

RESEARCH

Open Access

Pigeonpea genotypes influence parasitization preference and survival and development of the *Helicoverpa armigera* larval parasitoid, *Campoletis chloridae*

Shiddalingappa V Hugar^{1,2}, Hari C Sharma^{1*} and Kondikallu Basavan Goud²

Abstract

Studies were undertaken to identify pigeonpea, *Cajanus cajan* (L.) Millspaugh and the wild relative of pigeonpea, *Cajanus scarabaeoides* (L.) (accession ICPW 125,) genotypes that are hospitable to the pod borer, *Helicoverpa armigera* (Hübner) (Lepidoptera: Noctuidae) larval parasitoid, *Campoletis chloridae* Uchida (Hymenoptera: Ichneumonidae) for the management of this pest in pigeonpea based cropping systems. Percentage parasitization of the *H. armigera* larvae by the *C. chloridae* females was greater under no-choice conditions than under multi-choice conditions because of forced parasitization under no-choice conditions. Lowest parasitization was recorded on the wild relative, ICPW 125, which may be due to long nonglandular hairs and low survival of *H. armigera* larvae. Parasitization of *H. armigera* larvae was greater under no-choice, dual-choice and/or multi-choice conditions on ICPL 87, ICPL 87119 and ICPL 87091, which are susceptible to *H. armigera*, than on the pod borer-resistant genotypes ICPL 332WR, ICPL 84060 and ICPB 2042; while survival and development of the parasitoid was better on *H. armigera* larvae fed on ICPL 87, ICPL 87119, LRG 41, ICP 7035 and ICPL 87091 than on ICPL 332WR, ICPL 84060, ICPB 2042 and ICPW 125. The genotypes ICPL 87, ICPL 87119, LRG 42 and ICPL 87091 that are hospitable to *C. chloridae*, are better suited for use in integrated pest management to minimize the losses due to *H. armigera* in pigeonpea.

Keywords: Pigeonpea; *Helicoverpa armigera*; *Campoletis chloridae*; Biological control; Plant resistance; Tritrophic interactions; Compatibility

Introduction

Pigeonpea is one of the major pulses grown in the semi-arid tropics between 30°N and 30°S, covering about 50 countries in Asia, Africa and the Americas. It is damaged by more than 200 species of insects, of which *Helicoverpa armigera* (Hubner) (Lepidoptera: Noctuidae) is the most important pest in the semi-arid tropics (Reed et al. 1989; Sharma 2005). *Helicoverpa armigera* has a wide host range, and feeds on more than 250 crop species. It has developed very high levels of resistance to conventional insecticides, including synthetic pyrethroids (Kranthi et al. 2002). *Helicoverpa armigera* is a polyphagous pest (Bilapate 1984; Firempong and Twine 1986), damaging a wide range

of agricultural crops including cotton, tomato, sunflower, grain legumes, vegetables, cereals and fruit crops. It causes an estimated annual loss of over \$350 million in pigeonpea, and over \$2 billion in the semi-arid tropics on different crops despite application of insecticides costing over \$500 million annually (Sharma 2005).

Evaluation of more than 14,000 pigeonpea accessions for resistance to *H. armigera* has revealed low to moderate levels of resistance to this pest (Reed and Lateef 1990; Lateef and Pimbert 1990), and several genotypes with moderate levels of resistance to *H. armigera* have been identified (Patnaik et al. 1989; Lateef and Pimbert 1990; Borad et al. 1991; Kalariya et al. 1998). Varieties with moderate levels of resistance to pod borers have also been developed, and/or released for cultivation to the farmers (Sharma et al. 2005, 2010). Genotypes such

* Correspondence: H.Sharma@cgiar.com

¹International Crops Research Institute for the Semi-Arid Tropics, Patancheru 502324, Andhra Pradesh, India

Full list of author information is available at the end of the article

as ICPL 187-1, ICP 7203-1, ICPL 98008, T 21, ICP 7035 and ICPL 332 have shown moderate levels of resistance to *H. armigera* across planting dates (Kumari et al. 2010a). The *H. armigera* larvae reared on leaves or pods of ICPL 332, ICPL 84060, ICP 7035, ICPL 88039 and T 21 exhibit reduced larval and pupal weights, and prolongation of larval and pupal developmental periods, suggesting that antibiosis is one of the mechanisms of resistance, which may have implications for survival and development of the natural enemies of this pest (Kumari et al. 2010b).

Over 250 natural enemies have been recorded on *H. armigera* (Romeis and Shanower 1996), of which, the egg parasitoids, *Trichogramma* spp. and the larval parasitoids, *Campoletis chloridae* Uchida (Hymenoptera: Ichneumonidae), *Carcelia illota* Curran, *Palexotista* spp., and *Goniozus* spp. are predominant parasitoids of *H. armigera* in different agro-ecosystems. However, the activity and abundance of natural enemies varies across crops (Pawar et al. 1986), and different genotypes of the same crop (Romeis and Shanower 1996; Sharma et al. 2003; Dhillon and Sharma 2007). Host plant selection by the female parasitoids, involves a series of complex responses in a non-random manner to a hierarchy of physical and/or chemical stimuli that lead them to their potential hosts (Vet and Groenewold 1990; Lewis et al. 1991; Tumlinson et al. 1993). Parasitoids also respond to the volatiles emanating from both undamaged (McAuslane et al. 1990; Li et al. 1992; Turlings and Tumlinson 1992; Udayagiri and Jones 1992) and damaged (Whitman 1988; Turlings et al. 1990, 1995; Mattiacci et al. 1994; de Moraes et al. 1998; War et al. 2011) plants.

