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STUDY OF BIOPHYSICAL AND STRUCTURAL MECHANISMS OF RESISTANCE IN PIGEONPEA AGAINST POD BORER COMPLEX

B. L. JAT*, K. K. DAHIYA, HARISH KUMAR AND S. MANDHANIA
Department of Entomology, CCS Haryana Agricultural University, Hisar - 125 004, Haryana
Department of Biochemistry, CCS Haryana Agricultural University, Hisar - 125 004, Haryana
e-mail: bljat.hau@gmail.com

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***Corresponding author**

ABSTRACT

The maximum *H. armigera* and *M. vitrata* infestation was recorded in Pusa-992 (3.72% and 7.90%) and in D_2 (1st week of July) sown crop with infestation of 4.54 and 13.08 per cent, respectively. Whereas, the infestation of pod fly, *M. obtusa* was maximum in Manak (2.72%) and 2.58 per cent pod infestation in D_2 (1st week of July) sown crop. The infestation of pod borer complex was negatively associated with pod wall thickness (-0.909**, -0.739*, -0.870*, -0.834*, -0.840*, -0.705* and -0.745*) and non-glandular type A (-0.730*, -0.945**, -0.768*, -0.766*, -0.923** and -0.728*) and (-0.751*, -0.759*, 0.766*, -0.852*, -0.802*, -0.895** and -0.832*) glandular type B (-0.864*, -0.734*, -0.871* and -0.858*) and (-0.729*, -0.705*, -0.730* and -0.845*) density of pod trichomes of top and middle canopy of the plant. Fat (-0.884**, -0.754*, -0.743*, -0.871* and -0.750*) phenol (-0.900** and -0.806*) and tannin (-0.792*, -0.812* and -0.763*) content showed negative correlation with the pod infestation, whereas, crude protein (0.740*, 0.881**, 0.734*, 0.810*, 0.823*, 0.856*, 0.844* and 0.711*) and total soluble sugar (0.738*, 0.792*, 0.793*, 0.898**, 0.714*, 0.816*, 0.888** and 0.819*) showed positive association. Based on the results, it can be concluded that the variety Pusa-992 and Manak was most susceptible to the pod borers.

INTRODUCTION

In semi-arid tropics (SAT), pigeonpea [*Cajanus cajan* (L.) Millspaugh] is one of the significant grain vegetables (Nene *et al*., 1990). Pigeonpea is cultivated in more than 50 countries of Asia, Africa and the Caribbean as lifeline saver prerequisites (Sharma *et al*., 2003). Worldwide more than 200 species of insects have been accounted to cause overwhelming yearly misfortunes (Reed and Lateef, 1990; Mubarak *et al*., 2014). Among them, the pod borer complex *viz*., gram pod borer, *Helicoverpa armigera* (Hubner), spotted pod borer, *Maruca vitrata* (Geyer) and pod fly, *Melanagromyza obtusa* (Malloch) are of prime significance all through the world which sustains on reproductive parts of the plant (Sharma, 2001; Taylor, 1967; Shanower *et al*., 1999; Devi, 2005; Ahmad, 1938) and yearly misfortunes because of these unit pod borer complex harm have been accounted to be US $ 400 million by *H. armigera*, US $ 30 million by *M. vitrata* and US $ 256 million by *M. obtusa* (ICRISAT, 2007; ICRISAT, 1992a; ICRISAT, 1992b).

Insect pest damage is influenced regularly and impressively by the compound organization and morphological elements of the plants. Distinguish proof and use of cultivars resistant to pod borer complex can have momentous favorable circumstances, especially for generally low esteem pigeonpea crop (Sharma *et al*., 2003). These resistant or less susceptible cultivars can be utilized as a part of creating resistance which would give ecologically solid instrument to sustainable pest management (Sharma, 2005). More than 14,000 cultivated genotypes of pigeonpea tried against *H. armigera* and *M. obtusa* resistance indicated low to direct level of resistance (Reed and Lateef, 1990; Singh and Singh. 1990). High level of resistance to *H. armigera*, *M. vitrata* and *M. obtusa* in some pigeonpea lines have been reported by several workers (Sharma *et al*., 2001; Green *et al*., 2006; Lateef and Pimbert, 1990; Sunitha *et al*., 2008).

Several morphological or structural traits of plants, for example, trichome density, trichome length on leaves and pods and pod wall thickness have been reported to be associated with resistance to pod borers (Shanower *et al*., 1997; Halder *et al*., 2006; Jeffree, 1986; Lateef and Reed, 1981; Shanower *et al*., 1996). As indicated by David and Easwaramoorthy (1988) and Duffey (1986), trichomes act as an insect resistance component as a physical obstruction restricting an insect's contact with the plant, by creating poisons mixes which harm the insect through contact, ingestion/ inhalation and by producing gummy, sticky or polymerized concoction exudates which hinder the insects. Notwithstanding, the pod wall toughness did not assume any appreciable role on cowpea resistance to the *M. testulalis* larvae (Oghiakhe *et al*., 1992). Similarly, trichome orientation, their types, density and length impacts on the host plant resistance/ defenselessness susceptibility to the insect pests (Sharma *et al*., 2009; Valverde *et al*., 2001; Aruna *et al*., 2005; Bernays *et al*., 2000). In quantity of yield plants, trichomes have been exploited as an insect defense mechanism in soybean (Lam and Pedigo, 2001). Conjectured has been specified that glandular trichomes works as physical obstruction resulting mortality of arthropod pests (Muigai *et al*., 2002) because of some lethal mixes delivered by the trichomes (Kennedy, 2003).

