Morphological and chemical traits associated with resistance against spotted pod borer, *Maruca vitrata* in pigeonpea

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Abstract

Host plant resistance is an important tool for minimizing the losses in pigeonpea due to spotted pod borer, Maruca vitrata*, which is the most threatening hidden pest of pigeonpea crop. Experiment was carried out to study the morphological and chemical traits in pigeonpea associated with expression of resistance to* M. vitrata *and their incidence in different sowing dates. The incidence of* M. vitrata *varied significantly among different sowing dates. Crop sown on D_2 (1st week of July) resulted in maximum pod infestation by* M. vitrata *(13.1%). Minimum pod infestation (2.3%) and (2.9%) was recorded in D_4 (3rd week of July) and D_1 (3rd week of June) sown crop, respectively. Among different varieties, AL-201 registered lowest pod infestation (4.3%) as compared to Pusa-992 (7.9%). The non-glandular (type A), and glandular (type B) pod trichome density of top, middle and lower canopy of the plant and the pod wall thickness was responsible for the resistance to* M. vitrata*. Whereas, non-glandular (type C) pod trichomes, pod length, seed width and number of seeds per pod were associated with the susceptibility to spotted pod borer. Expression of resistance to* M. vitrata *pod infestation was associated with low amounts of crude protein and total soluble sugar and higher amount of fat content, phenol content and tannin content of seed as well as pod wall.*

Keywords: Morphological and chemical traits, *Maruca vitrata*, pigeonpea, sowing dates

Introduction

Pigeonpea, being a tropical crop, the pod borers have been recognized as the major constraints in increasing the productivity of pigeonpea crop (Bhandari and Ujagir, 2002; Sahoo and Senapati, 2002). Among vast array of pod borer community threatening the pigeonpea production, spotted pod borer, *M. vitrata* is the single most dreaded pest attacking flowering to pod formation stage resulting a big reduction in the production (Pappu *et al*., 2010). Larvae of spotted pod borer feed on buds, flowers and pods, remain inside the web formed by rolling and tying together the reproductive parts, hence called "hidden insect". Its seriousness in pigeonpea crop has been reported in India, Sri Lanka and Africa (Lateef and Reed, 1990), with an annual loss of US $ 400 million (ICRISAT, 2007) worldwide and in India, 9-51 per cent damage has been reported (Bhagwat *et al*., 1998). Its feeding potential found in tropical and sub-tropical areas due to vast array of host range, destructiveness and distribution is reported on cowpea, mungbean, urdbean and filed beans (Shanower *et al*., 1999).

To avoid pesticide usage, there is a need to develop additional methods to minimize the extent of losses. Among them, development of insect resistant cultivars has a remarkable potential for use in integrated pest management, particularly under subsistence farming conditions in developing countries (Sharma, 2005). Various biochemical parameters (Oghiakhe *et al*., 1992 and Sahoo and Senapati, 2001), *viz*., total sugar, reducing sugar, non-reducing sugar, amino acids, phenols and proteins in pods and morphological and structural attributes (Halder *et al*., 2006; Sharma *et al*., 2009; Sunita *et al*., 2013 and Jagtap *et al*., 2014), *viz*., pod wall thickness, trichome density, pod length, no. of pods per plant and days to 50 per cent flowering of plants play an important role in providing resistance to the plants against *M. vitrata*. Likewise, exudates of trichomes on the pod wall surface play an important role in the host selection by ovipositional behavior (Bernays and Chapman, 1994). Knowledge on genetic breeding program for development of resistant cultivars having all the morphological and biochemical desirable characteristics can be of great value and breeding for resistance is powerful tool escaping the insect pest damage. Breeding for resistance has been found very successful in reducing damage caused by insect (Maxwell and Jennings, 1980). Hence, it is desirable to develop or screen cultivars for resistance against pod borer, *M. vitrata*. Therefore, the present study was carried out to know the role of biochemical and morphological traits in and on the pods of pigeonpea crop in relation to expression of resistance to *M. vitrata* across different planting dates.

Materials and methods

Plant material

Experiment was conducted during *Kharif* seasons 2013 and 2014 at Pulses Farm, Department of Genetics and Plant Breeding, CCS Haryana Agricultural University, Hisar to study the morphological and chemical traits of resistance in pigeonpea against *M. vitrata*. Six pigeonpea varieties *viz*., Manak, Paras, Pusa-992, AL-201, PAU-881 and H03-41 were sown at four different dates *i.e.* D_1 (3rd week of June), D_2 (1st week of July), D_3 (2nd week of July) and D_4 (3rd week of July). Sowing was done in plot size of 4 rows of 4 m length (1.8 m x 4 m) with spacing of 45 cm x 15 cm keeping three replications in randomized complete block design. The plots were kept without insecticidal spray to allow the natural infestation of *M. vitrata* throughout the cropping season.