Genotypic resistance has a considerable influence on parasitism of insect pests in different crops. The nature of influence depends on the insect pest, natural enemy, and the crop (Sharma et al. 2003). The rates of parasitism by *Campoletis sonorensis* (Cameron) and *Cotesia congregata* (Say) have been reported to be significantly lower on the resistant wild tomato, *Lycopersicon hirsutum* f. *glabratum* (accession PI 134417), but had little effect on parasitism by *Cotesia marginiventris* (Cresson) and *Cardiochiles nigriceps* Viereck (Farrar et al. 1994). In chickpea, parasitism of *H. armigera* larvae by *C. chloridae* ranged from 8.33 to 28.00% (Gupta and Raj 2003), and varied considerably across genotypes (Kaur et al. 2004). However, there is no information on genotypic effects on the activity and abundance of natural enemies in pigeonpea. The present studies were undertaken to study the effect of different genotypes of pigeonpea on the parasitization of *H. armigera* larvae by *C. chloridae* to identify genotypes that are compatible with the natural enemies of this pest.

Material and methods

Experimental material

Plant material

Eight pigeonpea genotypes (ICPL 87, ICPL 87119, and ICPL 87091—susceptible, LRG 41, T 21, and ICP 7035—moderately resistant, and ICPL 84060, ICPL 332 WR and ICPB 2042 (Hairy pods) - resistant) and one accession of wild relative of pigeonpea, *Cajanus scarabaeoides* (L.) (ICPW 125) were grown in the field during the rainy season (June-Dec) in deep black soils (Vertisols). The test genotypes were planted twice at 30 day intervals to produce flowers and pods of all genotypes at the same time. Normal agronomic practices, as per ICRISAT procedure, were followed for raising the crop, but without insecticide application. The inflorescences were covered with a nylon bag at the initiation of flowering (flower bud formation) to protect the test samples from natural infestation by the insects.

Maintenance of insect cultures

Pod borer, *H. armigera*

The *H. armigera* culture was initiated by collecting the larvae from the farmers' fields and reared on the natural host for one generation before being introduced into the laboratory culture to avoid contamination with the nuclear polyhedrosis virus, bacteria or fungi. The *H. armigera* was reared on a chickpea flour based semi-synthetic artificial diet (Armes et al. 1992).

Larval parasitoid, *C. chloridae*

The cocoons of *C. chloridae* were collected from chickpea fields and kept individually in a glass vial (2 cm in diameter, and 10 cm in length) and plugged with cotton wool. Twenty newly eclosed female adult wasps were kept in each cage (10 cm diameter × 20 cm length, and covered with a lid having 60 wire-mesh) with other virgin wasps. A cotton swab with 10% sucrose solution was placed inside the cage as a food for the parasitoid adults. After mating, the females were used for parasitization of second instar *H. armigera* larvae, and then reared on chickpea based artificial diet as described by Sharma et al. (2008). The culture was maintained at $27 \pm 2^\circ\text{C}$, 65–75% RH, and 12 h photoperiod. Mated females and progeny of the same parent (originating from isofemales, i.e. culture initiated from a single female) were used for the experiments.

Effectiveness of *C. chloridae* in parasitization of *H.*

armigera larvae on different genotypes of pigeonpea

The effect of different genotypes of pigeonpea on parasitization of *H. armigera* larvae by the females of *C. chloridae* was studied under no-choice, dual-choice, and multi-choice conditions. For this purpose, the inflorescences (30 cm long) of different genotypes at the initiation of podding (with 50% flowers) were cut with a sharp knife,

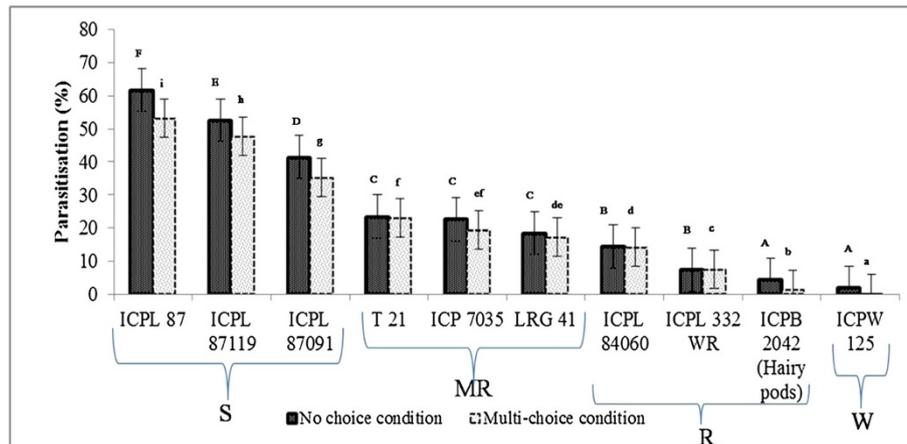


Figure 1 Influence of different pigeonpea genotypes on parasitization of *H. armigera* larvae by *C. chloridae* females under no-choice and multi-choice conditions. The bars followed by the same letter (upper or lower case) are not statistically significant at $P \leq 0.05$. S-Susceptible, MR-Moderately resistant, R-Resistant, and W-Wild resistant.

and immediately placed in a 100 ml conical flask containing 75 ml of one per cent sucrose solution, and held in an upright position using cotton wool. The inflorescences were infested with the 30 laboratory-reared second-instar *H. armigera* larvae. After 6 h, the infested inflorescences were exposed to the three, six and ten pairs of *C. chloridae* females under no-choice, double-choice and multi-choice conditions, respectively inside a cage (30 × 30 × 30 cm). The wasps were provided with 10% sucrose solution on a cotton swab as a food. After 48 h, the larvae were collected from the infested inflorescences and placed individually in 15 ml glass vials containing 10 g artificial diet. The larvae were reared on the artificial diet until cocoon formation.

