TRITROPHIC INTERACTION BETWEEN PIGEONPEA GENOTYPES, Helicoverpa armigera (Hübner) and NATURAL ENEMIES

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By

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CERTIFICATE

This is to certify that the thesis entitled **"TRITROPHIC INTERACTION BETWEEN PIGEONPEA GENOTYPES, *Helicoverpa armigera* (Hübner) AND NATURAL ENEMIES"** submitted by **Mr. SHIDDALINGAPPA V. HUGAR.,** for the degree of **DOCTOR OF PHILOSOPHY** in **AGRICULTURAL ENOMOLOGY,** to the University of Agricultural Sciences, Dharwad is a record of research work done by him during the period of his study in this University under my guidance and the thesis has not previously formed the basis for the award of any degree, diploma, associateship, fellowship or other similar titles.

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DHARWAD

OCTOBER, 2012 ***(SHIDDALINGAPPA V. HUGAR)***

Affectionately Dedicated
To

My Beloved Parents

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1. INTRODUCTION

Pigeonpea belongs to the subtribe Cajaninae within the tribe Phasealeae. The genus, *Cajanus* comprises of 32 species, of which *Cajanus cajan* (L.) Millspaugh is the only commercially cultivated species (Van der Maesen, 1990). About 90 per cent of the world's production of pigeopnpea is from India, where it probably originated (Van der Maesen, 1990; Nene and Sheila, 1990). It is one of the major pulses grown in the semi-arid tropics (SAT) between 30^{o}N and 30^{o}S, covering about 50 countries of Asia, Africa and America. The pigeonpea production is based primarily on subsistence farming for human consumption (as green or dried seeds) (Shanower *et al.*, 1999). As a source of high value protein, it plays an important role in the nutrition of mainly vegetarian and poor people in Asia and Eastern Africa. As conventional chemical control methods have turned out to be unsustainable because of resistance problems, pollution and health hazards (Sithanantham *et al.*, 2001), integrated pest management (IPM) became the generally advocated control technique. It comprises of : (1) host plant resistance to insects (2) suppression by the natural enemies and (3) need based application of insecticides (FAO, 1994).

In India, *Helicoverpa armigera* (Hübner) (Lepidoptera: Noctuidae) is a major pest of several economically important crops such as cotton, pigeonpea, chickpea, sorghum and tomato. The continuous availability of host crops, often planted as monocultures and the lack of crop rotation greatly contribute to maintenance of high population levels of *H. armigera* and the consequent damage to crops. More than 200 species of insects feed on pigeonpea, of which *H. armigera* is the most important pest causing heavy loss in pigeonpea.

Over 250 natural enemies have been recorded on *H. armigera* (Romies and Shanower, 1996), of which the egg parasitoids, *Trichogramma* spp. and the larval parasitoids, *Campoletis chlorideae* Uchida, *Carcelia illota* Curran, *Palexotista, Goniozus* spp., *etc.* are the predominant natural enemies in different agro-ecosystems. The activity and abundance of various parasitoids varies across crops (Pawar *et al.*, 1986) and different genotypes of the same species. There are several reports on the variation in activity and abundance of different natural enemies on various genotypes of

cotton, pigeonpea and chickpea (Romeis *et al.*, 1999a; Dhillon and Sharma, 2007). However, very little is known about the role of host plant in attracting or repelling the parasitoids.

Host selection in insects, particularly in female parasitoids, involves responses in a complex 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 have been shown to respond to volatiles emanating from both undamaged plants (McAuslane *et al.*, 1990; Li *et al.*, 1992; Turlings and Tumlinson, 1992; Udayagiri and Jones, 1992) and damaged plants (Whitman, 1988; Turlings *et al.*, 1990, 1995, 1998, 2000; Mattiaci *et al.*, 1994; de Moraes *et al.*, 1998; Dicke *et al.*, 1999; Gols *et al.*, 1999; Hoballah and Turlings, 1999). Semiochemicals offer good prospects as a tool for manipulating parasitoid behavior, particularly in view of possible application to enhance the efficacy of parasitoids in biological control programmes.

The quality of host plants influence the feeding, growth and development of phytophagous insects and can profoundly affect tritrophic interactions between plants, herbivores and their natural enemies (Price *et al.*, 1980; Price *et al.*, 1986; Murugan and George, 1992; Jeyabalan and Murugan, 1996). Changes in the biochemistry of plant tissues affect growth and survival of herbivores (Gange and Brown, 1989; Whitham *et al.*, 1991; Murugan and George, 1992) which in turn influences their natural enemies (Bloem and Duffey, 1990). Allelochemicals in the food chain affect parasitoids, pathogens and predators and the ability of these natural enemies to influence herbivore fitness and population growth is inturn altered. Various aspects of the development and survival of parasitoids can be adversely influenced by the presence of alkaloids, such as tomatine and nicotine, in the food of their herbivore hosts (Campbell and Duffey, 1979; Barbosa *et al.*, 1986; Thorpe and Barbosa, 1986).

The degree at which natural enemies make use of specific differences in volatile blends is expected to depend on their dietary specialization and /or their host /prey species (Vet and Dicke, 1992). Although some generalist parasitoids use specific cues for host location (Steidle *et al.*, 2003), they more often use general cues (Steidle and van

Loon, 2003). For generalist parasitoids, it is assumed that the use of general chemical cues present in all hosts or their respective food plants is an adaptive strategy (Vet and Dicke, 1992; Godfray, 1994). Behavioral responses of the parasitoids could be greatly affected by experience or learning (Turlings *et al.*, 1993). Learning to respond to infochemicals and the use of general cues were more often found in generalists than in specialists (Steidle and van Loon, 2003).

Several morphological traits such as pod toughness, structure of pod wall and trichomes on the pod surface have been reported to be associated with resistance to *H. armigera* (Shanower *et al.*, 1997). Besides the morphological traits, chemical compounds in trichome exudates and on pod wall surface also influence the host plant selection and colonization by *H. armigera* (Hartlieb and Rembold 1996; Green *et al.,* 2003). Chemicals extracted in acetone from *Cajanus scarabaeoides* (L.) pod surface result in feeding inhibition, whereas compounds extracted in methanol from the pod surface of cultivated pigeonpea act as phagostimulants (Romeis *et al.*, 1999; Green *et al.*, 2003). In addition, pigeonpea also contains anti-nutritional factors such as proteinase inhibitors, oligosaccharides, phenols, tannins and phytic acid (Singh, 1988), which may influence the host plant suitability to *H. armigera*.

Campoletis chlorideae Uchida (Hymenoptera: Ichneumonidae) is an important solitary koinobiont early larval endoparasitoid of many noctuid species including *H. armigera* (Mani, 1994; Yan and Wang, 2006), *Helicoverpa assulta* (Guenee), *Spodoptera litura* (Fabricius), *Spodoptera exigua* (Hübner), *Agrotis ypsilon* (Hufnagel), *Anomis flava* (Fabricius), *Pseudaletia separate* Walker and *Leucania loreyi* (Dup.) (Li *et al.*, 1997; Sato, 1988; Yan *et al.*, 2001; He *et al.*, 2002a,b; Hou *et al.*, 2002; Guo *et al.*, 2003). The parasitoid may have 8–10 generations per year (Zheng and Lu, 1981; Dai, 1990; You *et al.*, 2002) and has been recorded on the insect pests of many crops including cotton, maize, peanut, tomato, pepper and tobacco (Lu *et al.*, 1999; You *et al.*, 2002). *C. chlorideae* has been extensively studied as a potential biological control agent for *H. armigera* in China, Korea and India (Zheng and Lu, 1981; Dai, 1990; Nandihalli and Lee, 1995a, b; You *et al.*, 2002; Liu *et al.*, 2004; Pandey *et al.*, 2004). However, its interaction is very little known on *H. armiegra* infesting pigeonpea.

In India, *Trichogramma chilonis* Ishii is used in augmentative-release programmes aimed primarily for the control of the polyphagous pest, *H. armigera* which has a wide host range of 181 cultivated and wild species spread over 45 families (Manjunath *et al.*, 1989). It has been observed that parasitism levels on a specific host species vary widely, depending on the host plant on which the eggs are found (Keller *et al.*, 1985).

The egg parasitoids of the genus *Trichogramma* have been used successfully in other crop-pest-systems (Li, 1994; Romeis and Shanower, 1996). They were judged as promising control agents for integrated pest management of *H. armigera* in pigeonpea by Romeis *et al.* (1999a). Their main advantage over other natural enemies is their short generation time and the possibility for cost effective mass production (Li, 1994).

Several factors originating directly from the plant influence the parasitoid's ability to find its host. Price *et al.* (1980) mentioned (1) plant attractants like floral and extrafloral nectarines and various volatiles, (2) the position of the host on particular plant organs (some parasitoids prefer certain plant parts and avoid others), (3) plant structural refuges, protecting hosts from attack, and (4) plant surface structures, such as trichomes, which can hamper the searching parasitoid.

Pigeonpea has five types of trichomes. Types A and B are glandular and types C, D and E are non glandular. The trichome type A secretes a sticking exudate. Shanower *et al.* (1996) summarized the physiological properties of trichomes and mentioned the change of optical surface properties, the conservation of heat and moisture, the increase or decrease of plant transpiration rate and the alteration of herbivore and natural enemy load. As far as pest insects are concerned, the latter mechanism is based on one or combination of the following actions: (1) repellence of exudates, (2) limited contact with the surface, (3) entrapment (physical or chemical), (4) increase of the exposure time to biotic and abiotic factors, (5) inhibition of larval growth and (6) deterring of oviposition.

The presence of leaf hairs on pigeonpea might (1) increase the searching time of parasitoids, (2) entrapment the parasitoids and (3) repell the natural enemy due to the presence of volatile compounds (Shanower *et al.*, 1996).

The management of *H. armigera* with *Trichogramma* spp. on pigeonpea has certain problems:

1. Volatiles, produced by plants in the reproductive growth stage (the stage preferred for oviposition by *H. armigera*) are repellent to *T. chilonis* (Romeis *et al.*, 1997b) and probably to other *Trichogramma*tids.

2. Trichomes and trichome exudates on the surface of the reproductive plant organs inhibit the searching behaviour or trap the moving parasitoids.

3. Chemicals from the pod surface are deterrent to *T. chilonis* after contact (Romeis *et al.*, 1996a; 1998).

Price *et al.* (1980) and Bergman and Tingey (1979) have argued that theory on insect-plant interactions cannot progress without careful consideration of the third trophic level. Therefore, the present investigations have been undertaken to understand the tritrophic interactions involving the host plant, the insect and the natural enemies to give a fillip to bio-intensive integrated pest management.

1. Identification of pigeonpea genotypes that are hospitable to natural enemies, *Trichogramma chilonis* and *Campoletis chlorideae*.

2. Attractant / Repellent effect and influence of pigeonpea genotypes on *T. chilonis* and *C. chlorideae.*

3. Info-chemicals influencing parasitization of *H. armigera* eggs and larvae in pigeonpea.

2. REVIEW OF LITERATURE

The literature pertaining to interactions between pigeonpea genotypes, *Helicoverpa armigera* (Hubner) and natural enemies is very scanty, hence the literature pertaining to interaction between other crops, Lepidopteran pests and their natural enemies has been reviewed and the same is presented in the following pages.

Pigeonpea is grown extensively throughout the tropics, subtropics and warmer equatorial regions of Asia, East Africa and Central America between 30^{o} N to 35^{o} S latitude, particular in the semi-arid and lower humid tropics during the rainy season. The major production areas are located in India, Myanmar, Kenya, Malawi, Uganda and Tanzania. India alone occupies three-fourth of the global harvested area and contributes almost a similar share in total grain production. Globally, it is cultivated on 4.92 m ha with an annual production of 3.65 m t and productivity of 898 kg per ha (http://www.icrisat.org). Pigeonpea is the second most important pulse crop after chickpea in India. India has the largest acreage under pigeonpea (3.90 mha) with a total production and productivity of 2.89 m and 741 kg per ha, respectively (DAC, 2011). Pigeonpea is a monotypic species of *Cajanus*. In the revised taxonomic classification, 17 species of *Cajanus* are prevailing in the Indian subcontinent, 13 to Australia and one to Africa. India and Myanmar harbor eight species of *Cajanus*. *Cajanus cajanifolius* (Haines) van der Maesen found in the Indian subcontinent is generally considered the progenitor of pigeonpea (*Cajanus cajan* L. Millspaugh). The crop originated in India and moved to Africa about 4,000 years ago. It is the preferred pulse crop in dryland areas where it is intercropped or grown in mixed cropping systems with cereals or other short-duration annuals (Joshi *et al.*, 2001). Pigeonpea is known by more than 350 vernacular names, the most popular being *arhar, tur, Congo pea, gandul, guandu, Angola pea, yellow dhal, catjang pea, redgram, ambrevade, pois d'angdie, quinochoncho*. The connotation pigeon probably originated in America where its seeds reportedly were favored by pigeons.