Alike the manner of morphological characteristics, role of chemical attributes for example aggregate phenols, fat substance, tannin substance and lower amount of crude protein, total soluble sugar, reducing and non-reducing sugars and total amino acids as an insect defense mechanism has been very much archived against pod borer complex (Pandey *et al.*, 2011; Sharma *et al.*, 2009; Moudgal *et al.*, 2008). The chemical mixes in trichome exudates and pod wall surfaces also influences the host plant determination and colonization by pod borer complex (Bernays and Chapman, 1994; Hartlieb and Rembold, 1996; Green *et al.*, 2002, 2003). The significance of antixenosis mechanism of resistance against *H. armigera* and *M. vitrata* in pigeonpea has been documented well by a few workers (Sharma *et al.*, 2009; Sunitha *et al.*, 2008). Hostile and nutritious elements for example phenols, tannins, protein inhibitors, oligosaccharides and phytic acids have additionally been accounted for influence the host plant suitability (Singh, 1988). Keeping the above actualities as imperative components of resistance against pod borer complex, the present studies were undertaken to legitimize the part of biophysical and structural traits in connection to expression of resistance and different sowing dates against pigeonpea pod borer complex.

MATERIALS AND METHODS

Planting material

To know the resistance mechanism against pod borer complex, six cultivated pigeonpea varieties were grown during 2013 and 2014 at Pulses Research Farm, Department of Genetics and Plant Breeding, CCS Haryana Agricultural University, Hisar, India. Six varieties *viz*., Paras, Manak, AL-201, Pusa-992, H03-41 and PAU-881 were sown at four distinct dates i.e. D_1 (third week of June), D_2 (first week of July), D_3 (second week of July) and D_4 (third week of July) with three replications in randomized complete block design. The plot size was of 4 columns of 4 m length (1.8 m × 4 m). The spacing of 45 cm distance between the plants × 15 cm distance between lines was kept. The standard recommended agronomic practices (Anon, 2004) were followed to raise the crop.

Pod damage by pod borer complex under natural infestation in the field

The test varieties were assessed for pod damage in all the sowing dates under natural infestation in the field. Per cent pod damage by borer complex *viz*., *H. armigera*, *M. vitrata* and *M. obtusa* was recorded at maturity in pods harvested from randomly selected plants in every plot every replication. The per cent pod damage was worked out from all the four diverse sowing dates. 150 pods were randomly plucked from each plots and replicates in four distinctive sowing dates and conveyed to the research laboratory and examined critically. The pod damage by *H. armigera* and *M. vitrata* was identified by the circular and irregular bored holes with webbed excreta at the entrance of the holes on the pods. In case of pod fly, *M. obtusa* infestation, pin head sized bore holes closed to the septum and shrinking of developing seeds or half eaten seeds can be seen inside the pods. The total number of pods and pod borer complex damaged pods and seeds were counted independently and the outcome was expressed as per cent pod damage.

Morphological and chemical components

Data on certain morphological and chemical components of the test varieties *viz*., trichome density of pods of top, middle and bottom canopy of the plants (Sass (1964), pod length, pod wall thickness, seed length and seed width and number of seeds per pod was measured by digital Vernier Caliper).

Chemical constituents of seeds and pod wall

To study the biochemical constituents from seeds as well as pod wall, the sufficient numbers of pods of 15 days old were plucked from each replication of each plot and from all the different sowing dates. The 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. The one set of pods were oven dried at 60° C for 2-3 days. After drying, the test samples were grind. Grinded 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. The completely dried samples were used for the estimation of biochemical constituents *viz*., Crude protein (AOAC, 1985); Moisture content (Mehta and Lodha, 1979); Total soluble sugars (Dubios *et al*., 1956); Fats (AOAC, 1975); Total phenol (Bray and Thorpe, 1954); Tannins (AOAC, 1965) and Chlorophyll content (Hiscox and Israelstam, 1979) was used.

Statistical analysis

The data of the two seasons were subjected to analysis of variance (ANOVA). The ANOVA was carried out by using SPSS statistics, 19 version statistical packages as suggested by Steel and Torrie (1980). The association of different morphological and chemical components with the per cent pod damage was determined by correlation analysis.