No-choice conditions

Under no-choice conditions, a single inflorescence of the test genotype was kept inside a wooden cage (30 × 30 × 30 cm). Each experiment was repeated twice, and each set replicated 10 times.

Dual-choice conditions

Under dual-choice conditions, the *C. chloridae* females were offered the choice between the infested inflorescence of the test genotype and of the susceptible check, ICPL 87 placed at the opposite ends of a wooden cage. (30 × 30 × 30 cm). Each experiment was repeated 10 times. After 48 h, the relative parasitization (%) preference was computed as follows.

$$\text{Relative parasitization preference (\%)} = \frac{\text{No. of larvae parasitized on test genotype} - \text{No. of larvae parasitized on susceptible check}}{\text{No. of larvae parasitized on the test genotype} + \text{No. of larvae parasitized on check genotype}} \times 100$$

No effect on parasitization = No difference in relative parasitization between the test genotype and the susceptible check, ICPL 87.

Negative effect on parasitization = Parasitization of the *H. armigera* larvae on the test genotype is significantly lower than on the susceptible check, ICPL 87.

Positive effect on parasitization = Parasitization of *H. armigera* larvae on the test genotype is significantly greater than on the susceptible check, ICPL 87.

Multi-choice conditions

Under multi-choice conditions, the inflorescences of all the 10 test genotypes were arranged in a circular arena inside a wooden cage (60 × 60 × 60 cm). The experiment was conducted in a completely randomized block design, with two sets having three replications in each set. Observations were recorded on the numbers of *H. armigera* larvae recovered, and the proportion of larvae parasitized by *C. chloridae*. For recording the numbers of *H. armigera* larvae parasitized by *C. chloridae*, the larvae collected from inflorescences of one set were dissected immediately by placing them in a drop of Ringer's solution on a glass slide under a stereomicroscope, and the percentage parasitization was calculated as follows (Tian et al. 2008).

$$\text{Percentage parasitization} = \frac{(\text{Number of larvae parasitized}) / (\text{Number of larvae effectively parasitized} + \text{number of healthy larvae}) \times 100.$$

The second set was used to record the survival and development of *C. chloridae* as follows;

$$\text{Cocoon formation (\%)} = \left(\frac{\text{Number of cocoons formed}}{\text{Number of larvae parasitized}} \right) \times 100.$$

$$\text{Adult emergence (\%)} = \left(\frac{\text{Number of adults emerged}}{\text{Number of cocoons formed}} \right) \times 100.$$

Data were also recorded on egg and larval period, pupal period, and sex ratio of the parasitoid.

Statistical analysis

The data from no-choice, dual-choice and multiple choice conditions were subjected to analysis of variance using Genstat 13th edition. Significance of differences between the genotypes under no-choice and multi-choice conditions was tested by F-test, while the significance of differences between the genotypic means was judged by least significant difference at $P = 0.05$. Under dual-choice conditions, the significance of differences between the test genotypes and the susceptible check was judged by the students' paired t-test at $P = 0.05$.

Results

Effectiveness of *C. chloridae* in parasitization of *H. armigera* larvae on different genotypes of pigeonpea

No-choice conditions

Under no-choice cage conditions, there were significant differences in larval parasitization on different pigeonpea genotypes, and highest parasitization was recorded on ICPL 87 (61.74%), followed by ICPL 87119 (52.55%), ICPL 87091 and (41.39%) (Figure 1). Larval parasitization was quite low (4.50–23.41%) on T 21, ICP 7035, LRG 41, ICPL 84060, ICPL 332WR, and

ICPB 2042, suggesting that these genotypes were not hospitable to the larval parasitoid, *C. chloridae*. Least larval parasitization was observed on the pigeonpea wild relative, *C. scarabaeoides* accession ICPW 125 (2.00%), probably because of the presence of long hairs and/or chemicals that may be repellent to the adult wasps, and the possible adverse effects of secondary metabolites in this accession on the parasitoid survival and development.

Dual-choice conditions

Under dual-choice conditions, when the parasitoid females were offered a choice between the test cultivar and the susceptible check, ICPL 87, greater parasitization was recorded in the larvae released on ICPL 87 than on the test cultivars. The differences were much larger in case of ICPL 84060 (18.39 vs 53.82%), T 21 (21.14 vs 51.94%), ICPL 332 WR (11.43 vs 47.20%) and ICPW 125 (2.08 vs 24.62%) (Figure 2). The relative parasitization preference in relation to the susceptible check, ICPL 87 (RPP) by *C. chloridae* on different test genotypes as compared to ICPL 87 ranged from -5.01 to -84.2%. Highest RPP of -84.2% was observed on ICPW 125, followed by ICPL 332WR (-61.01%), ICPB 2042 (-58.96%), ICPL 84060 (-49.07%) and T 21 (-42.14%) (Figure 3).

Multi-choice conditions

Under multi-choice conditions, percentage larval parasitization was highest on the susceptible check, ICPL 87 (53.33%), followed by ICPL 87119 (47.67%). Least parasitization was recorded on *C. scarabaeoides* accession, ICPW 125 (0.13%), followed by ICPB 2042 (1.32%). The percentage parasitization of *H. armigera* larvae on rest of the genotypes varied from 7.46 to 35.33% (Figure 1).