Evaluation of *M. vitrata* infestation

M. vitrata infestation was ascertained by randomly selection of 150 pods from each plot per replication in all the sowing dates at the time of harvesting and brought to the laboratory and examined carefully during 2013 and 2014 cropping seasons. The irregular bore holes on the pods were considered as the infestation of *M. vitrata* and the per cent pod damage was worked out.

Impact of morphological and chemical traits on *M. vitrata*

The morphological traits *viz*., trichome density of pods (top, middle and bottom canopy), pod length, pod wall thickness, seed length and seed width and number of seeds per pod and chemical traits *viz*., crude protein, moisture content, total soluble sugars, fats, total phenols, tannins, and chlorophyll content of seed as well as pod wall were studied under laboratory conditions using standard procedures. To study the morphological traits, 25 fresh pigeonpea pods of 25 days old were randomly plucked and collected from each genotype per replication. Trichome density of pods (top, middle and bottom canopy of the plant) was studied by using the method described by Sass (1964). Pod wall thickness, pod length, seed length and width were measured by using Vernier Calipers. The number of seeds per pod from each genotype were counted based on number of locules filled as well as unfilled with the seeds.

To study the biochemical constituents from seeds as well as pod wall, enough pods of 15 days old were plucked from each replication of each plot. Pods were kept in marked brown paper bags having wax coated inner side. The samples were brought to the laboratory, kept in airtight plastic container, and stored at 4 °C in deep freeze during the study period. Pod wall and green seeds of these pods were taken for further biochemical analysis. One set of pods was oven dried at 60 °C for 2-3 days. After drying, the test samples were grinded and samples of seeds as well as pod wall were then kept in a paper envelop in oven at 50 °C for one day to ensure complete drying of the samples. Completely dried samples were used for the estimation of biochemical constituents.

The crude protein content of seeds as well as pod wall was estimated by the method described by AOAC (1985). The per cent protein content was calculated by multiplying nitrogen (%) with the factor of 6.25. Moisture content of seeds as well as pod wall was determined by the method described by Mehta and Lodha (1979). For the estimation of total soluble sugar in seeds as well as pod wall, the method described by Dubios *et al*., (1956) was followed. Fat estimation was worked out by using the method narrated by AOAC (1975). For the estimation of total phenol in seeds as well as pod wall, Folin Ciocalteau method narrated by Bray and Thorpe (1954) was followed. Tannin content in seed as well as pod wall was estimated by following the method of AOAC (1965). Chlorophyll content of seed as well as pod wall was estimated by using the method of Hiscox and Israelstam (1979).

Statistical analysis

Data were subjected to analysis of variance using SPSS statistics, 19 version statistical package as suggested by Steel and Torrie (1980). The correlation coefficients between spotted pod borer infestation and morphological and chemical traits were also carried out to know their association with resistance/susceptibility to *M. vitrata*.

Results and discussion

The research findings revealed that there was a significant difference in the per cent pod damage between sowing dates and varieties during both the years (2013 and 2014) and pooled results (Tables 1, 2 and 3). During the year 2013, the maximum pod damage (17.5%) was recorded in D_2 (1st week of July) sown crop followed by D_3 (2nd week of July) (6.0%) and D_1 (3rd week of June) sown crop (3.0%), respectively (Table 1). Whereas, the minimum pod damage (2.7%) was recorded in D_4 (3rd week of July) sown crop. The pod damage among different varieties revealed that the variety Pusa-992 registered with maximum pod damage (10.6%), followed by Manak (7.4%). Varieties PAU-881 (7.3%) and Paras (7.3%) were found statistically at par with each other. Minimum pod damage (5.6%) was recorded in H03-41 and it was statistically at par with AL-201 (5.8%). The interaction effect of varieties and sowing dates on the incidence of spotted pod borer damage was significant. It means the varieties and sowing dates had their influence on the pod borer damage.

Data on pod borer damage during the year 2014 are presented in Table 2 In D_2 (1st week of July) sown crop, the maximum pod damage was 8.7 per cent followed by D_3 (2nd week of July) sown crop (3.8%) and D_1 (3rd week of June) sown crop (2.8%). The minimum pod damage

Table 1. Per cent pod infestation by *M. vitrata* in different pigeonpea varieties during 2013

	Variety						
Sowing	Paras	Manak	AL-201	Pusa-992	PAU-881	H03-41	Mean
D_1	3.2 (10.4)	3.6 (10.9)	1.8 (7.7)	4.1 (11.7)	3.8 (11.2)	1.7 (7.4)	3.0 (9.9)
D_2	19.3 (26.0)	16.4 (23.9)	13.2 (21.3)	21.4 (27.6)	18.2 (25.3)	16.3 (23.8)	17.5 (24.6)
D_3	4.7 (12.5)	7.0 (15.4)	3.1 (10.2)	15.2 (23.0)	2.6 (9.4)	3.2 (10.3)	6.0 (13.5)
D_4	1.8 (7.8)	2.4 (8.9)	5.0 (12.9)	1.7 (7.5)	4.1 (11.7)	1.2 (6.2)	2.7 (9.2)
Mean	7.3 (14.2)	7.4 (14.8)	5.8 (12.0)	10.6 (17.4)	7.3 (14.4)	5.6 (11.9)	-
	Dates of sowing					0.2	
	Varieties					0.3	
CD (P = 0.05)	Dates of sowing × Varieties					0.5	