2.1 Identification of pigeonpea genotypes that are hospitable to natural enemies, *T. chilonis* and *C. chlorideae*

The oviposition behaviour of spotted bollworm, *Earias vittella* Fab. was studied on 23 cotton genotypes under field and laboratory conditions. There were substantial differences in the number of eggs laid on different genotypes. More eggs were deposited on the bolls compared to leaves and squares. Leaf hairiness was significantly and positively correlated with number of eggs laid both under field and laboratory conditions. The effect of oviposition on varietal susceptibility appeared to be modified through other factors, such as gossypol and tannins (Sharma and Agarwal, 1983).

Kauffman and Kennedy (1989a) collected eggs of *Heliothis zea* (boddie) and *Heliothis virescens* (Fabricius) from field-grown tomato accessions varying in levels of glandular trichome-based resistance to *Manduca sexta* (Linnaeus) and *Leptinotarsa decemlineata* (Say). Parasitism of eggs by *Trichogramma pretiosum* Riley and *T. exiguum* Pinto & Platner was greatest on the tomato cultivar susceptible to *M. sexta* and was lowest on all back-cross lines (PI 134417 x PI 134417) and the highly resistant *Lycopersicon hirsutum f. glabratum* (PI 134417). Regression analyses indicated that trichome density accounted for the greatest proportion of variance in parasitism of eggs by *Trichogramma* spp. However, because the methyl ketones 2-tridecanone and 2-undecanone, which contribute to the insect resistance of PI 134417, occur in the glandular trichome tips, their effects on parasitism by *Trichogramma* could not be separated from the effects of trichome density. Egg density, canopy volume and number of stem terminals per plot were unrelated to the percentage parasitism by the *Trichogramma* species studied.

Field studies in Kenya showed that *Trichogramma sp. nr. mwanzai* Schulten and Feijen did not attack eggs of *Busseola fusca* Fuller which were laid underneath leaf sheaths (Lu, 1991).

Three genotypes of sorghum and a short-duration pigeonpea genotype were sown in the experimental plots during the post-rainy season of 1992-93 in Andhra Pradesh, India, to investigate the low levels of parasitism of eggs of *H. armigera* by *Trichogramma* on pigeonpea. Adults of *Trichogramma* were found in pigeonpea plots.

The parasitoid was more abundant on pigeonpeas when it flowered after sorghum than when it flowered simultaneously with sorghum. The results suggest that the failure of *Trichogramma* to parasitize eggs of *H. armigera* on pigeonpeas was not due to the failure of the adult parasitoids to enter pigeonpea fields, but due to another, yet unexplained, mechanism (Duffield, 1993). Peter *et al.* (1995) reported that there was negative correlation between the types of trichomes, their orientation, density and length with insect damage in pigeonpea

Parasitism of eggs of *Diatraea saccharalis* (Fabricius) by *Trichogramma galloi* Zucchi was studied on four sugarcane varieties, SP 701143, SP 716163, RB 72454 and RB 765418. Egg parasitism was affected by sugarcane variety, ranging from 32.0 per cent on RB 765418 to 60.5 per cent on SP 701143. Sugarcane height and leaf architecture has affected the parasitism (Botelho *et al.*, 1995).

In trials conducted during 1996-97 in Andhra Pradesh, India, releases of *T. chilonis* were found ineffective for control of *H. armigera* on pigeonpeas and chickpeas (Romeis *et al*., 1997).

The use of *Trichogramma maidis* Pint. et Voeg. for the biological control of *Ostrinia nubilalis* (Hubner) in six maize hybrids was studied at Turda, Romania, during 1993-94. *T. maidis* was released after artificial infestation of maize with European corn borer. Studies revealed that Turda 100, Betulisa and Elan were medium tolerant and Turda 200, Turda 213 and Turda 260 were tolerant to corn borer attack. On an average, *T. maidis* reduced the incidence of corn borer attack by 62.8 per cent in the medium tolerant hybrids and by 24.7 per cent in the tolerant hybrids. This resulted in significant increases in grain yield (18.8-20.0%) in the medium tolerant hybrids; however, increases in yield in tolerant hybrids were not significant (Muresan and Mustea, 1997).

Paron *et al.* (1998) conducted research to evaluate *Helicoverpa zea* egg parasitization by *Trichogramma* spp. on three different maize genotypes: BR 205 (normal yellow endosperm), BR 451 (white endosperm, high quality protein maize) and BR 400 (sweet yellow endosperm). The genotypes were planted in two ways: all genotypes planted on the same day (1st trial) and at one-week intervals: first BR 205, followed by BR 451 and BR 400. In both trials there was no effect of maize genotypes

on *H. zea* egg infestation or parasitism by *Trichogramma* spp. (average of 8.0 in the 1st and 1.8 eggs/ear in the 2nd trial). However, parasitism varied significantly among cultivars, being 62.4% in BR 451, 47.0 per cent in BR 205 and 34.1 per cent in BR 400.

The interaction between eight wild species of Gossypium and a cultivated cotton cultivar MCU 9, resistant to *H. armigera* and the pest's natural enemies were studied. Parasitization of *H. armigera* eggs by *T. chilonis* was lowest on *G. raimondii* (25.3%) and highest (57.3%) on *G. harknessii*. The rates of predation and parasitization were negatively associated with trichome density (Mohite and Uthamasamy, 1998).

Asifulla *et al.* (1998) conducted field experiment during 1995-96 in Karnataka under rainfed conditions to elicit the parasitisation of *T. chilonis* on bollworm, *H. armigera*, *Earias* spp. and *Pectinophora gossypiella* (Saunders) eggs in different cotton cultivars. Parasitisation was higher in glabrous cv. DCH 32 (23.80%) and BCS-23-48-7 (17.8%) compared with 3.5 per cent in Abadhitha, 6.3 per cent in NHH 44 (6.3%), 9.8 per cent in AK-235 and 11.3 per cent in Jayadhar.

On pigeonpea, *H. armigera* laid more than 74.8 per cent of its eggs on calyxes and pods. Parasitism levels in host eggs collected from different plant structures varied significantly with 3.6, 0.3 and 40.7 per cent of eggs on calyxes, pods and leaves, respectively. During one of five seasons studied, however, high parasitism levels (up to 73%) were recorded on pigeonpea. During this season, *H. armigera* oviposited on pigeonpea plants in the vegetative growth stage and a high proportion of eggs were collected from leaves. Parasitism levels were positively correlated with the percentage of eggs collected from leaves. This study shows that the parasitization efficiency of *Trichogramma* spp. on pigeonpea depends mainly on the location of the host eggs (Romeis *et al*., 1999a).

Studies on species of parasitoids present and the extent of parasitization on *H. armigera* in pigeonpea fields in India not sprayed with insecticides in 1997 showed that eggs and early stage larvae were parasitized by hymenopterans, whereas later instars were attacked by dipterans and pathogens. Up to 11.25 per cent parasitization was observed by *T. chilonis*. Early instars were mostly parasitized by *Campoletis chorideae* (11.87%), whereas later instars were parasitized by *Carcelia* sp. (10.0%) (Dayakar and Ray 1999).

Populations of *H. armigera*, *H. zea*, *Heliothis virescens*, *Manduca sexta* and *M. quinquemaculata* (Haworth) their egg and larval parasitoids were sampled by Farrar *et al.* (1994) in North Carolina in fields of insect-resistant wild tomato*, Lycopersicon hirsutum f. glabratum* (accession PI 134417); the insect-susceptible commercial tomato cultivar 'Better Boy'; an F1 hybrid and a selected, moderately resistant genotype. The densities of eggs and small larvae of *H. zea* and *H. virescens* were higher on resistant genotypes than on susceptible ones, but the densities of larger larvae were similar on all genotypes. The rates of egg parasitism by *Trichogramma* spp. and *Telenomus sphingis* (Ashmead) were lower on the insect-resistant genotypes. The rates of parasitism by the larval parasitoids *Campoletis sonorensis* (Cameron) and *Cotesia congregata* (Say) were also reduced on the resistant genotypes. Plant genotype had little effect on rates of parasitism by *Cotesia marginiventris* (Cresson) and no effect on the rates of parasitism by *Cardiochiles nigriceps* Viereck.

Two experiments were carried out in September 1997 in Minas Gerais, Brazil, using three tomato genotypes (TOM-556, HI-1 and PI 134417) with varying levels of 2-tridecanone (2-TD). Fifty eggs of *Tuta absoluta* (Meyrick) were placed on plants and the number of eggs parasitized by five female *T. pretiosum* Riley was determined after 24 h. The results showed that parasitism on TOM-556 (low level of 2-TD) was significantly higher than on HI-1 and PI 134417 (high levels of 2-TD) (Goncalves-Gervasio *et al.*, 2000).

Beserra *et al.* (2002) evaluated the oviposition behaviour of *Spodoptera frugiperda* (Smith) and natural parasitism of this pest by *Trichogramma* spp. at different phenological stages of maize in Piracicaba, Sao Paulo, Brazil, during March-July 1998 and 1999, October-December 1998 and February-April 2000. The distribution of *S. frugiperda* eggs varied according to the phenological stage of maize. The preferred site for oviposition was the lower region of the plant and the abaxial leaf surface during the early development of the crop (4-6 leaves), changing to the middle and upper regions of the plant and the adaxial leaf surface at subsequent stages (8-10 and 12-14 leaves). A larger number of eggs was collected at the 4 to 6 and 8 to 10 leaf stages compared to plants in the 12 to 14 leaf stage. Natural parasitism was low, with a

maximum of 2.21 per cent eggs parasitized, especially on the lower and middle parts of the plant. The distribution and degree of parasitism by *Trichogramma* spp. on different regions of the plant were independent of the developmental stage of the crop.

Singh *et al.* (2001), studied the parasitization efficiency of *T. chilonis* on *Corcyra cephalonica* eggs, on different cotton cultivars (F 846, F 1378, LD 327 and LH 1556). On each plant, 1000 eggs of *C. cephalonica* on tricho-cards were stapled, with 250 eggs per leaf. Two hundred adults of *T. chilonis* were released on a cage containing the tricho-card stapled plants of each cultivar. The cultivar LD 327 and F 846 had the highest parasitization among the cultivars, while LH 1556 had the lowest. LD 327 had less number of trichomes on leaves compared to the least preferred cultivar LH 1556.

Basit *et al.* (2001) placed the eggs of *Corcyra* on leaves (50 eggs per leaf) of ahu and sali rice cultivars (Govind, Annada, Jaya, Chilarai and Lachit; and Ranjit, Luit, Satyaranjan, Kushal, Monsaruber and Basundhara, respectively) for parasitization by *T. chilonis*. Among the 5 ahu cultivars, the highest mean percentage of parasitization (56%) was in Annada, while the lowest was in Chilarai (18%). Among the sali cultivars, Monsaruber had the highest parasitization (52.5%), while Basundhara had the lowest (7.5%).

Tiwari *et al.* (2002) conducted a study to determine the relative efficacy of *T. chilonis* on two different cultivars of chickpea (PG-97-10 and Avarodhi) to control *H. armigera* in Pantnagar, Uttar Pradesh, India. *T. chilonis* failed to parasitize the *H. armigera* eggs on the crop. Parasitism was almost negligible in both cultivars. Maximum parasitism of 3.3 per cent was observed in Avarodhi, when *T. chilonis* was released. It was concluded that egg parasitoid *T. chilonis* was not favourable to control *H. armigera* on chickpea, until and unless the cultivars, which lack oxalic acid and malic acid, are developed, so that *T. chilonis* population could sustain itself on the crop.

Dandale *et al.* (2002) conducted a field cage experiment in Akola, Maharashtra, India, during 1997-98 *kharif* season under rainfed condition to study the egg laying response of *H. armigera* on cotton (*Gossypium hirsutum*) cultivars with hairy (DHY-286) and non-hairy (PKV-Rajat) leaves and its parasitization by an egg parasitoid, *T. chilonis*. A higher (69.14%) egg parasitization by *T. chilonis* was observed

on DHY-286 than on PKV-Rajat (26.07%). Higher number of eggs were laid on the leaves (84.61%) than on the squares (15.39%). The percentage of parasitization of eggs by *T. chilonis* was higher on the eggs laid on the leaves (72.37 and 29.57% in DHY-286 and PKV-Rajat, respectively) than on the eggs found on the squares (39.39 and 13.04% in DHY-286 and PKV-Rajat, respectively).

The tritrophic interactions were assessed under net cage conditions among tomato cultivars L-15, PKM-1, Arka Vikas, Arka Sourabh, Arka Ashish, *H. armigera* and egg parasitoids (*T. chilonis* and *T. pretiosum*). Significantly lower oviposition by *H. armigera* was observed on local genotypes, L-15 and PKM-1, while the oviposition was higher on IIHR genotypes, *viz.*, Arka Sourabh, Arka Vikas and Arka Ashish. Irrespective of genotypes, *T. pretiosum* recorded higher parasitism than *T. chilonis*. Further, it was observed that as the trichome density increased there was an increase in oviposition by *H. armigera* and a decrease in parasitism by *Trichogramma* species (Karabhantanal and Kulkarni, 2002).