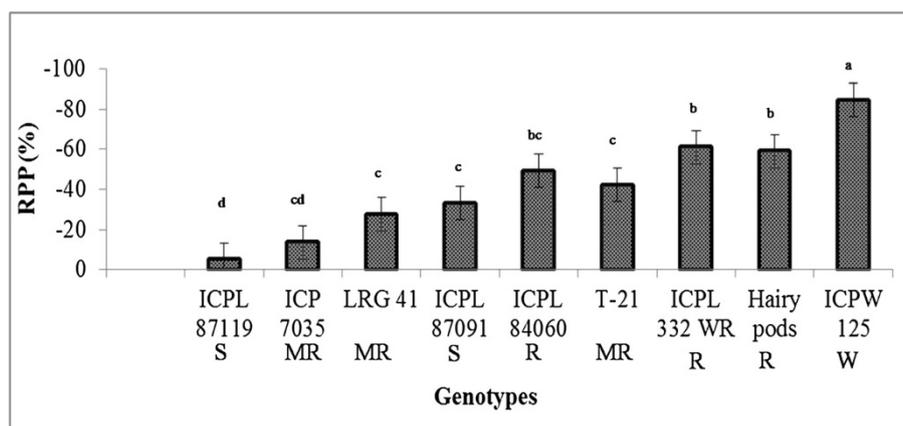


Figure 2 Parasitization of 2nd instar larvae of *H. armigera* by *C. chloridae* females on different genotypes of pigeonpea under dual-choice conditions. The bars followed by the same letter are not statistically significant at $P \leq 0.05$. RPP = Relative parasitization preference in relation to the susceptible check, ICPL 87. S-Susceptible, MR-Moderately resistant, R-Resistant, and W-Wild resistant.

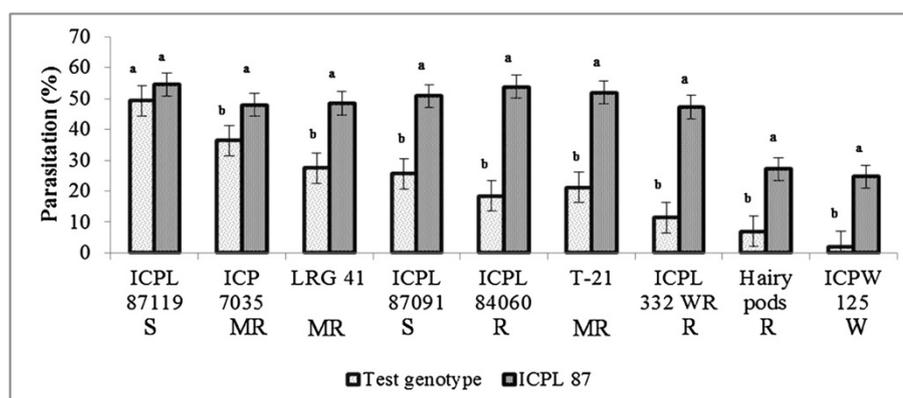


Figure 3 Parasitization preference of *C. chloridae* females towards 2nd instar larvae of *H. armigera* on different genotypes of pigeonpea in relation to the susceptible check, ICPL 87 under dual-choice conditions. A pair of bars followed by the same letter are not statistically significant at $P \leq 0.05$. S-Susceptible, MR-Moderately resistant, R-Resistant, and W-Wild resistant.

Effect of different pigeonpea genotypes on the development and survival of *C. chloridae*

Egg + larval period of *C. chloridae* reared on *H. armigera* larvae fed on the susceptible check, ICPL 87 was shortest (7.33 days), followed by those fed on ICPL 87119 (8.33 days). The egg + larval developmental period of *C. chloridae* was prolonged when the *H. armigera* larvae were reared on ICP 7035 (11.00 days), ICPB 2042 (12.00 days), ICPL 332 WR (12.33 days) and ICPW 125 (16.00 days) (Table 1). The pupal period of *C. chloridae* was shorter when the *H. armigera* larvae were fed on ICPL 87119 (7.68 days), followed T 21 (8.07 days), ICPL 87 (8.21 days) and ICPL 87091 (8.64 days) as compared to those fed on ICPL 332WR (9.40 days), ICP 7035 (9.57 days), ICPL 84060 (9.83 days) and LRG 41 (9.87 days). Pupal period of *C. chloridae* was prolonged by 4–6 days when the *H. armigera* larvae

were reared on the flowers/pods of ICPB 2042 and ICPW 125 (Table 1).

Percentage cocoon formation of *C. chloridae* was greater when the *H. armigera* larvae were fed on ICP 7035 (33.57%), followed by the larvae fed on ICPL 87119 (31.81%). Cocoon formation ranged from 19.91–22.03% when the *H. armigera* larvae were reared on ICPL 87, T 21, ICPL 84060, ICPL 87091 and LRG 41. However, cocoon formation was significantly lower (9.00–14.70%) when the *H. armigera* larvae were fed on ICPB 2042, ICPL 332WR and ICPW 125 as compared to that on ICPL 87119 (Table 1). Adult emergence of *C. chloridae* was highest when the *H. armigera* larvae were reared on flowers/pods of ICP 7035 (40.33%), followed by LRG 41 (39.67%). Least adult emergence was recorded on ICPW 125 (3.33%), followed by ICPB 2042 (5.33%). Longevity of *C. chloridae* adults was maximum when reared on

Table 1 Development and survival of *Campoplex chloridae* parasitizing 2nd instar *H. armigera* larvae on different genotypes of pigeonpea (ICRISAT, Patancheru, 2009-2010)

