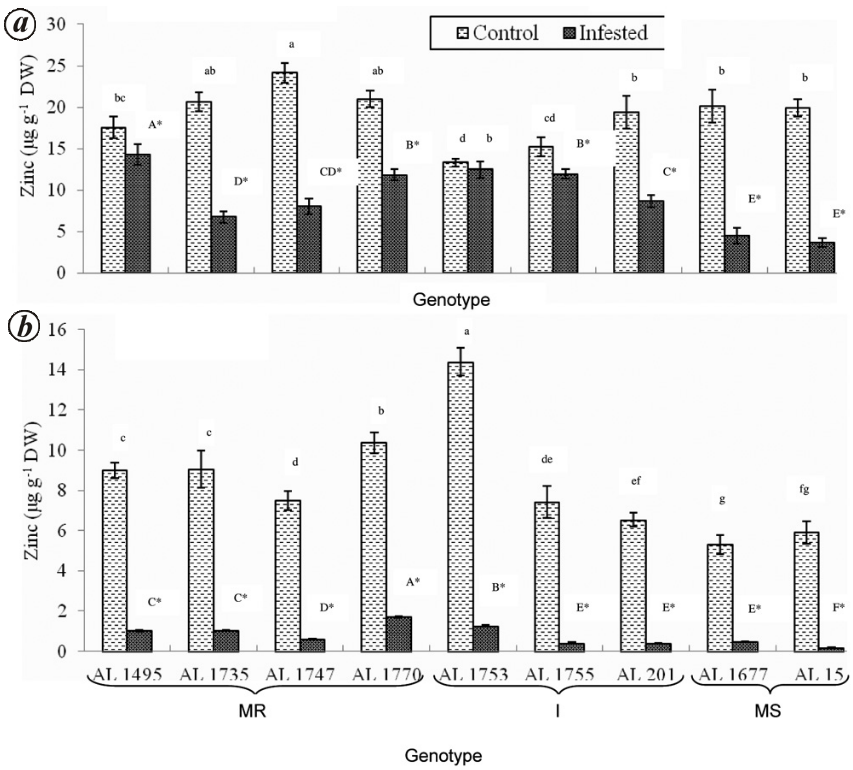

Figure 2. Zinc content in (***a***) developing seeds and (***b***) pod wall of tested genotypes. Vertical bars denote ± SD of three replicates. Bars with different small letter(s) represent significant differences between uninfested genotypes, and those with different capital letter(s) represent significant variation between infested genotypes at $P \leq 0.05$. Asterisk shows statistically significant differences in infested genotypes from their respective uninfested plants at $P \leq 0.05$ analysed by Tukey's test. MR, Moderately resistant; I, intermediate; MS, moderately susceptible.

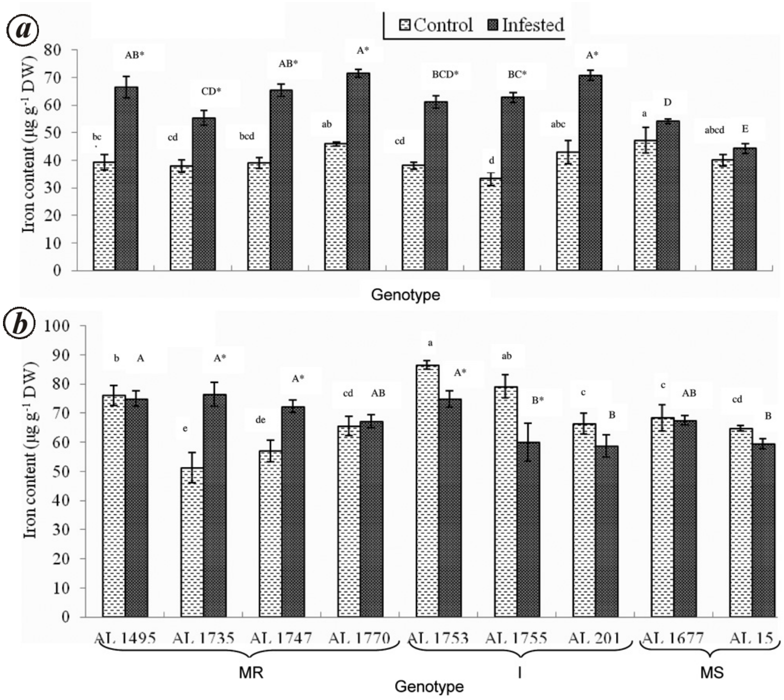

Figure 3. Iron content in (***a***) developing seeds and (***b***) pod wall of tested genotypes. Vertical bars denote ± SD of three replicates. Bars with different small letter(s) represent significant differences between uninfested genotypes, and those with different capital letter(s) represent significant variation between infested genotypes at $P \leq 0.05$. Asterisk shows statistically significant differences in infested genotypes from their respective uninfested plants at $P \leq 0.05$ analysed by Tukey's test.

content was observed in the pod wall, after pod borer attack (Figure 3).