D_1 (3rd week of June); D_2 (1st week of July); D_3 (2nd week of July); D_4 (3rd week of July)

Table 2. Per cent pod infestation by *M. vitrata* in different pigeonpea varieties during 2014

	Variety						
Sowing	Paras	Manak	AL-201	Pusa-992	PAU-881	H03-41	Mean
D_1	3.2 (10.3)	3.1 (10.0)	1.4 (6.5)	3.3 (10.4)	3.3 (10.3)	2.7 (9.3)	2.8 (9.5)
D_2	10.5 (18.8)	10.5 (18.8)	5.4 (13.3)	9.8 (18.2)	9.6 (18.0)	6.4 (14.6)	8.7 (17.0)
D_3	2.9 (9.8)	5.5 (13.4)	2.4 (9.0)	6.2 (14.4)	2.5 (9.1)	3.1 (10.1)	3.8 (11.0)
D_4	2.2 (8.4)	1.5 (6.8)	2.1 (8.2)	1.4 (6.8)	3.0 (9.9)	1.2 (6.1)	1.9 (7.7)
Mean	4.7 (11.9)	5.2 (12.3)	2.8 (9.3)	5.2 (12.4)	4.6 (11.8)	3.4 (10.0)	-
	Dates of sowing					1.1	
	Varieties					1.4	
CD (P = 0.05)	Dates of sowing × Varieties					2.7	

D_1 (3rd week of June); D_2 (1st week of July); D_3 (2nd week of July); D_4 (3rd week of July)

(1.9%) was observed in D_4 (3rd week of July) sown crop. Pod damage among different pigeonpea varieties was found to be significant and minimum pod damage (2.8%) was recorded in AL-201 and it was statistically at par with H03-41. Whereas, the maximum pod damage (5.2%) was recorded in Pusa-992, followed by Manak (5.2%), Paras (4.7%) and PAU-881 (4.6%), respectively. The interaction effect of varieties and sowing dates on the incidence of pod borer damage was significant.

The pooled results of two years (2013 and 2014) presented in Table 3 and indicated similar results. The pod borer damage in different sowing dates significantly differed from each other and the data revealed that the maximum pod damage (13.1%) was recorded in D_2 (1st week of July) sown crop followed by D_3 (2nd week of July) sown crop with the pod damage of 4.9 per cent. The minimum pod damage (2.3%) was recorded in D_4 (3rd week of July) sown crop and it was found at par with D_1 (3rd week of June) sown crop with the pod damage of 2.9 per cent. Among different varieties, the maximum pod damage (7.9%) was recorded in Pusa-992 followed by Manak (6.3%), Paras (6.0%) and PAU-881 (5.9%). However, the minimum pod damage (4.3%) was recorded in AL-201 and it was found statistically at par with H03-41 with the pod damage of 4.5 per cent. The interaction effect of sowing dates and varieties on the pod damage was observed to be significant.

Mohapatra and Srivastava (2003) observed more or less similar results. According to them the last week of July or 1st week of August sown crop reduced the pod damage incidence and the grain yield loss significantly. The effects are also in strong agreement with the findings of Patel *et al*. (2012), who noted maximum pod damage in the 1st week of July sown crop compared to 1st week of August sown crop and the sowing period had no impact on the pod and grain infestation as well as grain yield. Similarly, according to Reddy *et al*. (2001), the early sowing (mid-June) of the pigeonpea crop resulted in lower incidence of *M. vitrata* and the incidence was increased in the subsequent sowings. Whereas, Ganapathy (2010) reported that the incidence of spotted pod borer, *M. vitrata* was high in early (140-150 days) and late maturing (190-200 days) varieties of pigeonpea, moderate in medium duration (170-180 days).

Morphological and chemical traits of seeds and pod vs resistance to *M. vitrata*

The impact of different morphological and chemical attributes on host preferences was studied in relation to infestation of *M. vitrata* (Tables 4 and 5).

Trichome density of pods of top canopy of the plant. The findings with regards to the morphological and chemical traits of seeds as well as pod wall are discussed in relation to expression of resistance against spotted pod borer (Table 4 and Table 5). During the year 2013, highly significant and negative association was observed between pod infestation and the glandular (type A) pod trichomes (r = -0.973**) during D_1 (3rd week of June) sown crop and with non-glandular (type B) pod trichomes (r = -0.834*, r = -0.818*) during D_2 (1st week of July) and D_3 (2nd week of July) sown crops (Table 4). During 2014, the pod infestation

Table 3. Per cent pod infestation by *M. vitrata* in different pigeonpea varieties during (Pooled)