Genotypes	Egg + larval period (days)	Pupal period (days)	Cocoon formation (%)	Adult emergence (%)	Adult longevity (days)
ICPL 87 S	7.33 ± 0.33 ^a	8.21 ± 0.15 ^{ab}	22.03 ± 0.60 (27.98 ± 0.62) ^b	17.00 ± 1.15 (24.32 ± 1.17) ^d	23.00 ± 3.06 ^c
ICP 7035 MR	11.00 ± 0.58 ^d	9.57 ± 0.43 ^c	33.57 ± 1.83 (35.39 ± 1.94) ^a	40.33 ± 4.06 (39.38 ± 4.43) ^a	29.00 ± 1.15 ^d
LRG 41 MR	9.33 ± 0.34 ^{bc}	9.87 ± 0.13 ^c	19.91 ± 1.42 (26.47 ± 1.45) ^b	39.67 ± 0.87 (39.03 ± 0.96) ^a	20.00 ± 3.46 ^{bc}
ICPL 87091 S	9.33 ± 0.32 ^{bc}	8.64 ± 0.18 ^{abc}	20.25 ± 0.64 (26.74 ± 0.65) ^b	24.00 ± 2.08 (29.29 ± 2.15) ^c	29.70 ± 0.88 ^d
ICPL 84060 R	9.00 ± 0.10 ^{bc}	9.83 ± 0.17 ^c	19.93 ± 0.93 (26.50 ± 0.95) ^b	33.00 ± 0.56 (35.05 ± 0.61) ^b	18.70 ± 0.33 ^{bc}
T 21 MR	9.73 ± 0.18 ^c	8.07 ± 0.30 ^a	20.14 ± 0.71 (26.67 ± 0.72) ^b	15.67 ± 1.20 (23.28 ± 1.22) ^d	19.00 ± 0.58 ^{bc}
ICPL 332 WR R	12.33 ± 0.88 ^e	9.4 ± 0.87 ^{bc}	14.28 ± 0.62 (22.19 ± 0.63) ^c	9.67 ± 1.10 (18.05 ± 1.20) ^e	18.00 ± 0.58 ^{bc}
ICPB 2042 (Hairy pods) R	12.00 ± 0.57 ^{de}	12.17 ± 0.17 ^d	14.70 ± 1.32 (22.50 ± 1.33) ^c	5.33 ± 0.86 (13.26 ± 0.87) ^f	14.33 ± 1.76 ^{ab}
ICPW 125 W	16.00 ± 0.56 ^f	14.48 ± 0.37 ^e	9.00 ± 0.58 (17.44 ± 0.57) ^d	3.33 ± 0.87 (10.34 ± 0.86) ^f	10.70 ± 0.88 ^a
SE±	0.425	0.404	0.74	1.20	1.718
LSD (P _{0.05})	1.264 [*]	1.202 [*]	2.98 [*]	4.83 [*]	5.11 [*]

Values in parentheses are Arcsine transformed. The values followed by the same letter within a column are statistically non-significant at $P \leq 0.05$. S-Susceptible, MR-Moderately resistant, R-Resistant, and W-Wild resistant.

H. armigera larvae fed on ICPL 87091 (29.70 days), followed by ICP 7035 (29.00 days). The adult longevity was significantly lower in *C. chlorideae* reared on *H. armigera* larvae fed on ICPW 125 (10.70 days) and ICPB 2042 (14.33 days) than those fed on ICP 7035 and ICPL 87091.

Discussion

Effectiveness of natural enemies for controlling insect pests varies across crops, and different genotypes of the same crop (Sharma 1993; Sharma et al. 2003; Kaur et al. 2004; Dhillon and Sharma 2007). The present studies showed that the parasitization efficiency of the *H. armigera* larval parasitoid, *C. chlorideae* varies across different genotypes of pigeonpea. The host genotype not only influenced the parasitization of the host larvae, but also the survival and development of *C. chlorideae*, which may be because of the effect of the morphological and biochemical characteristics of the host genotype on *H. armigera* larvae, and the indirect effects on *C. chlorideae*. Percentage parasitization was greater under no-choice conditions as compared to that under multi-choice conditions, which may be largely because of non-availability of alternate host plant to the females of *C. chlorideae*. When the parasitoids were given a choice of all the test genotypes under multi-choice conditions, greater numbers of parasitoids were involved in seeking the host larvae, resulting in intraspecific competition, which might have resulted in lower levels of parasitism under multi-choice conditions. Competition is one of several factors influencing the effectiveness of parasitoids (Sirot and Bernstein 1996).

The *H. armigera* larvae feeding on susceptible genotypes, ICPL 87 and ICPL 97119 suffered significantly greater parasitization by *C. chlorideae* than the other genotypes tested under no-choice, dual-choice and multi-choice conditions, suggesting that host genotype plays a significant role in the effectiveness of *C. chlorideae* in parasitization of *H. armigera* larvae. Kaur et al. (2004) reported that as the incidence of a pest increases, the parasitoid activity also increases. In the present studies, the increased parasitization of *H. armigera* on the susceptible genotypes may also be influenced by survival of more numbers of *H. armigera* larvae on the susceptible genotype and lack of resistance to the herbivore, and possibly production of greater amounts of the volatile compounds that attract the *C. chlorideae* females for parasitization (War et al. 2011).

Clustering type of podding habit of ICPL 87 possibly provided more surface area for the movement of the *H. armigera* larvae, rendering them more prone to parasitization by *C. chlorideae*. ICPL 87119 - which has thicker pod walls, possibly hindered the entry of the *H. armigera* larvae into the pods making them more prone to parasitization by *C. chlorideae*. Creeping type growth habit and thick plant canopy of the *C. scarabaeoides*

accession, ICPW 125 recorded lowest parasitization under no-choice, dual-choice and multi-choice conditions, which may be due to the presence of long nonglandular hairs and low survival of *H. armigera* larvae because of high levels of resistance to *H. armigera* (Aruna et al. 2005; Sujana et al. 2008; Sharma et al. 2009), and a different blend of the chemicals on the pod surface (Green et al. 2002) and/or volatile compounds (Sharma et al. 2001) which influence the survival and development of the insect host, *H. armigera*. Behavior and parasitism rates of *Trichogramma pretiosum* (Riley) and *Trichogramma minutum* (Riley) in *H. armigera* are influenced by trichome and gossypol containing glands in cotton (El-Wakeil 2011), while trichomes in pigeonpea inhibit the searching behavior of *T. chilonis* Ishii (Romeis et al. 1998).