Walking speeds of both *T. brassicae* and *T. sibericum* were substantially lower on tomato than on pepper leaf disks. The difference may be due to the presence of glandular trichomes on tomato foliage. Total time spent on leaf disks during behavioural trials was lower on tomato than on pepper leaf disks for both species of wasps. The authors indicated that, this may be due to a higher propensity to disperse from tomato foliage than from pepper foliage. Lower walking speeds and shorter residence times on tomato leaves could result in a lower searching efficiency of wasps on tomato than on pepper (McGregor *et al.*, 2002).

The performance of three species of *Trichogramma*tids on *H. armigera* was evaluated in the laboratory and screenhouse conditions in Karnataka, India during 1996-97. Laboratory studies indicated that *T. chilonis* were more effective parasitoids of *H. armigera* than *T. brasiliense*. In screenhouse conditions, *T. chilonis* was the most effective parasitoid of *H. armigera* eggs on sunflower plants in comparison to the other two *Trichogramma*tid species. When 50 000 parasitoids were released per ha on sunflower and red gram, *T. chilonis* parasitized 50.1 and 11.4 per cent, respectively. The position of *H. armigera* eggs on different plant parts of sunflower had no effect on parasitism by *T. chilonis*. Parasitism by *T. chilonis* and *T. pretiosum* on *H. armigera*

eggs laid on different plant parts of red gram varied significantly. It parasitized 43.4 and 18.7 per cent *H. armigera* eggs on leaves and flowers, respectively and significantly lower (3.9%), on pods. The growth stage of red gram plants also had an effect on parasitism by *T. chilonis*, parasitism being extremely low on plants with pods (Ballal and Singh, 2003).

Tandon and Bakthavatsalam (2003) conducted three experiments on tritrophic interaction between *T. chilonis*, *H. armigera* and 21 pigeonpea genotypes in pots under polyhouse conditions. The first and second experiments were conducted on 11 genotypes grown in pots. In the third experiment, 10 new genotypes were evaluated. In the first experiment, the extent of egg parasitization on pods in different cultivars/genotypes varied from 1.25 to 8.25 per cent Parasitization of *H. armigera* eggs by *T. chilonis* was highest on ICPL-84060 (8.25%) and lowest on ICPL-151 (1.25%), which was at par with ICPL-87119 (2.75%). Plant resistance did not affect the extent of parasitization of *H. armigera* eggs by *T. chilonis* on different genotypes. Among the three genotypes resistant to pod borer (ICPL-84060, PPE-45-2 and ICPL-87089), parasitization was highest on the first and second and was lowest on the third. In the second experiment, parasitization of *H. armigera* eggs on leaves of different genotypes varied from 5.0 to 29.0 per cent Parasitization was highest on ICPL-84060 leaves (29%) and lowest on ICPL-87, ICPL-87089, ICPL-87119 and ICPL-151 leaves (6.5, 5.5, 5.0 and 5.0%, respectively). Parasitization of *H. armigera* eggs was generally higher on leaves than on pods. However, parasitization trend on different genotypes was similar to the first experiment. Overall, mean parasitization on leaves and pods varied from 3.12 to 18.62 per cent. In the third experiment, parasitization of *H. armigera* ranged between 8.88 and 14.44 per cent. Parasitization was highest on ACT-2 (M) AVT2 (14.44%) and lowest on PB/98-V6 and PB/98-V19 (both 8.88%).

Gupta and Desh Raj (2003) observed that the *H. armigera* larvae on chickpea were parasitized by *Apanteles* sp., *Diadegma fenestralis* (Holngren) and *Campoletis chlorideae* at Palampur, Himachal Pradesh, India, during two consecutive years (1997-98 and 1998-99). Among these, parasitization by the former two parasitoids remained negligible. However, the extent of parasitism by *C. chlorideae* ranged from 8.33 to 28.00 per cent.

Kaur *et al.* (2004) studied the extent of natural parasitism of *H. armigera* by *C. chlorideae* on chickpea cultivars L 550, BG 1053, PBG 1, PBG 5 and PDG 4 at different locations in Jalandhar district of Punjab, India during 2002-03. The parasitoid population varied from 0.02-1.50 cocoons per metre row length and the larval population ranged between 0.86 and 14.50 larvae per metre row length. The highest number of cocoons were recorded on PBG 5 (0.88) followed by L 550 (0.74). The *H. armigera* population was also high on PBG 5 (9.38 larvae/m row length) followed by L 550 (6.75 larvae/m row length).

The parasitoids, *Trichogramma dendrolimi* Matsumura and *T. chilonis* parasitized significantly more host eggs on lower than on upper and bottom leaves and a higher proportion of host eggs on the upper leaf surface than on the lower leaf surface regardless of plant height, which contrasted to egg deposition by *H. assulta*. On pepper plants, parasitism by *T. dendrolimi* and *T. chilonis* was 31.1 and 32.8 per cent, respectively, while on tobacco plants, it was 10.6 and 1.1 per cent, respectively (Hou *et al.*, 2006).

Antixenosis for oviposition was observed in case of ICPL 187-1, ICP 7203-1, ICPL 88039, T 21, ICPL 84060 and ICPL 332 under no-choice, dual-choice and multi-choice conditions. However, the number of eggs laid on ICPL 88039, T 21 and ICP 7203-1 did not differ significantly from those on ICPL 87 under dual-choice conditions. The susceptible check, ICPL 87 was highly preferred for oviposition by *H. armigera* (Kumari *et al.*, 2006).

Olson and Andow (2007) observed and recorded the walking pattern of *T. nubilale* females on leaves of *Zea mays*, Canna lilly, *Silphium perfoliatum* (cup plant), *Abutilon theophrasti* (velvetleaf), *Schizachyruim scoparium* (little bluestem), a smooth and a fuzzy polyester material and waxed paper. Females walked fastest on waxed paper and leaves of *S. scoparium* and slowest on leaves of *A. theophrasti* and the fuzzy material. Turning rates were high on Canna lilly and waxed paper. In general, walking speed was retarded by the presence and density of trichomes and possibly the lack of leaf veins. The effect of surface structures, such as trichomes is likely to scale to the body size of the searching parasitoid. Parasitoids can walk over short trichomes, but short directionally pointed trichomes (as on *S. scoparium*) can guide the search paths in

certain directions. The effects of long trichomes may depend on trichome density relative to the parasitoid body length. When trichome density is on the same order of magnitude as 1/L2 (*Z. mays*), wasps will stand between trichomes and will frequently run into trichomes, which will retard walking speeds and increase turning.

The accessions ICPW 1 (*Cajanus acutifolius* (Benth.)), ICPW 13 and 14 ((*C. albicans* (Benth.)), ICPW 159 and 160 ((*C. sericeus* (Benth. Ex Baker)), ICPW 68 ((*C. platycarpus* (Benth.)), ICPW 83, 90, 94, 125, 137, 141 and 280 ((*C. scarabaeoides* (L.)), ICPW 207 ((*Paracalyx scariosa* (Roxb.)) and ICPW 210 (*Rhynchosia aurea*) showed high levels of antixenosis for oviposition by *H. armigera* under no-choice, dual-choice and multi-choice conditions. High levels of antibiosis were observed when the larvae were reared on leaves and/or pods of *C. acutifolius* (ICPW 1), *C. cajanifolius* (ICPW 29), *C. sericeus* (ICPW 160), *P. scariosa* (ICPW 207), *C. scarabaeoides* and *C. albicans* (Wight & Arn) (Sujana *et al.*, 2008).

Gundannavar and Giraddi (2008) carried out studies at Dharwad, Karnataka to work out the relationships among chilli (*Capsicum annuum* L.) cultivars, the fruit borer, *H. armigera* and its egg-parasitoids, *Trichogramma* spp. Among the chilli cultivars, Byadagi kaddi was the preferred host for oviposition by *H. armigera* as well as the egg-parasitoids, as evidenced by higher egg counts and parasitisation by all the four species of *Trichogramma* included in the study. Whereas, the cultivar Tejashwini, was the least preferred as it hindered oviposition by *H. armigera*, probably due to presence of highest trichome density among the test cultivars. Similarly, all the four species of *Trichogramma* also parasitized lesser number of eggs of *H. armigera* laid on this cultivar.

Andrade *et al.* (2009) evaluated the parasitism of *H. virescens* eggs on leaves of commercial cultivars of white (BRS 8H) and colored (BRS Safira) cotton fibers, by *T. exiguum*, *T. pretiosum* and *T. atopovirilia*. The parasitism rate was higher on BRS 8H cotton with better parasitism of *T. atopovirilia* and *T. exiguum*, followed by *T. pretiosum*. *T. atopovirilia* achieved better results on both cotton cultivars, differing from *T. pretiosum* and indicated that the performance of these species can be affected by cultivars. The results suggest that differences between plants are the causes of variation in the results of *Trichogramma* parasitism in the same culture.

Costa *et al.* (2010) studied the natural egg parasitism of *Alabama argillacea* (Hubner) (Lepidoptera: Noctuidae) by *T. pretiosum* in different phenological stages of transgenic and conventional varieties of cotton (*Gossypium hirsutum* L.) in the region of Ipameri, GO. The level of parasitism of eggs of *A. argillacea* by *T. pretiosum* varied depending on the density of eggs on plants, not in terms of varieties and phenological stages.

Parasitization rates by *T. minutum* and *T. pretiosum* on three cotton cultivars were higher on the upper and lower leaves than on the middle leaves. Morphological traits, *i.e.* presence of black glands or trichome densities of the cotton cultivars played a significant role. The parasitization rates on cultivars with glands and lower trichome density were higher than with no glands and high trichome density. Moreover, GC-MS analysis revealed that volatiles and the phytosterol composition of leaves were significantly different for cotton cultivars. These chemical traits of host plants are considered in relation to *Trichogramma* behaviour (El-Wakeil, 2011).

2.2 Attractant / Repellent effect and influence of pigeonpea genotypes on *T. chilonis* and *C. chlorideae*

Kauffman and Kennedy (1989b) found that plants of five tomato lines varying in their level of 2-tridecanone-mediated resistance to the sphingid *Manduca sexta* and the chrysomelid *L. decemlineata*, to adversely affect larvae of the ichneumonid parasitoid *C. sonorensis* in a manner directly related to their level of resistance. There was high mortality of 5^{th} -instar parasitoid larvae during cocoon spinning on resistant foliage. Mortality was greatest (82%) on resistant plants of *Lycopersicon hirsutum f. glabratum* (accession PI 134417) and in F1 backcross. Mortality was intermediate (40 and 28%) on backcross selections with moderate and low levels of resistance and lowest (8%) on susceptible tomatoes. Removal of the glandular trichomes, which contain 2-tridecanone, eliminated differences in parasitoid mortality among plant lines. Bioassays with 2-tridecanone indicated that it is acutely toxic to 5^{th} -instar larvae of *C. sonorensis* at the quantities associated with highly resistant foliage and produces symptoms identical to those associated with resistant foliage. 2-Undecanone was also toxic to parasitoid larvae, but less than 2-tridecanone.

Kaiser *et al.* (1989) studied the responses of naive and experienced females of *T. maidis* to odours from host eggs, the sex pheromone of the pyralid *O. nubilalis* and maize extract, singly or in combination, in a 4-armed olfactometer. While naive individuals did not respond to odours from host eggs, the synthetic pheromone or maize extract presented singly, they did respond to a mixture of these cues. Prior oviposition in the odour of maize extract or in the combination of odours increased preference for the conditioning scent. This phenomenon did not occur when parasitoids were conditioned to egg odour or sex pheromone alone. It was suggested that female parasitoids can learn to associate some olfactory cues with the presence of the host. Immediately following the presentation of the combination of odours, a strong attraction of experienced wasps occurred; this decreased during the experiment to the level observed in naive insects. Adult conditioning to the combination of odours also resulted in reduced variability in the behavioural responses.

Several factors originating directly from the plant influence the parasitoid's ability to find its host. Price *et al.* (1980) mentioned (1) plant attractants like floral and extrafloral nectarines and various volatiles (2) the position of the host on particular plant organs (some parasitoids prefer certain plant parts and avoid others) (3) plant structural refuges, protecting hosts from attack and (4) plant surface structures, such as trichomes, which can hamper the searching parasitoid. Andow and Prokrym (1990) related all these factors to the 'structural heterogeneity' of plants. They suggest three major plant surface factors that are important for searching parasitoids: (1) plant size or surface area (2) the variation among plant parts ('structural heterogeneity'), like flowers, seeds and leaves with heterogeneous surfaces (e.g. absence or presence of trichomes) and (3) plant form or the connectivity of plant parts ('structural complexity'), which is the particular way in which the plant surface area is connected together. The authors demonstrated that structural complexity of the plant surface greatly influences the host finding.