RESULTS

Per cent pod damage by pod borer complex under field condition

H. armigera

The maximum per cent pod damage (3.72%) was recorded in Pusa-992 (Table 1) and it was statistically at par with Manak (3.71%), PAU-881 (3.59%) and Paras (3.24%), respectively, whereas, the minimum per cent pod damage (2.45%) was recorded in AL-201 and it was statistically at par with H03-41 (2.77%) and Paras (3.24%). Among different sowing dates, maximum pod damage (4.54%) was recorded in D_2 (1^{st} week of July) sown crop, while minimum pod damage of 1.70% was observed in D_4 (3^{rd} week of July) sown crop and it was followed by D_3 (2^{nd} week of July) and D_1 (3^{rd} week of June) sown crops. The interaction effect between varieties × sowing dates was observed significant.

M. vitrata

M. vitrata pod infestation was observed minimum (4.30%) in AL-201 and it was statistically at par with H03-41 with the pod damage of 4.48 per cent (Table 1). Whereas, maximum pod damage of 7.90 per cent was observed in Pusa-992 and it was followed by Manak (6.25%), Paras (5.97%) and PAU-881 (5.91%), respectively. Pod damage among different sowing

Table 1: Per cent pod infestation by major pod borer complex in different pigeonpea varieties and different sowing dates (Pooled)

Borer complex	Sowing	Varieties						Mean
		Paras	Manak	AL-201	Pusa-992	AL-881	H03-41	
H. armigera	D_1	3.92(11.41)	3.40(10.62)	2.62(9.31)	4.34(12.02)	3.46(10.71)	3.65(11.00)	3.56(10.85)
	D_2	5.64(13.71)	3.60(10.87)	3.41(10.59)	4.45(12.17)	5.58(13.63)	4.56(12.25)	4.54(12.20)
	D_3	2.00(8.12)	5.51(13.33)	2.42(8.90)	4.07(11.41)	3.27(10.10)	1.84(7.70)	3.18(9.93)
	D_4	1.39(6.75)	2.32(8.75)	1.33(6.63)	2.02(8.02)	2.06(8.24)	1.07(5.73)	1.70(7.35)
Mean	3.24(10.00)	3.71(10.89)	2.45(8.86)	3.72(10.90)	3.59(10.67)	2.77(9.17)		
S.Em. ±	Factor A		(Dates of sowing)			0.34		
	Factor B		(Varieties)			0.42		
	Factor A × B		(Dates of sowing × Varieties)			0.84		
CDP = (0.05)	Factor A		(Dates of sowing)			0.97		
	Factor B		(Varieties)			1.19		
	Factor A × B		(Dates of sowing × Varieties)			2.37		
M. vitrata	D_1	3.23(10.35)	3.35(10.51)	1.58(7.19)	3.69(11.07)	3.52(10.80)	2.19(8.45)	2.93(9.73)
	D_2	14.86(22.66)	13.44(21.49)	9.29(17.74)	15.62(23.27)	13.92(21.90)	11.37(19.70)	13.08(21.12)
	D_3	3.81(11.25)	6.25(14.46)	2.79(9.61)	10.73(19.11)	2.58(9.24)	3.17(10.19)	4.89(12.31)
	D_4	2.00(8.10)	1.97(8.00)	3.53(10.82)	1.57(7.18)	3.59(10.89)	1.18(6.19)	2.30(8.53)
Mean	5.97(13.09)	6.25(13.61)	4.30(11.34)	7.90(15.16)	5.91(13.21)	4.48(11.13)		
S.Em. ±	Factor A		(Dates of sowing)			0.19		
	Factor B		(Varieties)			0.23		
	Factor A × B		(Dates of sowing × Varieties)			0.47		
CDP = (0.05)	Factor A		(Dates of sowing)			0.55		
	Factor B		(Varieties)			0.66		
	Factor A × B		(Dates of sowing × Varieties)			1.33		
M. obtusa	D_1	1.87(7.87)	3.21(10.29)	1.36(6.67)	1.96(8.05)	1.80(7.67)	1.97(8.05)	2.03(8.10)
	D_2	3.26(10.39)	2.22(8.55)	2.08(8.29)	2.99(9.95)	2.24(8.60)	2.69(9.44)	2.58(9.20)
	D_3	2.46(9.02)	2.65(9.34)	1.24(6.39)	2.72(9.49)	2.75(9.54)	1.72(7.52)	2.26(8.55)
	D_4	2.29(8.64)	2.79(9.59)	1.74(7.58)	1.50(6.94)	3.77(11.11)	0.63(4.48)	2.12(8.06)
Mean	2.47(8.98)	2.72(9.44)	1.61(7.23)	2.29(8.61)	2.64(9.23)	1.75(7.37)		
S.Em. ±	Factor A		(Dates of sowing)			0.18		
	Factor B		(Varieties)			0.22		
	Factor A × B		(Dates of sowing × Varieties)			0.44		
CDP = (0.05)	Factor A		(Dates of sowing)			0.51		
	Factor B		(Varieties)			0.62		
	Factor A × B		(Dates of sowing × Varieties)			1.24		