Pigeonpea genotypes also showed substantial effects on the survival and development of *C. chlorideae* parasitizing second-instar *H. armigera* larvae. Egg + larval period and pupal period were longest on the *C. scarabaeoides* accession, ICPW 125 and shortest postembryonic developmental period was recorded on the *H. armigera* susceptible genotype ICPL 87, suggesting that secondary metabolites ingested by the *H. armigera* larvae from the host genotype either directly affected the survival and development of the parasitoid, *C. chlorideae* or through suboptimal prey because of poor growth of the *H. armigera* larvae due the adverse effects of the secondary metabolites, and/or poor nutritional quality of the insect and plant host. Changes in biochemical composition of host plants in response to herbivory also influence the growth and survival of herbivores (Gange and Brown 1989; Whitman et al. 1991), which in turn influences the activity and abundance of natural enemies (Bloem and Duffey 1990). Sithanatham et al. (1982) observed that parasitism of *H. armigera* larvae in chickpea was lower on the resistant genotypes than on the susceptible ones. The results of the present studies suggested that the ICPW 125, ICPB 2042 and ICPL 332WR are not compatible with the *H. armigera* larval parasitoid *C. chlorideae*.

Parasitization of *H. armigera* larvae by *C. chlorideae* was greater under no-choice, dual-choice and/or multi-choice conditions on ICPL 87, ICPL 87119 and ICPL 87091, which are susceptible to *H. armigera* than on the resistant genotypes ICPL 332WR, ICPL 84060, LRG 41 (Kumari et al. 2010a). Survival, development of the parasitoid was better on ICPL 87119, LRG 41, ICP 7035 and ICPL 87091 than on ICPL 332WR, ICPL 84060, ICPB 2042 and ICPW 125 - the pod borer resistant genotypes. The genotypes ICPL 87, ICPL 87119, LRG 42 and ICPL 87091, that are hospitable to *C. chlorideae*, are more suitable for use in integrated pest management to minimize the damage by *H. armigera* in pigeonpea. These varieties have also been released for cultivation to the farmers and have acceptable grain quality, except ICPL

87091. In view of the variation observed in genotypic resistance to *H. armigera*, there is need for in-depth studies to assess the genotypic compatibility with the natural enemies of the crop pests for integrated pest management.

The larvae of *H. armigera*, which escape parasitization continue to develop and produce the next generation. The surviving population becomes the source for future generations of the parasitoids, which develop in the parasitized larvae and contribute to the natural balance between the pest and the natural enemies. The continuous and cumulative effect of the natural enemies on insect pests reduces the overdependence on synthetic pesticides for pest management, and thus, contributes to environment conservation. The genotypes that are compatible with the natural enemies may also be used by the organic farming community for producing food free from pesticides.

Competing interest

The authors declare that they have no competing interests.

Authors' contributions

SVH carried out the research work on the "Pigeonpea Genotypes Influence Parasitization efficiency and survival and development of the *Helicoverpa armigera* Larval Parasitoid, *Campoletis chloridae*". Rearing and maintenance of the *H. armigera* and *C. chloridae* culture for conducting the experiments. Growing of different pigeonpea genotypes under ideal conditions and unbiased under the greenhouse condition and the inflorescence were covered with the nylon net to avoid the field infestation of the insect pest. Constructed the cages and conducted the experiment to study Effectiveness of *C. chloridae* in parasitization of *H. armigera* larvae on different genotypes of pigeonpea under no-choice, dual-choice and multi-choice condition. Conducted the experiment on the development and survival of *C. chloridae* on different pigeonpea genotypes. Statistical analysed the data for interpretation of the findings. HCS Provided plant materials, laboratory, materials, labors etc for conducting the experiments. Given scientific guidelines, way of conducting the experiments and guidance for conducting the experiments. Drafted the manuscripts for publication in the Journal. KBG Given procedure for conducting the experiments and drafted the manuscripts and statistically analysed data for publication in the Journal. All authors read and approved the final manuscript.

Acknowledgements

We thank the staff of entomology, ICRI SAT for help in insect rearing and bioassays. We also thank Dr AR War for critical review of the manuscript, and the National Food Security Mission, Ministry of Agriculture and Cooperation, Government of India, for financial support for this work.

Author details

¹International Crops Research Institute for the Semi-Arid Tropics, Patancheru 502324, Andhra Pradesh, India. ²Department of Agricultural Entomology, College of Agriculture, University of Agricultural Sciences (UAS), Dharwad 580005, Karnataka, India.