Sathe and Santhakumar (1990), investigated the factors responsible for host-finding behaviour in *C. chlorideae* in the laboratory. When female parasitoids were presented with the leaves of different food plants of their host (pigeonpea, chickpea, tomato, lady's finger, cauliflower and cabbage), the maximum searching period was on pigeonpea (mean of 96 s) and the minimum on cabbage (54 s). Females would also perform searching behaviour and some performed stabbing intention movements,

when presented with the leaves, flower buds and pods of pigeonpea damaged by 2nd -instar larvae of *H. armigera*. Intact host larvae, host larval saliva, larval faeces and ether extracts of host larvae also elicited searching movements followed by stabbing intention movements. No stabbing intention movements were performed on healthy parts of pigeonpea plants. Further experiments indicated that it was the odour of the plant and host that was mainly responsible for stimulating the females to perform searching followed by stabbing intention movements. It is concluded that the factors responsible for host finding by *C. chlorideae* are olfactory rather than visual.

The glandular trichome/methyl ketone-mediated insect resistance of wild tomato, *Lycopersicon hirsutum f. glabratum* accession PI 134417, to *Manduca sexta* and *L. decemlineata* was shown to adversely affect the *T. pretiosum*. Adult *T. pretiosum* were killed by direct contact with PI 134417 foliage and by exposure to its volatiles. This effect was greatly reduced or eliminated by removing the exudate of the glandular trichomes from the foliage. 2-tridecanone, a principal constituent of the foliar glandular trichomes of PI 134417, was toxic to adult *T. pretiosum* at concentration similar to those associated with PI 134417 foliage. The incubation of parasitized eggs of *H. zea* on PI 134417 foliage or 2-tridecanone-treated filter paper significantly reduced the proportion of eggs producing adult parasitoids. Similarly, the incubation of parasitized eggs of *H. zea* on filter paper treated with 2-undecanone, another constituent of the glandular trichomes of PI 134417, caused an increase in the percentage of host eggs containing dead parasitoid pupae (Kashyap *et al.*, 1991).

Vinson *et al.* (1994) investigated chemicals responsible for the attraction of *C. sonorensis* to tobacco and demonstrated that this parasitoid responds to a series of sesquiterpenes present in cotton and also to at least 2 compounds present in tobacco but not cotton, nicotine and farnesyl acetone. It was suggested that *C. sonorensis* does not only respond to a certain blend of chemical odours, but also to a group of compounds any number of which may be present in a particular plant.

Nandihalli and Lee (1995a) studied the effect of food plants (tobacco, red pepper [Capsicum] and artificial diet) on the development of *Helicoverpa assulta* (Guenée) and the results revealed no significant effect. However, tobacco increased fecundity (671 eggs) significantly more than Capsicum (505 eggs) and artificial diet

(423 eggs). Different tobacco varieties used as larval food exerted an influence on the biology of *H. assulta*. Among four tobacco varieties, KF-109 and NC-744 favoured development with a higher fecundity than NC-82 and Burley-21. The results on the effect of larval food on the ichneumonid parasitoid, *C. chlorideae* indicated that the total developmental period was significantly longer (15.9 days) with less survival of eggs and larvae (71.4%) when host larvae fed on Capsicum compared to tobacco or the artificial diet. Adult parasitoid emergence was not influenced greatly by host larval food.

Wang *et al.* (1997) studied the effects of gossypol on the growth of *H. armigera* and development of its endoparasitoid *C. chlorideae* and observed that the growth of *H. armigera* larvae was accelerated by adding 0.1 per cent gossypol to artificial diet, causing a 10.75 per cent reduction of the vulnerable period to *C. chlorideae*. Addition of 0.5 per cent gossypol to the diet prolonged the period when larvae of *H. armigera* were vulnerable to the parasitoid by 28.15 per cent. Negative effects of gossypol on the development of the parasitoid were demonstrated using artificial diet and cotton varieties WD-151 (glandless) and HG-BR-8 (glanded). Gossypol at 0.1 per cent concentration in artificial diet did not increase the body weight of adult parasitoids, but significantly extended the egg-larval time and shortened the pupal time. Gossypol at 0.5 per cent and HG-BR-8 reduced the body weight of adults, significantly prolonged the egg-larval period and decreased the pupal period.

Cruz *et al.* (1997) evaluated parasitism by *Campoletis flavicincta* (Ashmead) on larvae of *S. frugiperda* of different ages and foliar consumption by parasitized and unparasitized larvae in the laboratory at 25 ^{o}C, LD 12:12 and 70±10% RH. Healthy 6-day-old larvae consumed 209.3 cm^2 of maize leaves in 24 h, while larvae which had been parasitized three days earlier consumed 14.5 cm^2.

Boo and Yang (1998) studied olfactory attraction of *T. chilonis*, to the hot pepper (*Capsicum annuum*) and other host plants of its host insect species, *H. assulta*, in laboratory experiments. *T. chilonis* was attracted more to the hot pepper than tobacco (*Nicotiana tabacum* L.), eggplants (*Solanum melongena* L.), carrots (*Daucus carota* L.) or clean air flow. *T. chilonis* attraction was greater for pepper plants with both leaves and green fruits rather than plants with only leaves or fruits; plants with red fruits were least attractive to the parasitoid.

Silva (1998) studied the effect of the extract of *Amaranthus viridis* L. on the parasitic behaviour of *Trichogramma* spp. under laboratory and field conditions in Paraiba, Brazil, in 1997 and 1998. The average percentage of parasitized eggs in the treatments sprayed with extract of *A. viridis* was significantly higher than in the treatments sprayed with water. The total number of parasitoids found in the olfactometer was of 42,563 of which 19,209 parasitoids were found in the treatment sprayed with extract of *A. viridis* and 15,642 found in the control. About 7,712 wasps were found in the liberation container.

Plant characters responsible for the absence of egg parasitoids and the feasibility of increasing parasitism levels on chickpeas by mass-releasing *T. chilonis* were investigated by the Romeis *et al*. (1999b). The residence time of female *T. chilonis* on chickpea leaves was affected by trichomes and the acidic trichome exudates secreted on all green parts of the plant. Parasitoids spent longer time on chickpea leaves where the acidic trichome exudates had been washed off than on unwashed leaves and longer on leaves of a glabrous chickpea mutant than on washed leaves. When placed on unwashed chickpea leaves, 6.8 per cent of parasitoids were trapped and killed by the exudates. In a filter paper bioassay, female *T. chilonis* were deterred by high concentrations of malic and oxalic acids, the major components of the trichome exudate. Acetone and hexane extracts from the surface of chickpea leaves did not elicit a response from the parasitoids in the bioassay. Similarly, the parasitoids did not respond to volatiles emitted by chickpea plants in a four-armed air-flow olfactometer.

Bioassays using aqueous extracts of eight plants (sorghum, maize, sugarcane, pigeonpea, cotton, tomato, chickpea and marigold) were carried out by Madhu *et al.* (2000) in Petri dishes to observe their synomonal effect on parasitism by *T. brasiliense* and *T. japonicum*. Plant extracts were subjected to gas chromatography (GC) studies to identify the synomones present. Pigeonpea extract elicited the maximum response from both parasitoids. Marigold extract elicited a higher response from *T. brasiliense* whereas sorghum and cotton elicited a good response from *T. japonicum*. The response of parasitoids was lower to maize, sugarcane and tomato extracts compared to pigeonpea. Chickpea extract recorded the lowest response. Gas chromatography indicated the presence of nonadecane in sorghum in very small quantities. Maize and sugarcane did not contain any hydrocarbon which matched the standards. The presence of tricosane

was suggested in pigeonpea, hexadecane and octacosane in marigold and pentadecane in cotton. A GC of tomato indicated the presence of octacosane. Chickpea recorded a number of peaks but none matched the standards.

Murugan *et al.* (2000) tested the hypothesis that the quality of host plant parts determines the nutritional quality of herbivorous insects feeding on it to their parasitoids. A *Gossipium hirsutum-H. armigera-C. chlorideae* tritrophic system was evaluated. The superior nutritional quality of bolls and young leaves of *G. hirsutum* (MCU-5 variety) contributed to more efficient feeding, growth and reproduction of the bollworm, *H. armigera* and better survival of its larval parasitoid, *C. chlorideae*. Longer total developmental duration and decrease in adult longevity were observed in *H. armigera* reared on senescent leaves than in those reared on bolls. Consumption, growth rate and efficiency measures were significantly lower in parasitised *H. armigera* larvae than in unparasitised larvae. Percentage parasitism was highest (84.1%) in *H. armigera* fed on bolls. The parasitoid *C. chlorideae* displayed shorter developmental duration and improved survival on *H. armigera* fed on bolls.

Ganesh *et al.* (2002) investigated the effect of eleven different species of cruciferous plants on the parasitic behaviour of *T. chilonis*, *T. japonicum* and *T. poliae*. Cleaned eggs of *Corcyra cephalonica* were pasted onto cards and sprayed with acetone leaf extracts of the chosen cruciferous species. Female wasps (20 per card) were then allowed to parasitize the treated eggs (100 eggs per card) for 24 hours. Each species responded differently to the chemicals in the different extracts; *T. chilonis* had the highest mean egg parasitization (70.0%) on Indian mustard treated cards and the lowest (23.7%) on ornamental rai.

Flight cage experiments showed that the adults of *Trichogramma carverae* Oatman and Pinto benefited from alyssum (*Lobularia maritima* L.) bearing white flowers to a greater extent than light pink, dark pink or purple flowered cultivars, despite all cultivars producing nectar. Flower colour appeared to be a critical factor in the choice of plants used to enhance biocontrol and was likely also to be a factor in the role parasitoids play in structuring invertebrate communities (Begum *et al.*, 2004).

Gupta *et al.* (2004) conducted laboratory and field studies to gain new understanding of the biology and biological control potential of *C. chlorideae* on *H. armigera*. In the field experiment, conducted in Palampur, Himachal Pradesh, adult parasitoids were collected from the nearby chickpea fields and were brought to the laboratory for rearing. The parasitoid laid an average of 13.40 and 42.00 eggs after single mating and throughout its life span, respectively. The egg-larval and pupal period was 13.5 and 7.0 days, respectively. The emergence rate varied from 78.3 to 85.2 per cent. The sex ratio of male:female in mated progeny was 1:3.15±0.62. Adult longevity increased when provided with food source.

Shanmugam *et al.* (2005) investigated the synomonic effect of leaf, flower and square extracts of cotton (*Gossypium hirsutum*), as well as leaf extracts of tomato, pigeonpea, chickpea and *Lagascea mollis* Cav., each at 0.01, 0.05, 0.10, 0.50, 1.0 and 2.0 per cent, on the parasitization of *Corcyra* eggs by *T. chilonis*. Among the treatments, the cotton leaf extract at 0.5 per cent and tomato leaf extract at 2.0 per cent increased the parasitization by 84.57 and 88.75 per cent, respectively. The pigeonpea, chickpea and *L. mollis* leaf extracts did not show any increase in the parasitization. The cotton flower extract at various concentrations increased the parasitism between 78.99 and 83.00 per cent over the control, which is valuable to synchronize the *T. chilonis* release with the oviposition by bollworms at peak flowering stage to get maximum benefit.

Dhillon and Sharma (2007) studied the tritrophic interactions of *C. chlorideae* involving eight insect host species and six host crops under laboratory conditions. The recovery of *H. armigera* larvae following release was greater on pigeonpea and chickpea compared to cotton, groundnut and pearl millet. The parasitism by *C. chlorideae* females was least with reduction in cocoon formation and adult emergence on *H. armigera* larvae released on chickpea. Host insects also had significant effect on the development and survival of *C. chlorideae*. The larval period of *C. chlorideae* was prolonged by two-three days on *Spodoptera exigua* (Hubner), *Mythimna separata* (Haworth) and *Achaea janata* Fabricius when compared with *H. armigera*, *H. assulta* and *S. litura*. Maximum cocoon formation and adult emergence were recorded on *H. armigera* (82.4% and 70.5%, respectively) than other insect hosts.

Ishtiyaq and Shaw (2008) tested the response of *T. japonicum* to bioactive plant extracts of easily available plants against *Scripophaga incertulas* (Walker). In free choice conditions at Raipur (Chhattisgarh agro-ecosystem), there was continuous increment in parasitization by *T. japanicum* for up to 15 days. Parasitization by *T. japanicum* was enhanced significantly in *Tagetes erecta* (Marigold) treated plots (48.5%) followed by *Ocimum sanctum* (Tulsi) (42.6%) and was minimum in *Azadirachta indica* (Neem) treated plots (18.8%).

2.3 Info-chemicals influencing parasitization of *H. armigera* eggs and larvae in pigeonpea

Romeis *et al*. (1997b) conducted test whether volatile plant infochemicals contribute to the different parasitism levels on *H. armigera* by *T. chilonis* observed on sorghum and pigeonpea. In a four-armed airflow olfactometer, volatiles emitted by pigeonpea plants elicited a behavioral response from *T. chilonis* females. The response of the parasitoids varied depending on the growth stage of the plant. *T. chilonis* females did not respond to volatiles from pigeonpea in the vegetative stage, but were repelled by volatiles from plants in the reproductive stage. Plants in the reproductive stage were preferred for oviposition by *H. armigera*. Thus, pigeonpea is repellent to *T. chilonis* females at the time when the plant is attractive to the host.