Sowing	Variety						Mean
	Paras	Manak	AL-201	Pusa-992	PAU-881	H03-41	
D_1	3.2 (10.4)	3.4 (10.5)	1.6 (7.2)	3.7 (11.1)	3.5 (10.8)	2.2 (8.5)	2.9 (9.7)
D_2	14.9 (22.7)	13.4 (21.5)	9.3 (17.7)	15.6 (23.3)	13.9 (21.9)	11.4 (19.7)	13.1 (21.1)
D_3	3.8 (11.3)	6.3 (14.5)	2.8 (9.6)	10.7 (19.1)	2.6 (9.2)	3.2 (10.2)	4.9 (12.3)
D_4	2.0 (8.1)	2.0 (8.0)	3.5 (10.8)	1.6 (7.2)	3.6 (10.9)	1.2 (6.2)	2.3 (8.5)
Mean	6.0 (13.2)	6.3 (13.6)	4.3 (11.1)	7.9 (15.2)	5.9 (13.1)	4.5 (11.3)	-
	Dates of sowing					0.5	
	Varieties					0.7	
CD (P = 0.05)	Dates of sowing × Varieties					1.3	

D_1 (3rd week of June); D_2 (1st week of July); D_3 (2nd week of July); D_4 (3rd week of July)

was significant and negatively correlated with glandular (type A) pod trichomes (r = -0.776* and r = -0.731*) during D_1 (3rd week of June) and D_2 (1st week of July) sown crops and with non-glandular (type B) pod trichomes (r = -0.782* and r = -0.911**) during D_2 (1st week of July) and D_3 (2nd week of July) sown crops. Whereas, the significant and positive correlation was observed with non-glandular lengthy (type C) pod trichomes (r = 0.828*) during D_1 (3rd week of June) sown crop. The pooled over results of two years also showed similar results and significant and negative association (r = -0.945** and r = -0.766*) was observed between pod infestation and glandular (type A) pod trichomes during D_1 (3rd week of June) and D_2 (1st week of July) sown crops. With non-glandular (type B) pod trichomes, the association of pod infestation was also significant and negative (r = -0.871* and r = -0.858*) in D_2 (1st week of July) and D_3 (2nd week of July) sown crops. The susceptibility reaction (r = 0.721*) of pigeonpea crop with *M. vitrata* pod infestation was noted with the non-glandular lengthy (type C) pod trichomes during D_2 (1st week of July) sown crop.

Trichome density of pods of middle canopy of the plant. During the year 2013, the glandular (type A) and non-glandular (type B) pod trichomes showed their resistance against *M. vitrata* (r = -0.795*, r = -0.900**) and (r = -0.717*, r = -0.792*) in D_1 (3rd week of June) and D_2 (1st week of July) sown crops (Table 4). Whereas, with non-glandular lengthy (type C) pod trichomes the reaction was significant and positive (r = 0.726*, r = 0.741*, r = 0.801*) in D_1 (3rd week of June), D_2 (1st week of July) and D_3 (2nd week of July) sown crops, respectively. Similarly, during 2014 the correlation was also significant and negative (r = -0.878*, r = -0.790, r = -0.815*) between pod infestation and glandular (type A) pod trichomes in D_1 (3rd week of June), D_2 (1st week of July) and D_3 (2nd week of July) sown crops. Likewise, with non-glandular (type B) pod trichomes the association of pod infestation was strongly significant and negative (r = -0.936**) in D_3 (2nd week of July) sown

Table 4. Correlation coefficient (r) between morphological characters and pod borer, *M. vitrata* incidence in pigeonpea

	Morphological traits													
	Trichomes (/mm²)									Pod length (mm)	Pod wall thickness (mm)	Seed length (mm)	Seed width (mm)	No. of seeds/ pod
	Top canopy			Middle canopy			Lower canopy							
Sowing	A	B	C	A	B	C	A	B	C					
2013														
D_1	-0.973**	-0.457	0.354	-0.599	-0.539	0.726*	-0.518	-0.650	-0.363	0.232	-0.422	0.133	0.610	-0.123
D_2	-0.698	-0.834*	0.663	-0.795*	-0.717*	0.741*	-0.369	-0.634	-0.369	0.783*	-0.835*	0.667	0.089	0.433
D_3	-0.546	-0.818*	0.159	-0.900**	-0.792*	0.801*	0.041	0.198	-0.787*	0.838*	-0.817*	0.731*	0.739*	0.647
D_4	-0.136	0.259	-0.642	-0.625	0.550	0.022	-0.580	-0.643	0.187	0.711*	-0.611	0.600	0.846*	0.761*
2014														
D_1	-0.776*	-0.665	0.828*	-0.878*	-0.410	0.922**	-0.069	-0.098	0.118	0.630	-0.753*	0.519	0.948**	0.421
D_2	-0.731*	-0.782*	0.680	-0.790*	-0.577	0.654	-0.580	-0.869*	-0.393	0.407	-0.777*	0.032	-0.127	-0.056
D_3	-0.473	-0.911**	0.216	-0.815*	-0.936**	0.817*	0.177	0.124	-0.810*	0.669	-0.843*	0.556	0.582	0.698
D_4	-0.568	0.288	0.067	-0.520	0.256	0.385	-0.754*	-0.676	-0.286	0.335	-0.454	0.373	0.847*	0.625
Pooled (2013 and 2014)														
D_1	-0.945**	-0.577	0.586	-0.759*	-0.514	0.857*	-0.350	-0.444	-0.171	0.423	-0.594	0.312	0.797*	0.111
D_2	-0.766*	-0.871*	0.721*	-0.852*	-0.705*	0.755*	-0.497	-0.793*	-0.408	0.663	-0.870*	0.415	-0.007	0.233
D_3	-0.537	-0.858*	0.177	-0.895**	-0.845*	0.821*	0.077	0.183	-0.808*	0.810*	-0.840*	0.699	0.713*	0.673
D_4	-0.289	0.286	-0.451	-0.634	0.491	0.144	-0.678	-0.699	0.044	0.636	-0.601	0.567	0.905**	0.769*