Received: 21 April 2014 Accepted: 22 July 2014

Published: 28 July 2014

References

- Armes NJ, Bond GS, Cooter RJ (1992) The laboratory culture and development of *Helicoverpa armigera*. Natural Resources Institute Bulletin, 57, Chatham, UK
- Aruna R, Manohar Rao D, Reddy LJ, Upadhyaya HD, Sharma HC (2005) Inheritance of trichomes and resistance to pod borer (*Helicoverpa armigera*) and their association in interspecific crosses between cultivated pigeonpea (*Cajanus cajan*) and its wild relative *C. scarabaeoides*. Euphytica 145:247–257
- Bilapate GG (1984) *Heliothis* complex in India: a review. Agric Rev London 5:13–26
- Bloem KA, Duffey SS (1990) Effect of protein type and quantity on growth and development of larval *Heliothis zea* and *Spodoptera exigua* and the endoparasitoid *Hyposoter exigua*. Entomol Exp Applic 54:141–148
- Borad PK, Patel JR, Patel MG (1991) Evaluation of vegetable pigeonpea (*Cajanus cajan*) genotypes resistant to gram-pod borer (*Helicoverpa armigera*), plume moth (*Marasmarcha liophanes*) and podfly (*Melanagromyza obtusa*). Indian J Agric Sci 61:682–684
- De Moraes CM, Lewis WJ, Pare PW, Alborn HT, Tumlinson JH (1998) Herbivore infested plants selectively attract parasitoids. Nature 393:570–573
- Dhillon MK, Sharma HC (2007) Survival and development of *Campoletis chloridae* on various insect and crop hosts: implications for Bt-transgenic crops. J Appl Entomol 131(3):179–185
- El-Wakeil NE (2011) Impacts of cotton traits on the parasitization of *Helicoverpa armigera* eggs by *Trichogramma* species. Gesunde Pflanzen 63:83–93
- Farrar RR Jr, Barbour JD, Kennedy GG (1994) Field evaluation of insect resistance in a wild tomato and its effects on insect parasitoids. Entomol Exp Applic 71:211–226
- Firempong S, Twine P (1986) The biology and ecology of *H. armigera* and *H. punctigera* (Wallengren) (Lepidoptera: Noctuidae) in Australia: what do we know? Aust J Zool 34:779–814
- Gange AC, Brown VK (1989) Effects of root herbivory by an insect on a foliar-feeding species, mediated through changes in the host plant. Oecologia 81:38–42
- Green PWC, Stevenson PC, Simmonds MSJ, Sharma HC (2002) Can larvae of the pod borer, *Helicoverpa armigera* (Noctuidae: Lepidoptera), select between wild and cultivated pigeonpea, *Cajanus* sp. (Fabaceae)? Bull Ent Res 92:45–51
- Gupta RK, Raj D (2003) Natural parasitism by *Campoletis chloridae* Uchida, a promising parasitoid of *Helicoverpa armigera* (Hubner) on chickpea. J Biol Control 17:9–12
- Kalariya GB, Judal GS, Patel GM (1998) Reaction of pigeonpea genotypes against important insect pests. Gujarat Agric Uni Res J 23:33–38
- Kaur S, Brar KS, Shehnmur M (2004) Effect of different chickpea cultivar on parasitization of *Helicoverpa armigera* (Hubner) by *Campoletis chloridae* Uchida. J Biol Control 18:69–72
- Kranthi KR, Jadhav DR, Kranthi S, Wanjari RR, Ali SS, Russel DA (2002) Insecticide resistance in five major insect pests of cotton in India. Crop Prot 21:449–460
- Kumari AD, Reddy DJ, Sharma HC (2010a) Stability of resistance to pod borer, *Helicoverpa armigera* in pigeonpea. Indian J Plant Prot 38(1):6–12
- Kumari AD, Sharma HC, Reddy JD (2010b) Incorporation of lyophilized leaves and pods into artificial diet to assess antibiosis component of resistance to pod borer in pigeonpea. J Fd Leg 23:57–65
- Lateef SS, Pimbert MP (1990) The search for host plant resistance of *Helicoverpa armigera* in chickpea and pigeonpea at ICRI SAT Pages 14–18. In: Proceedings of the Consultative Group Meeting on the host selection behavior of *Helicoverpa armigera*, 5–7 March 1990. International Crops Research Institute for the Semi-Arid Tropics, Patancheru 502 324, Andhra Pradesh, India
- Lewis WJ, Tumlinson JH, Krasnoff S (1991) Chemically mediated associative learning: an important function in the foraging behavior of *Microplitis croceipes* (Cresson). J Chem Ecol 17:1309–1325
- Li Y, Dickens JC, Steiner WWM (1992) Antennal olfactory responsiveness of *Microplitis croceipes* (Hymenoptera: Braconidae) to cotton plant volatiles. J Chem Ecol 18:1761–1773
- Mattiacci L, Dicke M, Posthumus MA (1994) Induction of parasitoid attracting synomone in Brussels sprouts plant by feeding of *Pieris brassicae* larva: role of mechanical damage and herbivore elicitor. J Chem Ecol 20:2229–2247
- McAuslane HJ, Vinson SB, Williams HJ (1990) Influence of host plant on mate location by parasitoid *Campoletis sonorensis* (Hymenoptera:Chneumonidae). Environ Entomol 19:26–31
- Patnaik NC, Dash AN, Mishra BK (1989) Effect of intercropping on the incidence of pigeonpea pests in Orissa, India. Int Pigeonpea Newslett 9:24–25
- Pawar CS, Bhatnagar VS, Jadhav DR (1986) *Heliothis* species and their natural enemies, with their potential for biological control. Proc Indian Acad Sci (Anim Sci) 95(6):695–703
- Reed W, Lateef SS (1990) Pigeonpea: pest management. In: Nene YL, Hall SD, Sheila VK (eds) The pigeonpea. CAB International, Wallingford, UK, pp 349–374
- Reed W, Lateef SS, Sithanatham S, Pawar CS (1989) Pigeonpea and chickpea insect identification handbook. In: International Crops Research Institute for the Semi Arid Tropics. Information Bulletin No: 26, Patancheru, A.P. India, p 120
- Romeis J, Shanower TG (1996) Arthropod natural enemies of *Helicoverpa armigera* (Hubner) (Lepidoptera: Noctuidae) in India. Biocont Sci and Techn 6:481–508
- Romeis J, Shanower TG, Zebitz CPW (1998) Physical and chemical plant characters inhibiting the searching behaviour of *Trichogramma chilonis*. Entomol Exp Applic 87:275–284