Romeis and Zebitz (1998) studied the plant characters contributing to low *H. armigera* egg parasitism levels on pigeonpea and showed that the efficiency of *T. chilonis* on pigeonpea was dependent on the plant structure on which the host eggs were found. In a cage experiment, more than 55 per cent of eggs placed on leaves were parasitized, while 1 per cent of eggs on calyces and no eggs on pods were parasitized. In a filter paper bioassay, parasitoids were deterred by acetone and hexane surface extracts from pigeonpea pods but showed no response to water extract. The searching behaviour of the parasitoids was not affected by different solvent extracts from the surface of pigeonpea leaves. In a four-armed airflow olfactometer, *T. chilonis* was repelled by volatiles from pigeonpea pods but showed no response to volatiles derived from hexane extract of pod surfaces. Volatile infochemicals and hexane surface extracts from pods of two wild *Cajanus* species, *C. scarabaeoides* and *C. platycarpus,* were similarly deterrent to *T. chilonis*. The movement of the parasitoids on pigeonpea pods

and calyx was inhibited by long trichomes and wasps were trapped by sticky trichome exudates. Parasitoids walked significantly faster on leaves than on pods. The walking speed on both pods and leaves increased significantly after washing with hexane. The results showed that the plant growth stage and the plant structures preferred by *H. armigera* for oviposition are least suitable for *T. chilonis*, contributing to the low parasitoid efficiency on pigeonpea.

Tao *et al.* (2000) tested extracts from fresh cotton leaves, leaves damaged by cotton bollworm (*H. amigera*). Comparative tests of washed and unwashed cotton bollworm eggs showed that *T. chilonis* had a parasitism of 43.5 per cent in the unwashed eggs and 13.3 per cent in the washed eggs.

Gouinguene *et al.* (2005) recorded the antennal perception by three parasitoids (*Cotesia marginiventris* (Cresson), *Microplitis rufiventris* Kok. and *C. sonorensis*) to volatiles emitted by maize, cowpea and cotton plants after attack by the common caterpillar pest *Spodoptera littoralis*. Gas chromatography-electroantennography (GC-EAG) recordings showed that wasps responded to many, but not all, of the compounds present at the physiologically relevant levels tested. Interestingly, some minor compounds, still unidentified, elicited strong responses from the wasps. These results indicated that wasps were able to detect many odorant compounds released by the plants.

Sen *et al.* (2005) reported that the largest peak amplitudes of EAG in females of *T. chilonis* were obtained with citronellal, phytol, caryophyllene, R-(+)-limonene, linalool, carvacrol and citronellol while in males citronellol, caryophyllene, R-(+)-limonene and amyl acetate caused the highest response.

Yan and Wang (2006) showed that the maize volatiles induced by feeding damage of *M. separata* were found to be attractive to *C. chlorideae* in a Y-tube olfactometer. Eleven compounds were released in significant amounts from *M. separate* infested maize seedlings, of which five compounds (Z)-3-hexen-1-ol (Z)-3-hexenyl acetate (E)-2-hexenal, linalool and phenylethyl acetate were chosen for electrophysiological and behavioural tests. All five compounds elicited electroantennogram responses in *C. chlorideae*. However, only pure (Z)-3-hexenyl acetate and linalool were attractive to the parasitoid in the Y-tube. Interestingly, linalool

was also attractive to starved parasitoids over a range of doses tested. These results suggested that (Z)-3-hexenyl acetate and linalool may be key infochemicals in the host-foraging behaviour of *C. chlorideae* and linalool may act as a food source signal for the parasitoid.

Yan and Wang (2006) investigated the attractiveness of *H. armigera* and *Pseudaletia separata* Walker infested maize plants to *C. chlorideae* and analysed the volatiles emitted from infested plants and undamaged plants. In wind-tunnel bioassays, *C. chlorideae* was strongly attracted to herbivore-induced maize volatiles. Mechanically damaged plants, whether they were treated with caterpillar regurgitant or water, were more attractive to the parasitoid than undamaged plants. Coupled gas chromatography-mass spectrometer (GC-MS) analysis revealed that 15 compounds were commonly emitted by herbivore-infested and mechanically damaged maize plants, whereas only two compounds were released in minor amounts from undamaged plants. Infestation by *H. armigera* specifically induced four terpenoids, ß -pinene, ß -myrcene, D-limonene and (E)-nerolidol, which were not induced by infestation of *P. separata* and mechanical damage, plus caterpillar regurgitant or water. Two compounds, geranyl acetate and beta -sesquiphellandrene, were also induced by the infestation of *H. armigera*, but not by the infestation of *P. separata*. All treated maize plants released volatiles in significantly larger amounts than did the undamaged plants. Maize plants infested by *H. armigera* emitted greater amounts of volatiles than plants infested by *P. separata*.

Yan *et al.* (2006) investigated the electroantennogram (EAG) responses of the generalist parasitoid *C. chlorideae* to a range of plant volatiles and host pheromones and showed that the EAG responses were most pronounced for the C5-C7 alcohols, then declined as the carbon chain-length of compounds increased or decreased. Aliphatic aldehydes, acetones, acids and esters also triggered significant EAG responses. All monoterpene hydrocarbons elicited low EAG response, while the oxygenated monoterpenes elicited relatively high responses. Three aromatic compounds elicited significant EAG responses. Compounds that showed significant EAG responses at 100 µg elicited a rate-dependent EAG response, while alpha -pinene and (E)-caryophyllene elicited slight responses at all rates. The host pheromones elicited significant EAG responses at 100 and 1000 µg. Following exposure to 100 and 1000 µg of host pheromones, the male parasitoids showed responses that were more pronounced (by 2-fold) than the female.

Fatouros *et al.* (2007) investigated the effect of cues present on Brussels sprout plants infested by *Pieres brassicae* (L.) eggs on the behavioral response of the *T. chilonis* The parasitoid was arrested on leaf parts next to 1-day-old host egg masses. This arrestment was due to cues deposited during oviposition. The wasps parasitized host eggs up to three days old equally well showing that *T. evanescens* makes less use of infochemicals from *P. brassicae* than *T. brassicae*.

The olfactory behaviour of *T. dendrolimi* to nine pine needle volatiles were investigated with Y-tube olfactometer, four volatiles identified could affect the olfactory behavior of *T. dendrolimi*, they were alpha -pinene, beta -pinene, limonene and alpha -terpineol acetate, but it should be noted that alpha -pinene and beta -pinene have a most significant effect. Bioassays to parasitic behaviour of *T. dendrolimi* were conducted in laboratory, mixing different compounds by these four or three volatiles to compare single components to investigate the percentage of parasitism, the results showed that both of them could affect the percentage of parasitism significantly and this result was also same as the conclusion of olfactory behavior experiment basically. However, compounds did not cause highest percentage of parasitism compared single components, this suggested that some single components play a dominant role in parasitic behavior of *T. dendrolimi* (Wang *et al.*, 2008).

Yu *et al.* (2008) tested seven synthetic herbivore-induced plant volatiles (HIPVs) and a mixture of nonanal+(Z)-3-hexen-1-ol for their ability to attract beneficial insects in an open cotton field. Eleven species of the main natural enemies of insect pests in cotton fields were studied. Results revealed that the parasitic wasp *C. chlorideae* did not respond to any of the HIPVs tested.

Milonas *et al.* (2009a) showed that three different *Trichogramma* species were attracted to the synthetic sex pheromone of the olive pest *Prays oleae* (Bern) (Lepidoptera: Yponomeutidae). Bioassays with *Trichogramma bourarachae* Pintureau & Babault wasps showed a positive response of the parasitoids to three concentrations of the host pheromone.

The effect of the sex pheromone components of the lepidopteran olive pests *P. oleae* and *Palpita unionalis* (Hübner) (Lepidoptera: Pyralidae) was studied under laboratory conditions, on the foraging behaviour of the egg parasitoid *Trichogramma*

oleae. The response of *T. oleae* wasps to (Z)-7-tetradecenal and (E)-11-hexadecenal, major sex pheromone components of *P. oleae* and *P. unionalis* respectively, depended on the dose of the pheromone used in a Y-tube olfactometer bioassay. (E)-11-hexadecenal elicited maximum attraction (70%) at a dose of 1 µg, while a dose of 100 µg (Z)-7-tetradecenal attracted 80% of the tested wasps. (E)-11-hexadecenyl acetate, the second sex pheromone component of *P. unionalis* and the binary blend of (E)-11-hexadecenyl acetate: (E)-11-hexadecenal (7:3) were not attractive at these doses (Milonas *et al.*, 2009b).

The parasitoids *Trichogrammatoidea bactrae* Nagaraja and *Trichogramma confusum* Viggiani are potential biological control agents for the diamondback moth, *Plutella xylostella* (L.). In the olfactory response of two parasitoids to saturated hydrocarbons from host egg shells and adult scales of *P. xylostella* measured using a Y-tube olfactometer indicated that the percentages of mated females of *T. bactrae* entering the treatment arms of 2,6,10,14-tetramethyl-pentadecane, pentadecane and heptadecane were 80.65, 68.75 and 66.67 per cent, respectively, significantly higher than those entering the control arms, suggested that these three compounds could stimulate an intensive search behaviour by *T. bactrae*. However, the parasitoid did not respond to other 10 hydrocarbons. The percentages of mated females of *T. confusum* entering the treatment arms of 2,6,10,14-tetramethyl-pentadecane, pentatriacontane and pentadecane were 84.38, 70 and 62.16 per cent, respectively, significantly higher than those entering the control arms, revealing that *T. confusum* were significantly attracted by those three compounds. While the numbers of *T. confusum* entering the treatment and control areas had no differences in the tests with other 10 hydrocarbons (Lu *et al.*, 2010).

The behavioural responses of *T. ostriniae* to plant volatiles emitted from whole plants, leaves and flowers of prostrate and erect varieties of mungbean in a 4-armed olfactometer revealed that the female parasitiods were significantly attracted to the odours from some varieties of prostrate mungbean when the visit duration and the number of visits were considered, but were not attracted to the odours from any erect varieties. The attractive odours were shown to emanate from the leaves, rather than from the flowers of prostrate mungbean plants (Bai *et al.*, 2011).

3. MATERIAL AND METHODS

Studies on pigeonpea genotypes-*Helicoverpa armigera* -Natural enemies were conducted at the International Crops Research Institute for the Semi Arid Tropics (ICRISAT), Patancheru, Hyderabad between September 2009 and March 2012 to identify pigeonpea genotypes that are more hospitable to the natural enemies and have the potential for use in crop damage by *H. armigera*. Protocols used in understanding these interactions are described below.

3.1 Experimental material

3.1.1 Plant material

Nine pigeonpea genotypes from two species of pigeonpea (ICPL 87, ICPL 332 WR, ICPL 87119, ICPL 87091, LRG 41, ICPB 2042 (Hairy pods)ICP 7035, ICPL 84060 and T 21 and one accession a wild relative of pigeonpea *i.e. Cajanus scarabaeoides* (L.) (ICPW 125) were grown in rainy season (June–Dec) in deep black soils. The seed testa of the wild relative, ICPW 125, was cut at one end with a sharp knife and treated with thiram (1g per 100 seeds). The test genotypes were grouped into three sets based on maturity (early = ≤60 days, medium = 60-120 days and late = ≥120 days to flowering). The seeds were sown in ridges, 75 cm apart and there were four rows in each plot, 2 m long. The genotypes were planted at 30 days intervals to get flowers and pods of all genotypes at the same time. The seedlings were thinned 1 week after crop emergence. Wooden pegs (1.5 m high) were used to provide support for *C. scarabaeoides*, which has a creeping habit. Normal agronomic practices were followed for raising the genotypes. There was no insecticide application in these trials and covered with nylon nets for the samples to be collected.

3.1.2 Maintenance of insect cultures

3.1.2.1 Pod borer, *Helicoverpa armigera* (Hübner) (Lepidoptera: Noctuidae)

Culture was initiated by collecting the larvae of *H. armigera* 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* neonates were reared in groups of 200 to 250 in 200 ml plastic cups (having 2 to 3 mm layer of artificial diet on the bottom and sides) for five days on chickpea-based semi-synthetic artificial diet (Armes *et al.*, 1992) for five days. After five days, the larvae were individually transferred to 6-cell well plates (each cell well having 3.5 cm in diameter and 2 cm depth with 7 ml diet) till pupation to avoid cannibalism. Pupae were surface sterilized with 2 per cent sodium hypochlorite and were placed in groups of 50 in a plastic jar containing moistened vermiculite for the adult emergence. Adults were collected with the help of plastic vials and ten pairs were released in a oviposition cages (30 x 30 x 30 cm) having nappy liners (soft cotton cloth pieces). Adults were provided with 10 per cent sucrose in a cotton swab as a food in a petriplate. The nappy liners were removed daily and eggs were washed in 2 per cent sodium hypochlorite and air dried under the fan and then placed inside the plastic cups. After egg hatching, the neonates were transferred to the plastic cups containing artificial diet (Plate 1). The eggs and second instar larvae of *H. armigera* were used for experiments on *Trichogramma chilonis* Ishii and *C. chlorideae* Uchida, respectively under laboratory conditions.