A = Non-glandular pod trichomes

B = Glandular pod trichomes

C = Non-glandular lengthy pod trichomes

* Significant at P = 0.05; ** Significant at P = 0.01

D_1 (3rd week of June); D_2 (1st week of July); D_3 (2nd week of July); D_4 (3rd week of July)

crop. Whereas, with the non-glandular lengthy (type C) pod trichomes, the correlation was highly significant and positive (r = 0.922**, r = 0.817*) in D_1 (3rd week of June) and D_3 (2nd week of July) sown crops. The pooled results of both the years also showed resistant effects (r = -0.759*, r = -0.852*, r = -0.895**) against *M. vitrata* with glandular (type A) pod trichomes in D_1 (3rd week of June), D_2 (1st week of July) and D_3 (2nd week of July) sown crops and (r = -0.705*, r = -0.845*) with non-glandular (type B) pod trichomes in D_2 (1st week of July) and D_3 (2nd week of July) sown crops, respectively. Whereas, the association of pod infestation with non-glandular lengthy (type C) pod trichomes was significant and positive (r = 0.857*, r = 0.755*, r = 0.821*) in D_1 (3rd week of June), D_2 (1st week of July) and D_3 (2nd week of July) sown crops, respectively.

Trichome density of pods of lower canopy of the plant. The glandular (type A) and non-glandular (type B) pod trichomes of the lower canopy of the plant were not found associated with the resistance against *M. vitrata* during the year 2013 but the non-glandular lengthy (type C) pod trichomes showed their resistance (r = -0.787*) against *M. vitrata* in D_3 (2nd week of July) sown crop. During the year 2014, the correlation between glandular (type A) pod trichomes and pod infestation was significant and negative (r = -0.754*) in D_4 (3rd week of July) sown crop. With non-glandular (type B) pod trichomes, the correlation was also significant and negative (r = -0.869*) in D_2 (1st week of July) sown crop. Similarly, with non-glandular lengthy (type C) pod trichomes, the correlation was significant and negative (r = -0.810*) in D_3 (2nd week of July) sown crop. The pooled results also showed significant and negative correlation (r = -0.793*) between pod infestation and non-glandular (type B) pod trichomes in D_2 (1st week of July) sown crop. The non-glandular lengthy (type C) pod trichomes also showed significant and negative association (r = -0.808*) with the pod infestation in D_3 (2nd week of July) sown crop.

The research findings indicating that more the trichome density on pods minimum would be the pod infestation. The trichomes are common features on vegetative and reproductive structure in many plant species and they have been used to breed insect resistant cultivars in several agricultural crops (Peter *et al*., 1995). The trichome density as well as trichome length showed their resistance against *M. vitrata* that have been widely studied and acted as physical barrier in its movement in mungbean (Halder *et al*., 2006) and pigeonpea crops (Soundararajan *et al*., 2013; Wubneh and Taggar, 2016). Oghiakhe (1995) reported that pubescence interfered the oviposition of the insects and ovipositional non-preference due to presence of trichomes was found to be one of mechanisms of resistance to *M. vitrata* on cowpea. Contradictory non-significant and negative correlation was observed by Sunita *et al*. (2013) between trichome density and pod damage due to *M*. vitrata in pigeonpea. The contradictory effects were also noted by Sunitha *et al*. (2008) in pigeonpea; Halder and Srinivasan (2011) and Oghiakhe *et al*. (1992) reported in cowpea and Kamakshi and Srinivasan (2008) in field bean crops.

Pod length. The pod infestation is proportionately related to the pod length of the plant as it provides the area for feeding to insect pests in different crops. During the year 2013 a significant and positive correlation (r = 0.783*, r = 0.838* and r = 0.711*) was observed between *M. vitrata* and pod length during D_2 (1st week of July), D_3 (2nd week of July) and D_4 (3rd week of July) sown crops, respectively (Table 4). During the year 2014, in none of the sowing dates the correlation between *M. vitrata* and pod length was significant. In the pooled results, pod length showed its susceptibility (r = 0.810*) to *M. vitrata* in D_3 (2nd week of July) sown crop. The pod length provides susceptibility effects to *M. vitrata* in mungbean crop (Halder *et al*., 2006). Similarly, Thakur *et al*. (1989) reported the positive relationship between pod length and pod borer infestation. However, Gumber *et al*. (2000); Dhakla *et al*. (2010) and Sunita *et al*. (2013) noted that there was no association between pod length and pod borer damage and susceptibility.