Table 2: Correlation of pod borer complex with morphological parameters of pigeonpea (pooled)

Pod borer complex	Morphological traits													
	Trichomes on plant canopy (/mm²)									Pod length (mm)	Pod wall thickness (mm)	Seed length (mm)	Seed width (mm)	No. of seeds/ pod
	Top			Middle			Lower							
	A	B	C	A	B	C	A	B	C					
D_1														
H. armigera	-0.730*	-0.864*	0.646	-0.751*	-0.729*	0.964**	0.129	0.059	0.019	0.774*	-0.909**	0.746*	0.860*	0.535
M. vitrata	-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
M. obtusa	-0.304	-0.360	0.200	-0.604	-0.299	0.807*	0.153	-0.056	-0.161	0.552	-0.460	0.044	0.271	0.476
D_2														
H. armigera	-0.768*	-0.734*	0.803*	-0.766*	0.048	0.639	-0.725*	-0.099	0.129	0.825*	-0.739*	0.638	0.577	0.780*
M. vitrata	-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
M. obtusa	-0.146	-0.691	0.594	-0.802*	-0.611	0.192	-0.219	-0.444	-0.471	0.643	-0.834*	0.727*	0.228	0.354
D_3														
H. armigera	-0.531	-0.662	0.139	0.414	-0.730*	0.510	-0.088	-0.384	-0.794*	0.185	-0.612	0.169	0.228	0.267
M. vitrata	-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
M. obtusa	-0.923**	-0.408	0.797*	0.418	-0.513	0.794*	-0.219	-0.041	-0.746*	0.597	-0.705*	0.667	0.173	0.460
D_4														
H. armigera	0.133	0.416	0.742*	0.832*	-0.337	-0.492	-0.760*	0.103	-0.801*	0.014	0.289	0.759*	0.133	0.416
M. vitrata	-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*
M. obtusa	-0.728*	-0.136	0.233	-0.248	-0.273	0.752*	-0.718*	-0.809*	-0.652	0.201	-0.745*	0.129	0.649	0.684

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

dates was significant and maximum pod damage (13.08%) was observed in D_2 (1st week of July) sown crop, while minimum pod damage was recorded in D_4 (3rd week of July) sown crop (2.30%) as compared to 4.89 and 2.93 per cent pod damage in D_3 (2nd week of July) and D_1 (3rd week of June) sown crops, respectively. The interaction effect of pod damage between different varieties × different sowing dates was observed significant.

M. obtusa

Infestation of pod fly, *M. obtusa* among different pigeonpea varieties (Table 1) revealed that low pod damage was observed in AL-201 (1.61%) and it was statistically at par with H03-41 (1.75%). Similarly, maximum pod damage (2.72%) was observed in Manak and it was statistically at par with PAU-

881 (2.64%) and Paras (2.47%). Per cent pod damage among different sowing dates was observed significant and maximum pod damage of 2.58 per cent was in D_2 (1st week of July) sown crop, while minimum pod damage (2.03%) was observed in D_1 (3rd week of June) and it was statistically at par with D_4 (3rd week of July) and D_3 (2nd week of July) sown crops with the pod infestation of 2.12 and 2.26 per cent. The interaction effect of pod infestation by *M. obtusa* between varieties × different sowing dates was observed significant.

Morphological traits

Types of trichomes and their density on pods

Trichomes (types and density) were counted on top, middle and lower pods (Table 4). Trichome density and types (type A and B) were comparatively higher in AL-201, H03-41 and PAU-881. In all the different sowing dates these trichomes were higher in moderately resistant genotypes. In AL-201 and H03-41, very high trichome density of type A and B was observed, whereas, in Paras, Manak and Pusa, the density of former trichomes was very low. However, the density of type C trichomes was higher in these genotypes as compared to AL-201 and H03-41.

Pod length, seed size (length and width) and number of seeds per pod

Table 3: Correlation of pod borer complex with biochemical parameters of pigeonpea (Pooled)