3.1.2.2 Artificial diet for rearing *H. armigera*

For preparing the chickpea based diet for insect culture, all the ingredients (Armes *et al.,* 1992) (Table 1) were weighed separately. The ingredients of Fraction A and water (W1) were mixed thoroughly in a large bowl of 2 L capacity by using a hand mixer. The yeast was mixed with water (W2) in a saucepan on a hot plate and heated to boiling point, agar-agar was added and boiled and then again agar was mixed with other ingredients (Fraction A) in a plastic bowl and stirred until even consistency was obtained. This semi-cooled diet was poured into trays or 250 ml plastic cups (0.5 cm thin layer) placed on a level surface and allowed to cool under a laminar flow for one hour. Plastic cups were covered with a lids, whereas the, trays were wrapped with polythene sheet to avoid contamination. Nearly 300 ml diet was sufficient to rear 30-neonate larvae upto pupation.

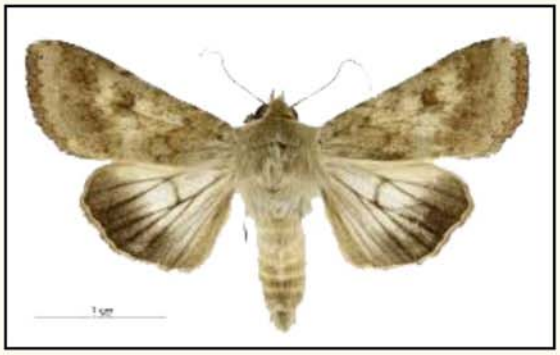
Liners used as a substrate for laying eggs by *Helicoverpa armigera*

Multi-cell well used for rearing larvae of *Helicoverpa armigera*

Cages containing vermiculate for placing pupa of *Helicoverpa armigera* till emergence

Oviposition cage of *Helicoverpa armigera*

Female *Helicoverpa armigera*



Male *Helicoverpa armigera*

Plate 1: Rearing of *Helicoverpa armigera* on artificial diet in the laboratory

Table 1: Composition of artificial diet for rearing *H. armigera* larvae

Ingredients	Quantity
Fraction A	
Chickpea flour	75 g
L-ascorbic acid	1.175 g
Sorbic acid	0.75 g
Methyl-4-hydroxy benzoate	1.25 g
Aureomycin	2.875 g
Yeast	12 g
Formaldehyde (40%)	1.0 ml
Vitamin stock solution	2.5 ml
Water (W1)	112.5 ml
Fraction B	
Agar-agar solution	
Agar-agar	4.325 g
Water (W2)	200 ml

3.1.2.3 Rice moth, *Corcyra cephalonica* Stainton (Lepidoptera : Pyralidae)

The nucleus culture of *C. cephalonica* was obtained from the Acharya N. G. Ranga Agricultural University, Rajendranagar, Hyderabad, India. Eggs were inoculated on sorghum and groundnut powder (mixed in the ratio of 4 : 1) in plastic boxes (15 cm diameter), with tops covered by 1 mm mesh lid. Rice moth life cycle completed in one month from egg to adult stage. The larvae feed on the grains and pupated inside grains by forming netting. These plastic boxes containing adults were kept inside a wooden cage having a entry hole on one of the sides, which was covered with cloth. The adults were collected by the aspirator connected to a suction pump. The adults of 20 pairs were paired in a cage having a mesh at the bottom for oviposition. The eggs were collected from the mesh and used for maintenance of *T. chilonis* (Plate 2).

3.1.2.4 *Trichogramma chilonis* (Hymenoptera:Trichogrammatidae)

The nucleus culture of *T. chilonis* was obtained from the Acharya N. G. Ranga Rao Agricultural University, Rajendranagar, Hyderabad, India, in the form of

"Trichocards" (10 x 15 cm^2) *i.e.*, *C. cephalonica* eggs parasitized by *T. chilonis* females. The egg parasitoid was maintained periodically. Every each batch lasted for eight days.

Trichocards were cut uniformly into a size of 2 x 7.5 cm^2 and there were 10 strips of each trichocard. Each strip was kept in a glass vial and capped with a cotton plug. Eight days after parasitisation, adults emerged from parasitized *C. cephalonica* eggs on the trichocards. Fresh trichocards were made by pasting fresh *C. cephalonica* eggs on a cardboard paper sheet. These trichocards were exposed to uniform densities of *T. chilonis* adults (M: F ratio 1:1) emerged from the previous culture. After emergence, the adults were active for about 3 days and 10 days, without and with dried honey drops on paper sheet, respectively. Everyday, a new batch of trichocards were developed. The parasitoid culture was maintained throughout the experimental period at 27± 1^oC, 60-85% RH and 12 hours photoperiod. One to 12 hours old insects on the basis of antennal characters (Sen *et al.*, 2005) were used for experiments (Plate 2).

3.1.2.5 Larval parasitoid, *Campoletis chlorideae* Uchida (Hymenoptera: Ichneumonidae)

The cocoons of *C. chlorideae* were collected from chickpea fields and kept individually in a glass tube (2 cm in diameter × 10 cm in height) and plugged with cotton wool, until adult emergence. Adult female wasps were easily distinguishable from the males by the presence of a prominent ovipositor on the posterior abdomen. Twenty pairs of adults were kept in a cage (10 cm diameter x 20 cm length and closed with plastic cap lid having 60 wire- mesh, having a cotton swab with 10% sucrose solution). Immediately after mating, the females along with the males were transferred to a another cage. Single mated 5-10 days old female wasp was transferred to a transparent plastic vial (15 ml capacity) kept in an inverted position on a Petridish. Single *H. armigera* larva (3-day old / late second- or early third, instar, nearly 1 cm in length) was offered to a female wasp for oviposition. The females which showed efficient parasitisation were selected for further studies on antibiotic effect of genotypes. In general, *C. chlorideae* females took 1–2 min for parasitizing a larva. Using this technique, 80–100 larvae were parasitized using 3-4 females. The parasitized

Parasitised egg cards of *T. chilonis*

Suction pump used for collecting *Corcyra cephalonica* adults

Oviposition cage for *C. cephalonica*

Plate 2: Rearing of *Trichograma chilonis* in the laboratory

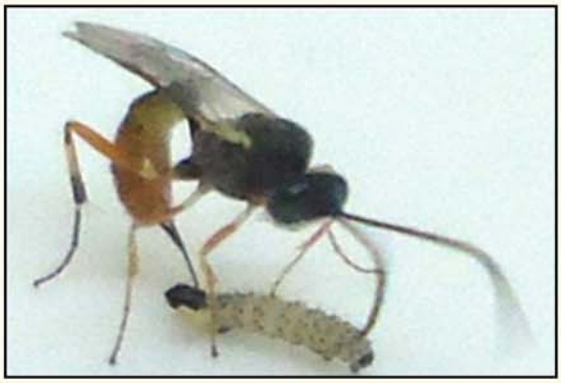
H. armigera larvae were removed and placed on chickpea based artificial diet in a transparent glass tube (2 cm dia, 10 cm long) plugged with cotton wool until adult emergence. Newly eclosed adult wasps (≤24 h hours) were kept in cages with other virgin wasps. Most of the females mated immediately after releasing into the cages and were immediately collected and kept separately for use in experiments. The culture was maintained at 27 ± 2°C, 65–75% RH, 12 hours photoperiod (Plate 3).

3.2 Identification of pigeonpea genotypes hospitable to natural enemies, *Tricogramma chilonis* and *Campoletis chlorideae*

The purpose of this study was to assess the attractiveness of different pigeonpea genotypes to *H. armigera* and their compatibility with the egg and larval parasitoids, *Trichogramma* spp. and *C. chlorideae*. To identify the componental traits associated with the parasitisation of *H. armigera*, a number of morphological and biochemical traits of the test genotypes were recorded in plants grown under field conditions. Data were recorded on pod length, width, podwall thickness and trichome length and density on leaves, flowers and pods and correlated with parasitisation of eggs and larvae of *H. armigera* by *T. chilonis* and *C. chlorideae*, respectively.

3.2.1 Length, breadth of pods and pod wall thickness.

The length and breadth of pods of each genotype were observed with the help of digital Vernier Callipers, while pod shape was observed visually. There were three replications for each genotype and each replication had fifteen pods. For the measurement of podwall thickness, the test samples were collected in stoppered glass vials (10 ml capacity) containing formalin-acetic acid-alcohol (FAA) solution (ethanol 50 ml; glacial acetic acid 5 ml; formalin 10 ml; H_2O 35 ml). After 24-48 hours of storage in FAA solution, the test samples were washed and preserved in 70 per cent alcohol until further use. For observations, the preserved pods were washed in normal tap water and transverse sections were taken with the help of a blade. These sections were placed on a slide and pod wall thickness was measured under a microscope fitted with a caliberated occular micrometer.



C. chlorideae **parasitizing** ***H. armigera*** **larva**

Grown up ***C. chlorideae*** **grub coming out of parasitized** ***H. armigera*** **larva**

C. chlorideae **adult female**

C. chlorideae **adult male**

Adult rearing cage for ***C. chlorideae***

Mating pair of ***C. chlorideae***

Plate 3: Rearing of ***Campoletis chlorideae*** **in the laboratory**

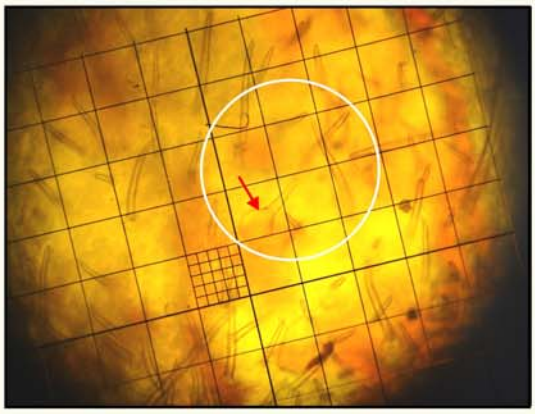
3.2.2 Trichome length, types and their density on leaves, calyx and pods

Trichome types and their density on different pigeonpea genotypes were recorded on the leaves, flowers and pods as per the methods described by Peter *et al.* (1995) and Romies *et al.* (1999). For measuring the trichome length and density on the pigeonpea genotypes, 10 uniformly developed leaves, flowers and pods were selected at random from three replications of the test genotypes and each replicate had 15 leaves, flowers and pods. Trichome density and length were measured in accordance with Jackai and Oghiakhe (1989).

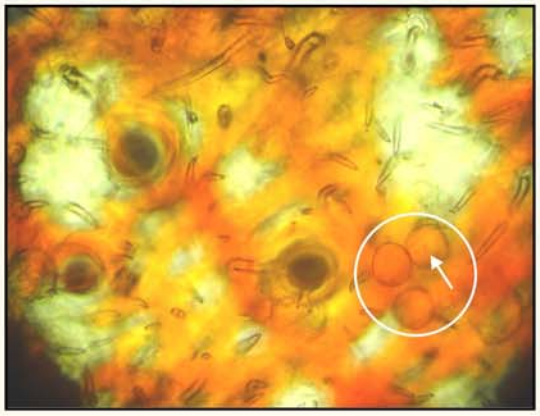
For the observations on trichome density, the pod surface was peeled off and stained with saffranine. To facilitate counting of trichomes, a 6 mm diameter section was taken in an index card and placed over the cover slip. The samples were mounted on a slide with a drop of lactic acid and covered with a cover slip. The number of trichomes in the marked area were counted under a 80X microscope and expressed as numbers per unit area (mm^2). Data were recorded on the number of different types of trichomes (type A, B, C and D) (Fig.) (Romeis *et al.*, 1999b and Sharma *et al.*, 2005). Type A trichomes were glandular and secrete an exudate, which is present in the form of droplets at the tips of these trichomes. Type B trichomes contained oily substance and were globular in structure. Type C and D trichomes were non-glandular, but the type D trichomes were much longer than the type C trichomes (Plate 4). Type E trichomes were multilobed and glandular, but their numbers were too low and were not counted in the present study. Similarly, trichome density on leaves and calyx of the flowers was also counted. Caliberation of the ocular micrometer was done using the following formula;

$$\text{One ocular unit } (\mu m) = \frac{\text{Number of divisions on stage micrometer}}{\text{Number of divisions on ocular micrometer}} \times 10$$

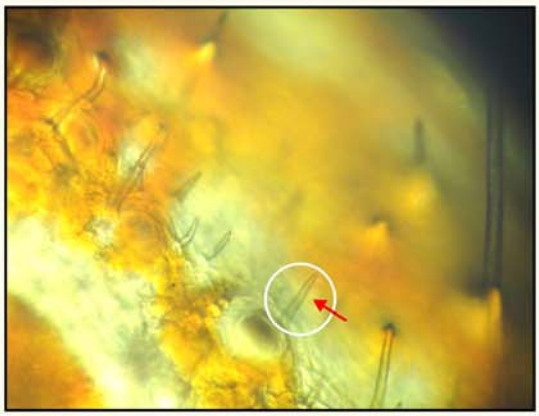
Trichome length on pods was measured by gently pressing the sticky transparent tape on the pod surface and the trichomes that adhered to the sticky surface were then fixed on a glass slide and the trichome length was measured under a binocular microscope with the help of ocular micrometer. Similarly, trichome length on leaves and calyx of the flowers were also measured.