- Sharma HC (1993) Effect of insecticide application and host plant resistance on parasitization of sorghum midge, *Contarinia sorghicola*. *Biocont Sc Technol* 4:53–60
- Sharma HC (ed) (2005) *Heliothis/Helicoverpa* management: emerging trends and strategies for future research. Oxford & IBH, and Science Publishers, USA, New Delhi, India, p 469
- Sharma HC, Green PWC, Stevenson PC, Simmonds SMJ (2001) What makes it so tasty for the pest? Identification of *Helicoverpa armigera* feeding stimulants and the location of their production in pigeonpea, Final technical report submitted to Department for International Development, United Kingdom. ICRIAT, Patancheru 502 324, Andhra Pradesh, India, p 85
- Sharma HC, Pampapathy G, Sullivan DJ (2003) Influence of host plant resistance on activity and abundance of natural enemies. In: Ignacimuthu S, Jayaraj S (eds) Biological control of insect pests. Phoenix Publishing House, New Delhi, India, pp 282–296
- Sharma HC, Pampapathy G, Dhillon MK, Ridsdill S (2005) Detached leaf assay to screen for host plant resistance to *Helicoverpa armigera*. *J Econ Entomol* 98:568–576
- Sharma HC, Dhillon MK, Arora R (2008) Effects of *Bacillus thuringiensis* δ -endotoxin fed *Helicoverpa armigera* on the survival and development of the parasitoid *Campoletis chloridae*. *Entomol Exp Applic* 126:1–8
- Sharma HC, Sujana G, Manohar Rao D (2009) Morphological and chemical components of resistance to pod borer, *Helicoverpa armigera* in wild relatives of pigeonpea. *Arth Pl Interact* 3:151–161
- Sharma HC, Srivastava CP, Durairaj C, Gowda CLL (2010) Pest management in grain legumes and climate change. In: Yadav SS, McNeil DL, Redden R, Patil SA (eds) Climate change and management of cool season grain legume crops. Springer Science + Business Media, Dordrecht, The Netherlands, pp 115–140
- Sirost E, Bernstein C (1996) Time searching between host searching and food searching in parasitoids: state-dependent optimal strategies. *Behav Ecol* 7:189–194
- Sithanatham S, Rao VR, Reed W (1982) The influence of host-plant resistance in chickpea on parasitism of *H. armigera* Hubner larvae. *Inter Chickpea Newslett* 6:21–22
- Sujana G, Sharma HC, Manohar Rao D (2008) Antixenosis and antibiosis components of resistance to pod borer, *Helicoverpa armigera* in wild relatives of pigeonpea. *Int J Trop Insect Sci* 28:191–200
- Tian SP, Zhang JH, Yun-Hua Yan YH, Wang CZ (2008) Interspecific competition between the ichneumonid *Campoletis chloridae* and the braconid *Microplitis mediator* in their host *Helicoverpa armigera*. *Entomol Exp Applic* 127(10–19):2008
- Tumlinson JH, Turlings TCJ, Lewis WJ (1993) Semiochemically mediated foraging behavior in beneficial parasitic insects. *Arch Insect Biochem Physiol* 22:385–391
- Turlings TCJ, Tumlinson JH (1992) Systemic release of chemical signals by herbivore injured corn. *Proc Natl Acad Sci U S A* 89:8399–8402
- Turlings TCJ, Scheepmakeer JWA, Vet LEM, Tumlinson JH, Lewis WJ (1990) How contact foraging experiences affect preferences of host related odours in the larval parasitoid, *Cotesia merginiventris* Cresson (Hymenoptera: Braconidae). *J Chem Ecol* 16:1577–1589
- Turlings TCJ, Loughrin JH, McCall PJ, Rse USR, Lewis WJ, Tumlinson JH (1995) How caterpillar damaged plants protect themselves by attracting parasitic wasps. *Proc Natl Acad Sci U S A* 92:4169–4174
- Udayagiri S, Jones RL (1992) Flight behavior of *Macrocentrus grandii* Goidanich (Hymenoptera, Braconidae), a specialist parasitoid of European corn borer (Lepidoptera, Pyralidae)—factors influencing response to corn volatiles. *Environ Entomol* 21:1448–1456
- Vet LEM, Groenewold AW (1990) Semiochemicals and learning in parasitoids. *J Chem Ecol* 16:3119–3135
- War AR, Sharma HC, Paulraj MG, War MY, Ignacimuthu S (2011) Herbivore induced plant volatiles - their role in plant defense for pest management. *Pl Sig Behav* 6(12):1973–1978
- Whitman TG, Maschinski J, Larson KC, Paige KN (1991) Plant response to herbivory: the continuum from negative to positive and underlying physiological mechanisms'. In: Price PW, Lewinsohn TM, Fernandes GW, Benson WW (eds) Plant animal interactions evolutionary ecology in tropical and temperate regions. Wiley and Sons, New York, pp 227–256
- Whitman DW (1988) Allelochemical interactions among plants, herbivores and their predators. In: Barbosa P, Letourneau DK (eds) Novel aspects of insect-plant interactions. Wiley, New York, pp 11–64

doi:10.1186/2193-1801-3-378

Cite this article as: Hugar et al.: Pigeonpea genotypes influence parasitization preference and survival and development of the *Helicoverpa armigera* larval parasitoid, *Campoletis chloridae*. *SpringerPlus* 2014 3:378.

Submit your manuscript to a SpringerOpen[®] journal and benefit from:

- Convenient online submission
- Rigorous peer review
- Immediate publication on acceptance
- Open access: articles freely available online
- High visibility within the field
- Retaining the copyright to your article

Submit your next manuscript at ► springeropen.com