Pod wall thickness. During the year 2013 the pod wall thickness showed a significant and negative correlation (r = -0.835*, r = -0.817*) with the pod infestation in D_2 (1st week of July) and D_3 (2nd week of July) sown crops (Table-4). During the year 2014 the correlation between pod wall thickness and pod infestation was significant and negative (r = -0.753*, r = -0.777*, r = -0.843*) in D_1 (3rd week of June), D_2 (1st week of July) and D_3 (2nd week of July) sown crops, respectively. In pooled results the correlation between pod wall thickness and pod infestation was also significant and negative (r = -0.870*, r = -0.840*) in D_2 (1st week of July) and D_3 (2nd week of July) sown crops. The thick pod wall exhibited lesser preference for larvae than genotypes having thinner pod wall (Jagtap *et al*., 2014). The present findings are fully supported by Sunitha (2006), who reported that pod wall thickness showed a highly significant and negative correlation with pod damage by *M. vitrata* in pigeonpea. The thickness of the pod wall associated with resistance to *M. vitrata* has earlier been studied as one of the insect resistant traits in cowpea (Sharma, 1998) and in mungbean Halder *et al*. (2006). Contradicting results of non-significant and negative correlation between pod wall thickness and per cent pod damage have been reported by Wubneh and Taggar (2016) in pigeonpea crop.

Seed length. The seed length did not show any significant resistance or susceptibility relation with the pod infestation except in D_3 (2nd week of July) sown crop (r = 0.731*) during the year 2013. In the year 2014 and in pooled results, the seed length was non-significantly associated with the susceptibility to *M. vitrata* infestation in all the sowing dates (Table 4). The seed length had a non-significant negative effect on the incidence of *M. vitrata* in pigeonpea (Sahoo and Senapati, 2000). With respect to *H. armigera*, the positive correlation of seed size had been reported (Dodia and Patel, 1994; Wightman *et al*., 1994), which corroborates with the present findings.

Seed width. The correlation between seed width and *M. vitrata* pod infestation during the year 2013 was significant and positive r = 0.739* and r = 0.846* in D_3 (2nd week of July) and D_4 (3rd week of July) sown crops, respectively (Table 4). During the year 2014 the significant and positive correlation (r = 0.948** and r = 0.847*) was reported between seed width and pod infestation in D_1 (3rd week of June) and D_4 (3rd week of July) sown crops. In the pooled results, the association of seed width with pod infestation was also significant and positive (r = 0.797*, r = 0.713* and r = 0.905**) in D_1 (3rd week of June), D_3 (2nd week of July) and D_4 (3rd week of July) sown crops, respectively. The results are in confirmity with the findings of Sahoo and Senapati (2000), according to them more the seed width higher would be the *H. armigera* incidence in pigeonpea crop. However, *M. vitrata* pod infestation was non-significant and negatively associated with the seed width. The more pigeonpea seed size registered maximum oviposition preference by *Callosobruchus* sp., the effect have been reported by Patil and Jadhav (1984). Contrasting effects also stand with this as larger pigeonpea seed size provide resistance against *C. chinensis* (Regupathy and Rathnaswamy, 1970).

Number of seeds per pod. The number of seeds per pod could not determine any significant relation with the pod infestation by *M. vitrata* during year 2013 in all the sowing dates except D_4 (3rd week of July) sown crop which sowed significant and positive correlation (r = 0.761*). During the year 2014, none of the sowing dates showed any significant association between number of seeds per pod and *M. vitrata* infestation. In the pooled results, number of seeds per pod showed expression of susceptibility (r = 0.769*) to *M. vitrata* infestation only in D_4 (3rd week of July) sown crop. The greater number of seeds per pod showed positive correlation with the pod borer complex damage (Anonymous 2007). Whereas, Ghetiya (2010) reported non-significant positive association between pod damage and number of seeds per pod.

Chlorophyll content. The chlorophyll content of seed as well as pod wall did not show any significant association with the pod damage in all the sowing dates during both the study periods and pooled over results. Correlation studies carried out by Mallikarjuna *et al*. (2009) stated that pod colour had significant relationship with the *M. vitrata* larval incidence in *dolichus* bean. Tripathi and Purohit (1983) noted maximum pod borer damage on green colour pods in pigeonpea as compared to pods having brown streaks. Varieties with green colour pod wall were found susceptible to the pod borer complex in pigeonpea. Results were contradicted by Jagtap *et al*. (2014), according to them, genotypes having green and green with brown streaks colour pod evinced lesser preference for *H. armigera* larval feeding than the genotypes having green pods with purple streaks.