Pod borer complex	Biochemical constituents Chlorophyll (mg g-1)		Moisture (%)		Crude protein (%)		Fat (%)		Phenol (mg g-1)		Total soluble sugar (%)		Tannin (µg g-1)	
	Seed	Pod wall	Seed	Pod wall	Seed	Pod wall	Seed	Pod wall	Seed	Pod wall	Seed	Pod wall	Seed	Pod wall
D_1														
H. armigera	0.485	0.626	0.391	0.435	0.304	0.740*	-0.884**	-0.060	-0.900**	-0.656	0.738*	0.698	-0.792*	-0.086
M. vitrata	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
M. obtusa	0.281	0.404	0.559	0.546	0.881**	0.407	-0.069	-0.121	-0.041	-0.379	0.690	0.198	-0.096	-0.217
D_2														
H. armigera	0.384	0.465	0.815*	0.119	0.639	0.104	-0.675	-0.743*	-0.625	-0.697	0.793*	0.898**	-0.812*	-0.630
M. vitrata	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
M. obtusa	0.247	0.487	0.023	0.578	0.498	0.734*	-0.655	-0.750*	-0.242	-0.395	0.417	0.246	-0.763*	-0.321
D_3														
H. armigera	0.655	0.219	0.119	0.595	0.810*	0.497	0.580	-0.547	-0.547	0.361	0.250	0.543	0.149	-0.585
M. vitrata	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
M. obtusa	0.861*	0.228	0.489	0.760*	0.856*	0.844*	0.020	-0.606	-0.606	0.231	0.816*	0.888**	-0.614	-0.066
D_4														
H. armigera	0.753*	0.206	0.023	0.313	0.711*	-0.253	-0.080	-0.113	0.028	0.181	0.356	0.819*	0.676	0.262
M. vitrata	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
M. obtusa	0.719*	0.316	0.099	0.127	0.425	-0.288	-0.128	-0.467	-0.167	0.104	0.335	0.682	0.214	0.096

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

Table 4: Morphological traits of various pigeonpea varieties in different sowing dates

Genotype/ Variety	Trichomes on pods (/mm-2) Top			Middle			Lower			Pod length (mm)	Pod wall thickness (mm)	Seed size (mm)		No. of seeds/ pod
	A	B	C	A	B	C	A	B	C			Seed length	Seed width	
D_1														
Paras	108.34	5.76	9.17	65.24	4.33	4.2	62.29	0	0.06	52.09	0.83	6.92	4.65	3.3
Manak	110.8	4.82	6.01	75.42	4.14	3.8	81	0.01	0.02	53.24	0.97	6.88	4.42	3.5
AL-201	152.3	8.06	1.68	135.24	6.92	1.87	71.94	0.03	0.02	47.63	2.19	6.72	4.01	2.7
Pusa-992	80.64	2	6	85.84	0.04	5.07	82.31	0.02	0.05	54.12	0.67	7.22	4.56	3.4
PAU-881	105.7	5.78	8.55	97.46	7.98	4	64.38	0	2	49.57	1.67	7.00	4.57	2.9
H03-41	151.46	3.88	8.07	96	6.34	3.8	121.04	1.03	2.93	54.41	1.06	7.26	4.48	4
D_2														
Paras	107.42	4.18	9.27	55.44	4.39	3.87	59.33	0.07	0.5	49.15	0.71	7.76	4.66	3.68
Manak	116.28	5.34	6.53	86.22	4.04	4	83	0	1.02	40.31	1.39	6.21	4.12	3.31
AL-201	146.78	8.49	1	119.14	7.66	2	83.44	0.8	1	35.62	2.28	6.74	4.58	3.41
Pusa-992	95.12	4.72	6.27	78.31	1.1	5.17	83	0.04	0.5	50.47	1.15	8.22	4.40	3.81
PAU-881	66.32	5.00	8.13	82.66	7.89	6.14	61	0.6	1.87	51.00	1.45	7.56	4.61	4
H03-41	140.33	5.22	7.66	88	6.51	3.78	95.66	0.9	2	50.33	1.44	8.04	4.33	4.06
D_3														
Paras	113	7.67	8	80.8	4.29	4	60.44	2	1.55	47.44	1.28	7.06	4.55	3.56
Manak	110.06	2.33	6.71	93.07	0.5	4.12	78.34	0.82	0.80	43.17	1.18	6.58	4.39	3.66
AL-201	155.03	6.88	0.88	125.87	6.88	2	80.56	0.61	2.22	37.58	1.88	5.92	4.41	3.3
Pusa-992	78.08	0	7	79.73	1	4.91	67	1.19	0.51	57.29	1.02	8.33	4.68	3.86
PAU-881	79.15	5.778	8.46	88.26	7.69	3.14	70.39	0.07	1.77	44.08	1.76	7.25	4.06	3.51
H03-41	153.73	3.88	7.16	96	6	3.19	109.47	1.46	2.91	45.61	1.83	7.02	4.12	3.79
D_4														
Paras	110.33	9.22	9.27	78	4	4	62.13	0.1	0	43.00	1.42	5.56	4.44	3.00
Manak	114.8	2.66	6.53	92	1.18	4.36	82.67	0	0.1	48.67	1.28	6.14	4.25	3.26
AL-201	142.1	8.58	1	121.02	9.49	2	84.53	0.09	3	52.42	1.55	7.00	4.76	3.36
Pusa-992	86.91	0.9	6.27	66.44	1.58	4	70.93	1	0	47.35	1.39	6.48	4.45	3.31
PAU-881	67.2	4.46	8.13	85.17	5	4.19	66.66	0.02	0.06	52.71	1.45	7.36	4.86	3.53
H03-41	151.46	6.27	7.64	94	6.59	1.08	118.66	2	3	49.45	1.88	6.76	3.92	2.88