Zn has been reported as a protective agent in plants[9]. It is a cofactor of antioxidative enzyme, superoxide dismutase (SOD), which detoxifies the superoxide radical. In addition, it is an integral part of DNA-binding proteins, viz. zinc finger proteins, which get expressed on account of abiotic and biotic stresses[4,10]. The decline in Zn content in developing seeds and pod wall (Figure 2) might be due to the accumulation of tannins on account of *H. armigera* herbivory[6] as they have the ability to chelate metal ions. The decrease in Zn content has been reported to upregulate NADPH oxidases which increases the formation of superoxide radicals[9]. Torres *et al.*[11] reported that plant immune responses are usually accompanied by the production of superoxide radicals at the surrounding pathogen-infected sites. The enhanced production of superoxide radicals might upregulate the antioxidative defence system in plants such as the upregulation of SOD, etc. Kaur *et al.*[6] reported the upregulation of SOD in pigeon pea on account of *H. armigera* infestation. The decrease in Zn content might be responsible for the down-regulation of catalase in response to *H. armigera* infestation[6], as catalase is inhibited by superoxide anion[12].

On the other hand, the capability of moderately resistant genotypes (AL 1495, AL 1735, AL 1747, AL 1770) to maintain relatively high Zn content than moderately susceptible genotypes (AL 1677, AL 15) after the pod borer attack suggested Zn as one of the factors providing resistance against *H. armigera* herbivory (Figure 2). Pollard and Baker[13] reported that locust *Schistocerca gregaria* prefers to feed on low Zn-containing leaves of *Thlaspi caerulescens* than on high Zn-containing leaves. Moreover, the negative association between per cent pod damage and Zn content in infested pod wall ($r = -0.56$, $P \leq 0.1$) revealed that higher the Zn content, lower is the pod damage. High Zn content might benefit the plants by being a metal cofactor of SOD and part of zinc finger proteins which get upregulated under stress conditions. Huang *et al.*[4] reported that increased tolerance of rice to cold, drought and oxidative stress is mediated by the overexpression of a gene that encodes the zinc finger protein, ZFP245. The involvement of zinc finger proteins in biotic stress signalling was observed when OsSAP1 and OsSAP11 (zinc finger proteins) were reported to get upregulated in response to pathogen infection in tobacco[10].

Another response of *H. armigera* herbivory was the significant accumulation of Fe in developing seeds (Figure 3). Fe is also a cofactor of SOD and thus helps in scavenging the reactive oxygen species. Moreover, it has been reported that decrease in Zn content causes the accumulation of Fe[9], which was observed in our study as well. The negative association between percentage of pod damage and Fe content in infested developing seeds ($r = -0.52$) and pod wall ($r = -0.60$, $P \leq 0.1$) indicated some contribution of Fe in providing resistance against

H. armigera infestation in pigeon pea. Increased iron content in apoplast after pathogenic fungi attack[14] coupled with a report that nitric oxide mediates iron-induced ferritin accumulation[15] which is involved in protecting plants against oxidative stress[16] and another report indicating upregulation of nitrate and nitrite content which can increase NO production upon *H. armigera* herbivory[17] suggest possible role of iron in plant protection against insect attack. However, the exact role of Fe, hidden under multilayered plant immune responses needs to be unravelled.

In biofortification research, Zn foliar spray has been suggested to enhance grain/seed Zn content[18,19]. The observed negative association between Zn content and insect herbivory prompts us to suggest that such foliar application will not only lead to biofortification of grains/seeds, but may also lead to better protection against insect attacks.

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Design of barrage on heterogeneous and anisotropic soils

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The present study reports on the design of barrages on heterogeneous and anisotropic soils, based on the analysis of subsurface flow by finite element method. The study indicates that the location of impervious layer below the sheet piles marginally changes the uplift pressures, but with an advantage of reduction in the exit gradient. On the contrary, the location of a pervious layer below the sheet piles drastically changes the uplift pressures along with a drastic increase in the exit gradient and therefore, will have a major impact on the design of a barrage. The isotropic and anisotropic soils behave differently under subsurface flow considerations and unlike isotropic soils, the depth of upstream sheet pile/cut-off can be an important factor for the design of a barrage on anisotropic soils. The uplift pressures and exit gradients can be reduced by increasing the depth of upstream sheet pile for anisotropic soils.

Keywords: Barrages, heterogeneous and anisotropic soils, river engineering, waterways and canals.

THE importance of barrages in India in view of the alarming water scarcity is noteworthy[1], as it is used to divert river water through canal system for irrigation and other useful purposes in tropical and subtropical countries. A

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