Moisture. The moisture content of the seed did not show any significant relationship with the *M. vitrata* pod damage in all the sowing dates during both the years and in pooled results. But, the more pod wall moisture attracts more pest infestation and was associated with the susceptibility (r = 0.734* and r = 0.739*) to *M. vitrata* in D_1 (3rd week of July) sown crop of year 2013 and pooled results. Moisture content of the pods showed its significant and positive association with the per cent pod damage by *M. vitrata* and have been reported by (Nasiya and Subramanian, 2016) in cowpea crop. Moisture content of the plant attracts the insects (Bates, 1971) and from this study it could clarify the role of moisture in plant herbivore interactions and it also influence the nutritional quality of the plant. Higher moisture content has been reported to be associated with higher infestation because it makes the plant tissues more succulent. The finding of the present study agrees with earlier reports and suggests that higher moisture content in the pods enhances the nutritional quality of the host and therefore makes it more attractive to the feeder.

Crude protein. The non-significant positive correlation between crude protein of seed and pod infestation was observed in all the sowing dates during the year 2013, 2014 and pooled results. Correlation between crude protein of pod wall and pod infestation was significant and positive (r = 0.740*, r = 0.836*) in D_2 (1st week of July) and D_3 (2nd week of July) sown crops during the year 2013. During 2014, the association between pod infestation and crude protein of pod wall was significant and positive (r = 0.727*) in D_3 (2nd week of July) sown crop. Similarly, in the pooled results the correlation was also found significant and positive (r = 0.823*) in D_3 (2nd week of July) sown crop. These results are supported by (Anantharaju and Muthiah, 2008), who reported that more sweetness is responsible for higher spotted pod borer infestation in pigeonpea. The hypotheses indicating that more pod damage would be there if increase the protein content and vice-versa. Kamakshi *et al*. (2008) reported that protein content exhibited significant and positive correlation with pod damage by pod borer complex in field pea genotypes. Halder and Srinivasan (2007) also reported that higher amount of protein is associated with susceptibility of urdbean to *M. vitrata*.

Fat content. The fat content of seed showed a significant and negative association (r = -0.797*) with the expression of resistance to *M. vitrata* in D_3 (2nd week of July) sown crop. Fat content of pod wall also showed resistance effect (r = -0.787* and r = -0.794*) against *M. vitrata* in D_1 (3rd week of June) and D_2 (1st week of July) sown crops during 2013 (Table 5). Fat content of seeds of D_1 (3rd week of June) and D_3 (2nd week of July) sown crops during the year 2014 showed expression of resistance (r = -0.880** and r = -0.792*) against *M. vitrata*. With the fat content of pod wall, the correlation was significant and negative (r = -0.831*) in D_2 (1st week of July) sown crop. Similarly, in the pooled results the correlation between pod infestation and fat content of seed in D_1 (3rd week of June) and D_3 (2nd week of July) sown crops and with the fat content of pod wall in D_2 (1st week of July) sown crop was significant and negative (r = -0.754* and r = -0.811*) and (r = -0.871*), respectively. Resistance effect of higher fat content in field bean crop against *M. vitrata* have been reported by Kamakshi *et al*. (2008).

Phenol content. Phenol content of seed did not produce any significant negative effect in all the sowing dates. The phenol content in the pod wall had significant and negative effect (r = -0.774*, r = -0.747*) with the *M. vitrata* pod infestation in D_1 (3rd week of June) and D_2 (1st week of July) sown crops during the year 2013. During 2014, the phenol content

Table 5. Correlation coefficient (r) between biochemical constituents and pod borer, *M. vitrata* incidence in pigeonpea

	Biochemical constituents													
	Chlorophyll (mg g^{-1})		Moisture (%)		Crude protein (%)		Fat (%)		Phenol (mg g^{-1})		Total soluble sugar (%)		Tannin (µg g^{-1})	
Sowing	Seed	Pod Wall	Seed	Pod wall	Seed	Pod wall	Seed	Pod wall	Seed	Pod wall	Seed	Pod wall	Seed	Pod wall
2013														
D_1	-0.258	0.613	0.311	0.734*	0.469	0.187	-0.590	-0.787*	-0.407	-0.774*	0.628	-0.013	-0.295	-0.136
D_2	0.561	0.238	0.105	0.074	0.050	0.740*	-0.686	-0.794*	-0.491	-0.747*	0.222	0.531	-0.589	-0.580
D_3	0.668	0.279	-0.046	0.131	0.332	0.836*	0.797*	-0.322	-0.322	-0.311	0.562	0.693	-0.383	-0.618
D_4	0.489	0.455	-0.387	-0.325	0.348	-0.535	0.466	0.220	0.037	0.406	0.602	0.250	-0.342	-0.396
2014														
D_1	0.375	0.533	0.601	0.646	0.559	0.460	-0.880**	-0.275	-0.504	-0.500	0.911**	0.562	-0.721*	0.013
D_2	0.545	-0.353	0.128	0.028	0.077	0.324	-0.297	-0.831*	0.040	-0.755*	0.019	0.532	-0.121	-0.032
D_3	0.617	0.344	0.119	0.287	0.552	0.727*	0.792*	-0.259	-0.259	0.099	0.368	0.724*	-0.216	-0.740*
D_4	0.598	0.164	-0.232	-0.347	0.273	-0.067	0.206	-0.232	-0.231	-0.045	0.097	0.168	-0.396	-0.350
Pooled (2013 and 2014)														
D_1	0.008	0.615	0.459	0.739*	0.537	0.320	-0.754*	-0.607	-0.475	-0.699	0.792*	0.242	-0.502	-0.078
D_2	0.595	-0.025	0.123	0.058	0.066	0.598	-0.552	-0.871*	-0.275	-0.806*	0.142	0.571	-0.411	-0.363
D_3	0.667	0.302	-0.004	0.174	0.395	0.823*	0.811*	-0.312	-0.312	-0.211	0.522	0.714*	-0.347	-0.661
D_4	0.559	0.390	-0.362	-0.355	0.347	-0.417	0.412	0.085	-0.049	0.284	0.477	0.240	-0.383	-0.408