Table 5: Biochemical constituents of pigeonpea varieties in different sowing dates (dry weight basis)

Genotype/ Variety	Pod wall composition on dry weight basis							Green seed composition on dry weight basis						
	TSS (%)	Protein (%)	Phenol (mg g^{-1})	Chlorophyll (mg g^{-1})	Moisture (%)	Fat (%)	Tannins (μg g^{-1})	TSS (%)	Protein (%)	Phenol (mg g^{-1})	Chlorophyll (mg g^{-1})	Moisture (%)	Fat (%)	Tannins (μg g^{-1})
D_1														
Paras	2.68	12.25	0.65	2.41	73.2	2.6	59.80	5.00	23.46	0.75	1.58	73.4	3.3	73.94
Manak	2.69	11.91	0.78	2.26	72.8	2.4	50.54	4.45	24.51	0.42	1.54	71.4	3.3	61.22
AL-201	1.92	10.51	1.92	1.96	69.8	2.9	97.34	2.88	22.76	1.24	1.55	65	4.7	118.87
Pusa-992	2.38	12.25	0.45	2.04	71.6	2.3	34.63	3.04	21.36	0.34	1.43	67	4.0	67.39
PAU-881	2.24	9.46	1.74	1.68	71.2	2	58.03	4.35	21.01	0.68	1.39	67.6	4.2	85.17
H03-41	2.29	11.91	1.99	1.80	69.4	5.2	51.48	4.37	22.10	0.89	1.72	68.2	3.4	94.53
D_2														
Paras	2.01	10.54	1.52	1.59	70.8	2.90	38.71	6.01	21.01	1.35	0.63	64.6	4.8	42.12
Manak	3.26	10.16	1.94	0.98	69.2	1.90	27.16	3.85	21.71	1.14	0.47	62.4	3.5	72.08
AL-201	1.88	10.18	2.97	1.54	70.00	2.00	55.22	5.93	20.31	2.12	0.53	63.2	5.2	81.43
Pusa-992	2.65	10.51	1.21	1.56	69.6	3.00	30.88	4.21	23.46	1.11	0.66	62.2	3.1	29.87
PAU-881	2.50	8.400	2.24	1.47	68.8	3.20	37.44	5.03	19.96	1.63	0.63	68	5.9	53.35
H03-41	2.06	10.86	1.92	1.51	69.2	2.70	33.69	4.54	23.11	1.59	0.29	64.6	4.6	52.41
D_3														
Paras	2.59	11.56	1.68	1.25	68.2	3.2	59.90	4.03	23.41	0.52	0.57	68.6	3.6	37.88
Manak	4.68	10.51	0.69	1.26	69.8	3.3	46.80	5.58	25.56	0.48	0.58	69.2	3.9	45.89
AL-201	1.66	9.11	1.77	0.95	70.4	3.8	117.00	3.35	24.16	0.76	0.71	68	4.6	116.34
Pusa-992	4.10	11.21	0.89	1.03	69	2.5	75.81	4.17	23.46	0.53	0.74	62.2	3.4	90.79
PAU-881	2.37	10.16	1.07	1.03	69	2.9	104.83	4.84	19.96	0.66	0.54	68.6	4.1	121.68
H03-41	3.71	9.81	2.36	1.14	68.6	3.2	63.64	5.87	22.14	0.49	0.74	66.4	3.8	116.06
D_4														
Paras	3.80	12.61	1.59	1.04	72	2.1	34.66	2.74	23.11	1.18	0.95	73.4	3.4	98.28
Manak	6.56	9.11	1.33	1.06	73.4	2.6	73.95	3.96	21.71	0.33	0.93	74	3.6	78.65
AL-201	3.19	9.81	2.69	1.26	70.4	4.3	232.12	2.53	20.31	1.19	0.7	68.6	5.5	239.61
Pusa-992	3.65	12.96	1.46	1.02	70.4	3.3	87.04	1.60	24.16	1.12	0.46	67.4	5.4	136.65
PAU-881	3.43	11.23	1.74	0.81	69.6	4.6	184.39	2.28	25.56	0.98	0.61	68	5.5	120.74
H03-41	2.66	11.68	2.41	1.25	70.4	3.7	82.36	4.08	23.21	0.42	0.58	70.4	4.9	131.97

Pod length of AL-201 was comparatively less in comparison to other genotypes in all the different sowing dates (Table 4). Seed size (length and width) of AL-201 in all the different sowing dates was slightly less as compared to other genotypes. The number of seeds per pod also comparatively low in AL-201 and in the other genotypes, number of seeds per pod was higher in all the different sowing dates.

Pod wall thickness

Among different genotypes, the thickness of the pod wall was higher in moderately resistant genotypes AL-201, H03-41 and PAU-881 as compared to other genotypes (Table 4). However, the thickness of the pod wall was observed higher in all the genotypes as in delay the sowing time as compared to normal sowing time.