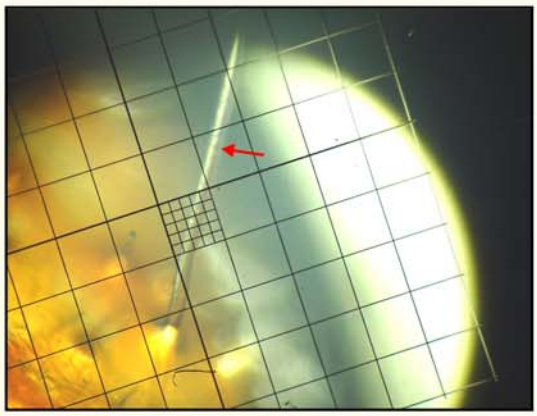
Type A Trichome



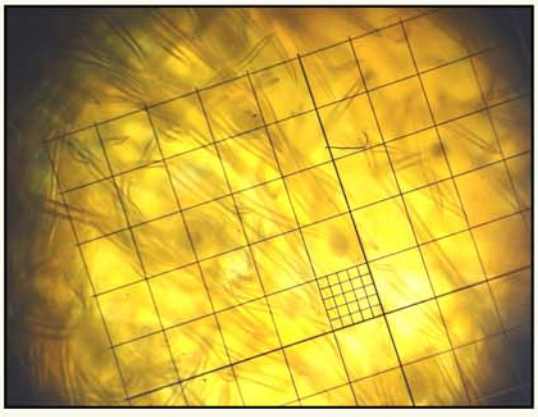
Type B Trichome



Type C Trichome



Type D Trichome



Dense Trichomes on ICPW 125

Plate 4: Different types of Trichomes on calyxes of pigeonpea genotypes

3.2.3 Influence of pigeonpea genotypes on parasitism of *H. armigera*

Experiments were conducted on this aspect as mentioned below;

a) Oviposition by *H. armigera* on different pigeonpea genotypes,

b) Effect of different pigeonpea genotypes on efficiency of *T. chilonis* to parasitize *H. armigera* eggs and

c) Effect of different pigeonpea genotypes on parasitisation by *C. chlorideae*.

Inflorescences of pigeonpea genotypes of similar size (30 cm long), same age and maturity with flowers and flower buds and young pods, free from insect eggs and larvae, were excised from the plants grown in the field. The inflorescences were immediately placed in conical flasks (150 ml) containing 100 ml of 2 per cent sucrose solution to keep them in a turgid condition. The inflorescences were secured with cotton plugs in the conical flasks to keep them in an upright position. Studies on the effect of different genotypes of pigeonpea on parasitism of *H. armigera* eggs by *T. chilonis* and the larvae by *C. chlorideae* were carried out under no-choice, dual-choice and multi-choice conditions (Plate 5) at 27 ± 2^{o}C and 60-85% RH with 12 hours photoperiod under laboratory conditions.

3.2.3a Oviposition by *H. armigera* on different pigeonpea genotypes

For no-choice experiments, a single inflorescence was kept in a conical flask inside the wooden cage (30 x 30 x 30 cm^3). Three replications were maintained for each genotype. Two pairs of 2- day old adult moths of *H. armigera* were released in each cage and the number of eggs laid was recorded after 48 hours on flowers, leaves and pods (Part A).

For dual-choice experiments, conical flasks with the test genotypes and the check genotype (susceptible check, ICPL 87) inflorescences were kept inside the wooden cage (30 x 30 x 30 cm^3). Three pairs of 2- day old moths of *H. armigera* were released in each cage. There were three such replications in a complete randomized block design. The numbers of eggs laid were recorded after 48 hours on flowers, leaves and pods (Part B).

For multiple choice experiments, 60 x 60 x 60 cm^3 cages were used. Inflorescences of all the genotypes placed in separate conical flasks were kept inside the cage. Ten pairs of 2- day old moths of *H. armigera* were released inside the cage. There were three replications in a randomized block design (Part C).

3.2.3b Effect of different pigeonpea genotypes on parasitisation of *H. armigera* eggs by *T. chilonis*

Parasitisation preference of *H. armigera* by *T. chilonis* on different pigeonpea genotypes was studied under no-choice, dual-choice and multi-choice conditions (Plate 5).

Under no-choice experiments, inflorescences of the single genotype with eggs of *H. armigera* from Part A were exposed to parasitisation by *T. chilonis* in a completely randomized block design. Six hour old 25 pairs of *T. chilonis* were released inside each cage with the help of a fine smooth camel hair brush (Plate 5).

For the dual choice experiments, inflorescences of the test genotype and the susceptible check (ICPL 87) with *H. armigera* eggs were used from part B of dual choice conditions with oviposited eggs. 30 pairs of *T. chilonis* were released inside each cage with the help of fine smooth camel hair brush. There were ten replications.

For the multiple-choice experiments, 60 x 60 x 60 cm^3 cages with inflorescences of ten genotypes with *H. armigera* eggs from Part C were used and six hours old 300 pairs of *T. chilonis* were released inside each cage with the help of a fine smooth camel hair brush. There were three replications in a completely randomized block design (Plate 5).

After 48 hours, the eggs were collected from different plant parts of each genotype from each replication. After 72 hours, observations were made on numbers of parasitized and unparasitised eggs based on the colour of the eggs. Adult emergence from the parasitized eggs was recorded from sixth day onwards, from the date of parasitization of the eggs.

3.2.3c Influence of pigeonpea genotypes on parasitism of *Helicoverpa armigera* larvae by *Campoletis chlorideae*.

Under no-choice conditions influence of pigeonpea genotypes on parasitization of *H. armigera* by *C. chlorideae* was studied by keeping an inflorescence of the test genotype inside the wooden cage and 30 laboratory-reared *H. armigera* second-instar larvae were released onto the inflorescence inside the cage. Three pairs of *C. chlorideae* were then released inside the cage for parasitisation of *H. armigera* larvae. The wasps were provided with 10 per cent sucrose solution on a cotton swab as food. Afer 48 hours, the larvae were collected and placed individually inside a 15 ml vial containing 10 g artificial diet. The larvae were reared on artificial diet till cocoon formation by the parasitoid. Each experiment was replicated ten times. Data were subjected to analysis of variance using a completely randomized block design (Plate 5).

Under dual-choice conditions, inflorescences of the test genotype and the susceptible check, ICPL 87 were placed inside the wooden cage. 30 laboratory reared *H. armigera* second-instar larvae were released on each inflorescences. Six pairs of *C. chlorideae* were released inside the cage for parasitism. Each experiment was replicated five times. Significance of differences between the test genotypes and the susceptible check (ICPL 87) was compared by paired 't' test at $P<0.05$ (Plate 5).

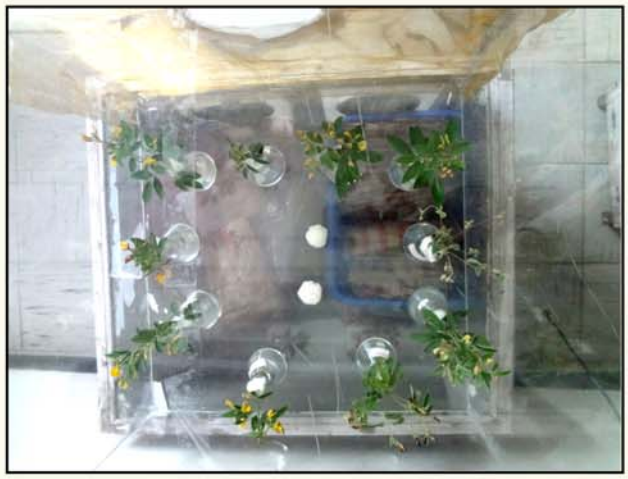
After 48 hours of initiating the experiment, the relative parasitisation preference was worked out as follows;

$$\text{Relative ovipositional preference} = \frac{\text{No. of larvae parasitised on test genotype x No. of larvae parasitised on check genotype}}{\text{No of larvae parasitised on test genotype + No. of larvae parasised on check genotype}} \times 100$$

Under multi-choice conditions, the inflorescences of all the ten genotypes were arranged in a circular arena inside a wooden cage (60 x 60 x 60 cm^3) and 30 second instar *H. armigera* larvae were released on each inflorescence. Ten pairs of *C. chlorideae* were released inside the cage and allowed free access to parasitize the larvae of *H. armigera* for 48 hours. After 48 hours, the larvae were removed from the

No-choice cage condition

Dual-choice cage condition



Multi-choice cage condition

Plate 5: Preference of pigeonpea genotypes by *Helicoverpa armigera* and parasitoids under different choice conditions

respective genotypes and reared individually in 15 ml vials containing artificial diet. The experiment was conducted in a completely randomized block design with three replications.

Observations were recorded on number of *H. armigera* larvae recovered and the proportion parasitized. For recording the number of larvae parasitized, the larvae collected from inflorescences were dissected immediately by placing them in a drop of Ringer's solution on a slide glass under a stereomicroscope, and per cent parasitisation was calculated as follows;

Per cent parasitisation = (Number of larvae parasitized / Number of larvae stung) x 100 (Tian *et al*., 2008).

Data was recorded on egg and larval period, pupal period, percentage cocoon formation and adult emergence and sex ratio of the parasitoid was recorded and subjected to suitable statistical analysis.

3.2.4 Statistical analysis

The data from no-choice, dual choice and multiple choice conditions were analysed with the help of Genstat 13th edition. Morphological and biochemical parameters of test genotypes were analysed by using CRD. Morphological parameters were correlated with percentage parasitisation of *H. armigera* eggs by *T. chilonis* and the larvae by *C. chlorideae*.

3.3 Effect of host genotypes on the egg parasitoid, *Trichogramma chilonis* and larval parasitoid, *Campoletis chlorideae*

3.3.1 Attractant/repellent effects of host genotypes on the egg parasitoid, *Trichogramma chilonis* and the larval parasitoid, *Campoletis chlorideae*

Attractant/repellent effects of a diverse array of pigeonpea genotypes on the *H. armigera* larval parasitoid, *C. chlorideae* were studied under laboratory conditions using olfactometer tests as described by Romeis *et al.* (1997b).

The genotypic effect was assessed by studying;

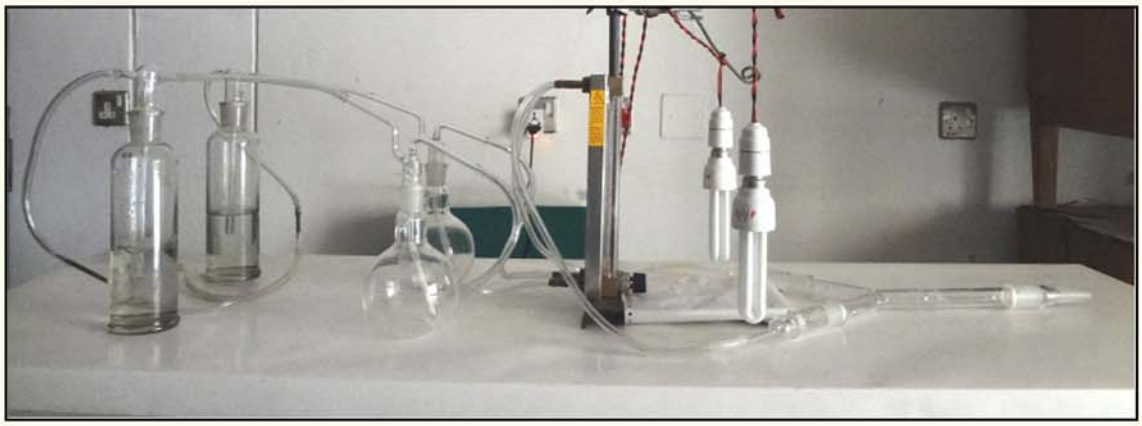
i) Attraction to odours from the flowers of different genotypes in comparison to normal air and

ii) Relative attraction to odours from the flowers of the test genotype and the flowers of the susceptible check, ICPL 87.