* Significant at P = 0.05; ** Significant at P = 0.01

D_1 (3rd week of June); D_2 (1st week of July); D_3 (2nd week of July); D_4 (3rd week of July)

of pod wall showed significant and negative correlation (r = -0.755*) with the pod infestation by *M. vitrata* only in D_2 (1st week of July) sown crop. Similarly, in the pooled results the correlation between phenol content of pod wall and *M. vitrata* pod infestation was significant and negative (r = -0.806*) in D_2 (1st week of July) sown crop. The phenol content in seeds as well as in pod wall have been considered as a source of resistance against *M. vitrata*. Sunitha *et al*. (2008), reported that the presence of phenols in flowers and pods of short duration pigeonpea had negative influence on the larval growth of *M. vitrata*. The results are also in conformity with the findings of Anantharaju and Muthiah, (2008); according to them, the total phenolic content is negatively correlated with the spotted pod borer incidence in pigeonpea. The same effect has been studied (Halder and Srinivasan, 2007; Halder *et al*. (2006) in urdbean and mung bean crop.

Total soluble sugar. The more total sugar content in seeds as well as in pod wall is the good indicator to increase the incidence of insect-pests. During the year 2013, the non-significant positive association between total soluble sugar content of seed as well as pod wall and *M. vitrata* pod damage was observed in all the sowing dates. The total soluble sugar of seed showed significant and positive association (r = 0.911**, r = 0.792*) with *M. vitrata* pod infestation in the D_1 (3rd week of July) sown crop of the year 2014 and pooled results. Sugar content of pod wall showed susceptibility (r = 0.724* and r = 0.714*) to *M. vitrata* in D_3 (2nd week of July) sown crops of the year 2014 and pooled results, respectively. The sugar content in pods showed significant and positive correlation with pod damage due to *M. vitrata* (Sunitha *et al*., 2008). The results are also in conformity with the findings of Murkute *et al*. (1993), who reported that high content of total sugars in pods of pigeonpea cultivars is responsible for susceptibility to spotted pod borer. In mung bean and urdbean crop, the higher amount of total sugar, reducing sugar and non-reducing sugar content in pods has been reported to be responsible for higher spotted pod borer infestation (Halder and Srinivasan 2007; Halder *et al*., 2006).

Tannin content. The tannin content of the seed as well as pod wall showed non-significant negative association in all the sowing dates during 2013. During the year 2014, spotted pod borer infestation was significant and negatively correlated (r = -0.721*) with the tannin content of seed in D_1 (3rd week of July) sown crop and tannin content of pod wall (r = -0.740*) in D_3 (2nd week of July) sown crop (Table 5). However, in the pooled results non-significant and negative association between *M. vitrata* pod infestation and tannin content of seed as well as pod wall was observed in all the sowing dates. The results confirmed existence of resistance to the *M. vitrata* with the tannin content in pod. The findings are in close agreement with the results of Kamakshi *et al*. (2008), who reported that higher total tannin content was good indicator of resistance to spotted pod borer and infestation was negatively correlated with the total tannin content in field bean genotypes. Emmanuel *et al*. (2002) suggested that tannins acted by reducing the digestibility of tissues. Thus, the rice genotypes with high tannins possibly offer resistance against *Sogatella furcifera*. In maize, the same relationship has also been reported (Rao and Panwar, 2001).

Based on the present studies, it can be inferred that the early sowing of the pigeonpea crop could minimize the spotted pod borer, *M. vitrata,* infestation and variety AL-201 can be grown as a preferred variety as compared to other pigeonpea varieties in the preferred agro-climatic zone. Morphological traits *viz*., trichome density and pod wall thickness and biochemical constituents *viz*., fat, phenol and tannin content of seed as well as pod wall were found associated with resistance, whereas, the pod length, seed length, seed width and number of seeds per pod and crude protein and total soluble sugar content in seeds as well as in pod wall were associated with the susceptibility of pigeonpea crop to the spotted pod borer infestation.

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