Biochemical composition of seed as well as pod wall

Total soluble sugars

Less than 5 per cent of the total soluble sugars were recorded in pod wall on dry weight basis (Table 5) in all the genotypes (AL-201, H03-41, PAU-881, Pusa-992 and Paras) across different sowing dates except in genotype Manak (6.56%) in D_4 (3rd week of July) sown crop. In moderately resistant genotypes *viz*., AL-201, H03-41 and PAU-881, the amount of total soluble sugars were comparatively low from 1.92 to 3.71 per cent. Whereas, in remaining genotypes, higher amount of total soluble sugars was observed. Total soluble sugars on dry weight basis in green seeds was also less than 6 per cent in all the genotypes. Low level of per cent total soluble sugars were observed in genotype AL-201 (1.92, 1.88, 1.66 and 3.19%), H03-41 (2.29, 2.06, 3.71 and 2.66%) and PAU-881 (2.24, 2.50, 2.37 and 3.43%).

Per cent soluble proteins

Soluble per cent protein content in pod wall composition on dry weight basis was observed lower in genotype AL-201 (10.51, 10.18, 9.11 and 9.81%), H03-41 (11.91, 10.86, 9.81 and 11.68%) and PAU-881 (9.46, 8.40, 10.16 and 11.24%) as compared to other genotypes in all the different sowing dates (Table 5). Per cent protein content on dry weight basis in green seed composition was also observed lower in genotype AL-201, H03-41 and PAU-881.

Phenol content

Phenol content in pod wall composition of genotype AL-201, H03-41 and PAU-881 on dry weight basis was observed higher (1.07 to 2.97 mg g^{-1}) in all the different sowing dates (Table 5). In the remaining genotypes the phenol content was observed less than 2 mg g^{-1}. In green seed composition on dry weight basis, the phenol content in moderately resistant genotypes was higher (0.42 to 2.12 mg g^{-1}) as compared to susceptible genotypes (Paras, Manak and Pusa-992) with the phenol content of 0.33 to 1.12 mg g^{-1}.

Per cent fat content

The per cent fat content was 2 to 5.2 per cent (Table 5) on dry weight basis in pod wall composition in moderately resistant genotype AL-201, H03-41 and PAU-881 in all the different sowing dates, whereas, in genotype Paras, Manak and Pusa-992, the fat content was 1.90 to 3.3 per cent on dry weight basis. In green seed composition, the fat content was also observed higher (3.4 to 5.9%) in genotype AL-201, H03-41 and PAU-881 on dry weight basis as compared to other genotypes with lower per cent fat content of 3.1 to 5.5%.

Condensed tannins

The level of condensed tannins in green seed composition was higher than those in pod wall composition (Table 5). On dry weight basis, the amount of tannins in pod wall composition was comparatively higher (33.69 to 232.12 μg g^{-1}) in genotype AL-201, H03-41 and PAU-881 in all the different sowing dates. Lower amount of tannins was observed in genotype Paras, Manak and Pusa-992 (27.16 to 87.04 μg g^{-1}). In green seed composition on the dry weight basis the amount of tannins was also registered higher (52.41 to 239.61 μg g^{-1}) in moderately resistant genotypes (AL-881, H03-41 and PAU-881) as compared to genotype Paras, Manak and Pusa-992 with the tannins amount of 29.87 to 136.65 μg g^{-1}) in all the different sowing dates.

Correlation coefficient of morphological and biochemical traits with expression of resistance to pod borer complex

H. armigera

A significant and negative association (-0.730*, -0.768*, -0.864*, -0.734*, -0.751*, -0.766* and -0.729*) was observed between per cent pod damage by *H. armigera* and density and types of trichomes (type A and B) of top and middle canopy of the pods in D_1 (3rd week of June) and D_2 (1st week of July) sowing dates (Table 4). In D_3 (2nd week of July) and D_4 (3rd week of July) sowing dates the correlation between per cent pod damage and density and types of trichomes was unusual and not frequent. Per cent pod damage and pod wall thickness was significant and negatively correlated (0.909** and 0.739*) in D_1 (3rd week of June) and D_2 (1st week of July) sowing dates. Significant and positive association (Table 5) between pod damage and crude protein content of pod wall (0.740*) and total soluble sugar of seed (0.738*) was observed. Whereas, significant and negative correlation was observed between per cent pod damage and per cent fat content (-0.884*) and amount of total phenols (-0.900*) and condensed tannins (-0.792*) of seed, respectively.

M. vitrata

Infestation of *M. vitrata* was significantly and negatively correlated (-0.945**, -0.766*, -0.871*, -0.858*, -0.759*, -0.852*, -0.895**, -0.705* and -0.845*) with the density and types of trichomes (type A and B) of the top and middle canopy of the plant (Table 4). With the pod wall thickness the correlation of *M. vitrata* was also significant and negatively correlated (-0.870* and -0.840*) in D_2 (1st week of July) and D_3 (2nd week of July) sowing dates. Per cent fat content of seed was significant and negatively correlated (-0.0.754* and -0.811*) with *M. vitrata* pod infestation (Table 5) in D_1 (3rd week of June) and D_3 (2nd week of July) sowing dates and with fat content (-0.871*) and amount of total phenols (-0.806*) of pod wall in D_2 (1st week of July) sowing date. Concentration of total soluble sugars (0.792*) of seed was significantly positively correlated in D_1 (3rd week of June) and total soluble sugars (0.714*) of pod wall in D_3 (2nd week of July) sowing dates. Non-significant association was observed between *M. vitrata* pod infestation and condensed tannins.

M. obtusa

Non-glandular pod trichomes (type A) was significantly and negatively correlated (-0.923** and -0.728*) with pod fly infestation in D_3 (2nd week of July) and D_4 (3rd week of July) sowing dates (Table 4). Whereas, the correlation between pod fly infestation and non-glandular lengthy (type C) pod trichomes of the middle canopy of the plant was significant and positive (0.807*, 0.794* and 0.752*) in D_1 (3rd week of June), D_3 (2nd week of July) and D_4 (3rd week of July) sowing dates. Pod trichomes (type A, B and C) of lower canopy of the plant was significantly and negatively correlated (-0.718*, -0.809* and -0.746*) in D_4 (3rd week of July) and D_3 (2nd week of July) sowing dates. Pod wall thickness was also significant and negatively correlated (-0.834*, -0.705* and -0.745*) with pod fly infestation in D_2 (1st week of July), D_3 (2nd week of July) and D_4 (3rd week of July) sowing dates. Infestation of pod fly was significant and positively correlated (0.861* and 0.719*) with chlorophyll content of seed as well as pod wall in D_3 (2nd week of July) and D_4 (3rd week of July) sown crop (Table 5). Crude protein content of seed during D_1 (3rd week of June) sown crop was significant and positively correlated (0.881**), during D_2 (1st week of July) sown crop with crude protein content of pod wall (0.734*) and during D_3 (2nd week of July) sown crop with crude protein content of seed as well as pod wall (0.856* and 0.844*), respectively. Fat content and condensed tannins of pod wall was significant and negatively correlated (-0.750*) and (-0.763*) in D_2 (1st week of July) sown crop. Total phenol content of seed as well as pod wall did not show any significant relationship with pod fly infestation. Total soluble sugar of seed and pod wall showed significant and positive correlation (0.816* and 0.888**) with pod fly infestation in D_3 (2nd week of July) sown crop.

Non-glandular lengthy pod trichomes (type C) of top and middle canopy of the plant showed their significant and positive relationship (Table 4) with the pod bore complex whereas, the non-glandular lengthy pod trichomes (type C) of lower canopy of the plant showed significant and negative relationship.

DISCUSSION

For cultivation of short duration pigeonpea varieties, morphological traits and biochemical components are quite important components of resistance against pod borer complex. Types of trichome, their orientation, density and length inûuence the host plant resistance/ susceptibility to insect pests (Jeffree, 1986; David and Easwaramoorthy, 1988; Peter *et al*., 1995; Valverde *et al*., 2001; Gurr and McGrath, 2001). However, according to Chu *et al*. (2000), trichomes at times also impart susceptibility to whiteûy, *Bemisia tabaci* (Gen.) in cotton. Among the types of trichomes, glandular trichomes and their exudates act as an important resistance mechanism to insects owing to the compounds exuded by them (Ranger and Hower, 2001; Frelichowski and Juvik, 2001). Among all the genotypes, non-glandular pod trichomes (type A) and glandular pod trichomes (type B) was high on the pods of AL-201, H03-41 and PAU-881. The hypothesis given by Hartlieb and Rembold (1996) stated that glandular secretions from trichomes in pigeonpea act as attractants to the adults of *H. armigera*.

Additionally, biochemical components present in the tissues of the host plant exert a profound inûuence on biology of insect pests (Beck, 1965; Smith, 1989; Sharma, 2009). In wild relatives of the pigeonpea, the total soluble sugars were less as compared to the pods of cultivated pigeonpea with higher sugar content, and this may be one of the factors leading to greater feeding by *H. armigera* larvae on the pods of cultivated pigeonpea compared to that on the accessions of wild pigeonpea (Sharma *et al.*, 2009). MacFoy *et al.* (1983) recorded high concentrations of sugars and amino acids in the cowpea cultivar Vita-1, which is susceptible to spotted pod borer, *Maruca testulalis* (Geyer). Low amounts of phenols in the pods and flowers of pigeonpea cultivars might be another reason for their high susceptibility to *H. armigera* and *M. testulalis* (Ganapathy, 1996). Phenol content and condensed tannins were observed in high amounts in later sowing crops or late maturing genotypes and were observed in high level in AL-201, H03-41 and PAU-881 as compared to other genotypes. According to Smith (1989), condensed tannins in plants act as insect growth inhibitors owing to their presumed binding to the proteins.

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