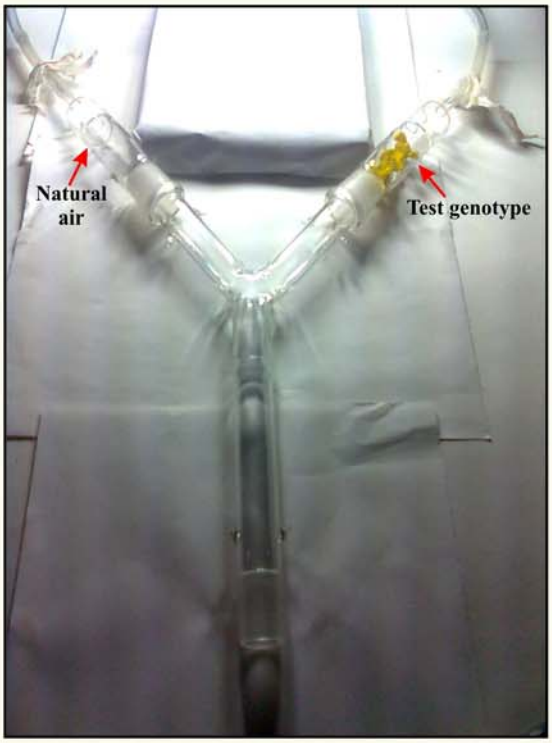
A Y-tube olfactometer was used to assess the response and attractiveness of female *C. chlorideae* to the source of flower volatiles (Plate 6). The olfactometer consisted of Y-tube (4 cm diameter x 16 cm long stem glass and 4 cm x 13 cm arm glass). The room was illuminated with a fluorescent light (40 Watt) over the olfactometer. Under no-choice conditions, one arm contained 1 g fresh flowers while the other arm was left empty. Under dual-choice conditions, one arm contained 1 g flowers of the susceptible check (ICPL 87) while the other arm contained 1 g flowers of the test genotype (Plate 6). Purified air was pumped through the arms of the olfactometer and flowed over flowers in, while the other, which did not contain anything served as a control. Newly mated female (3 days old) *C. chlorideae* or six hours old mated *T. chilonis* female was released at the beginning of the main stem and allowed a free choice between the two arms of the olfactometer. The numbers of female parasitoids travelling up to the end of the arms and stayed there without returning back were recorded for each comparison. After five tests, the position of the two arms was interchanged to avoid a directional bias. The experiment was repeated twenty times. Observations were recorded on the numbers of wasps responding to a particular odour source and the time taken to reach the target. The data were analysed by Chi-Square test (Zar, 1984).

3.3.2 Influence of pigeonpea genotypes on the biology of *Campoletis chlorideae*

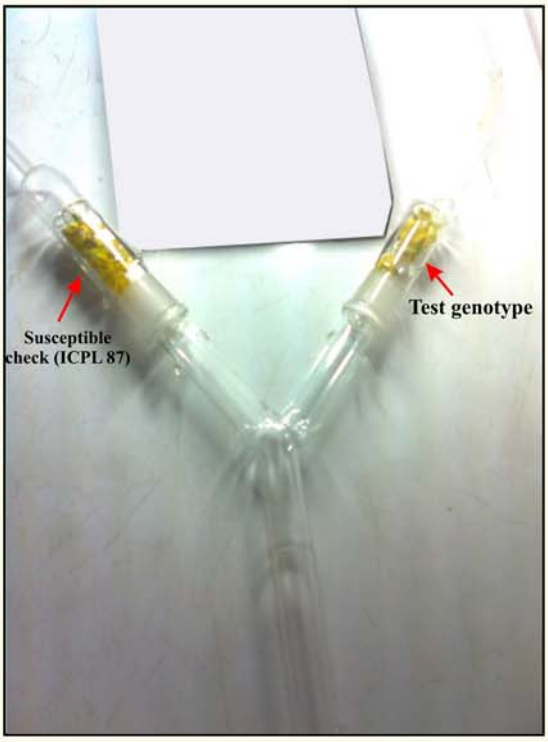
To assess the indirect effects of host genotypes through the *H. armigera* larvae on the development and survival of *C. chlorideae*, the *H. armigera* larvae fed on leaves, flowers and lyophilized pods of different pigeonpea genotypes (Plate 7) were exposed to seven days old females of *C. chlorideae* for parasitization. There were three replications in a completely randomized block design and each replicate had 20 larvae. Single second instar larva (nearly 1 cm in length), was exposed to mated *C. chlorideae*



Olfactometer set-up used for attractant/repellent study of parasitoids



Test genotype compared with natural air



Test genotype compared with susceptible genotype

Plate 6: Olfactometer used for attractant/repellent study of parasitoids

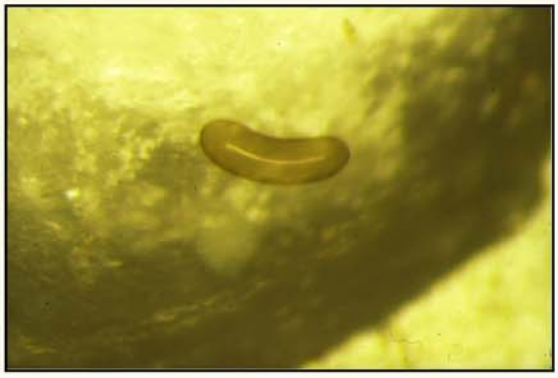
females and allowed to sting the larvae only once. The parasitized larvae were kept for the observations individually parasitized by a single female wasp to avoid any errors due to the performance of the female wasps. After 48 hours, parasitized and unparasitised larvae were used for indices on consumption and utilization of food. The experiments were carried out at 27 ± 1°C, 75% RH and 14:10 (L:D) hours photoperiod.

For studying the biology of the wasp on *H. armigera* larvae fed on leaves and flowers of different pigeonpea genotypes, the parasitized larvae were reared on the tender leaves (third leaf from the top) and on an inflorescence using detached leaf assay (Sharma *et al.*, 2005).

To study the biology of the wasp on *H. armigera* larvae fed on diet with lyophilized pods, the parasitized larvae were reared on diets with lyophilized plant parts (Table 2) (Kumari *et al.*, 2010) (Plate 7).

Table 2: Composition of artificial diet used for rearing *H. armigera* larvae with lyophilized leaf/pod powder

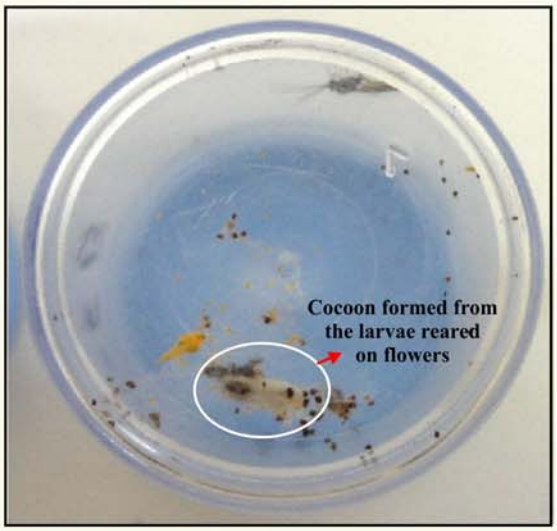
Ingredients	Quantity
Chickpea flour	55 g
Lyophilized leaf/ pod powder	20 g
L-ascorbic acid	1.175 g
Sorbic acid	0.75 g
Methyl-para-hydroxy benzoate	1.25 g
Aureomycin	2.875 g
Yeast	12 g
Formaldehyde (40%)	1.0 ml
Vitamin stock solution	2.5 ml
Water	112.5 ml
Agar-agar solution	
Agar-agar	4.325 g
Water	200 ml



Egg of *C. chlorideae*

Cocoons of *C. chlorideae*

Detached inflorescence of pigeonpea used for rearing *H. armigera* larva



C. chlorideae cocoon on pigeonpea flower

Cultivated pigeonpea genotype

Wild pigeonpea genotype

Detached leaf assay to study the biology of *C. chlorideae* on leaves

Plate 7: Influence of pigeonpea on the biology of *Campoletis chlorideae*

Duration of post-embryonic development and adult emergence of the parasitoid were observed on *H. armigera* larvae fed on different plant parts. Percentage parasitisation was computed from the number of larvae parasitized and number of adults emerged from the parasitized larvae.

For recording the number of larvae parasitized, the larvae stung by the *C. chlorideae* females were dissected immediately by placing them in a drop of Ringer's solution on a slide glass under a stereomicroscope (Tian *et al*., 2008) and data were recorded on number of larvae parasitized.

The percentage of cocoon formation and the adult formed were worked out as follows;

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

$$\text{Adults emerged (\%)} = \frac{\text{Number of adults emerged}}{\text{Number of larvae parasitized}} \times 100$$

3.3.2.1 Nutritional indices

Consumption and utilization of food was studied in parasitized and unparasitised fourth instars of *H. armigera* (2.6 cm; 0.234 mg). A gravimetric technique was used to determine weight gain, food consumption and the amount of faeces produced. Pre-weighed parasitised and unparasitised larvae were kept in separate containers and allowed to feed for 24 hours on pre-weighed leaves, flowers and lyophilized immature pods of different genotypes separately. The larvae were re-weighed to compute weight gain. The larvae were then oven dried for 48 hours at 60^{o}C and re-weighed to record dry weight of the larvae.

The un-consumed leaves, flowers and lyophilized pods at the end of each day were oven-dried and weighed to calculate dry weight of the food consumed by the larvae.

The quantity of food ingested was estimated by subtracting the dry weight of diet remaining at the end of each experiment from the total dry weight of diet provided to the larvae.

The faeces were collected daily, weighed, oven-dried and then re-weighed to record dry weight of the faeces. Food consumption, growth rates and post-ingestion food utilisation efficiencies (all based on dry weight) were calculated as described by Waldbauer (1968) and as used by Sharma and Norris (1991).

Consumption Index (C.I. mg/mg/day) = (Wt of food ingested - Wt of frass) / (Mean Wt of the larval instar x feeding period)

Relative growth rate (RGR mg/mg/day) = (Wt gained) / (Mean Wt of the larval instar x feeding period)

Efficiency of conversion of digested food (ECD%) into body matter = [Wt gained / (Wt of food ingested - Wt of frass)] x 100

Weight of food consumed (mg) = Wt of food ingested – Wt of faeces

Approximate digestibility (%) = [(Wt. of food consumed – Wt. of faeces) / Wt. of food consumed] x 100

Efficiency of conversion of ingested food (ECI%) into body matter = (Wt gained / Wt of food ingested) x 100

3.3.2.2 Estimation of biochemical constituents in diffeent pigeonpea genotypes

The biochemical constituents such as total sugars, total phenols and protein content were estimated in leaves, flowers and young pods of 10 pigeonpea genotypes. Fresh parts of the leaves, flowers and young pods used for the study on the antibiotic effects of host genotypes were collected and freeze dried. The freeze dried plant parts were powdered in a grinder to a fine powder (60 mesh). The samples were analysed by using the procedures described by Sharma *et al.* (2011).

3.3.2.2.1 Carbohydrates

The dried sample (50 mg each) was macerated in a grinder with 20 ml of ethanol and left for 12 hours. The samples were then centrifuged at 1200 rpm for 15 min, the supernatants removed and concentrated on a water-bath. The volume of aqueous concentrates was made up to 50 ml with distilled water (Extract A) and processed further by following the method of Loomis and Shull (1937) to estimate total soluble sugars.

Residual pellet obtained by centrifugation was suspended in a mixture of 5 ml of 52 per cent perchloric acid and 6.5 ml of distilled water, shaken vigorously (5 min) and centrifuged (2500 rpm). This step was repeated three times and the supernatants were collected. The volume was made up to 100 ml with distilled water (Extract B). An aliquot of 1 ml was used to estimate starch (McCready *et al.*, 1950).

Aliquot (1ml) of each of the test samples from Extract A and B were used for quantifying total carbohydrates using phenol-sulphuric acid method (Dubois, 1951). A standard curve was prepared using glucose. A stock solution of glucose (100 µg/ml) was prepared in distilled water, of which 0.1 to 0.9 ml aliquots were transferred to a series of test tubes and the volume raised to 1 ml with distilled water. To each of these, 1 ml of 5 per cent aqueous phenol was added quickly in an ice chest and shaken gently and then 5 ml of concentrated H_2SO_4 was added by agitating the test tube. The test tubes were kept in a water-bath (26º– 30ºC) for 20 min and the optical density (ODs) of the yellow orange color thus developed was recorded at 490 nm in a spectrophotometer after setting the instrument for 100 per cent transmission against the blank. Four replicates of each sample were run and the mean values calculated. A regression was computed between known concentrations and their respective ODs (based on Beer's Lamberts Law). The concentration (mg/g dry weight) of total soluble sugars was estimated from the standard curve for glucose. Three replicates of each sample were taken and their mean values recorded. The content in terms of glucose equivalent and the conversion factor (0.9) were used to estimate values of glucose to starch in each case.

Standards with different concentrations (*i.e.*, 25, 50, 75, 100 and 125µg of glucose) were prepared from the working standard and their absorbance was read by taking 1 ml aliquots.

Total soluble sugars were calculated by using the formula:

$$\frac{\text{Conc. of Standard}}{\text{Absorbance of standard}} \times \text{Absorbance of 1 ml extract} \times \frac{1}{1000000} \times \frac{3\text{ml}}{0.1\text{g}} \times 100$$

3.3.2.2.2 Proteins

A 60 mg of the dried test sample was macerated in 10 ml of cold TCA (10%) for 30 min kept at 4º C for 24 hours and then centrifuged (Osborne, 1962). The supernatant was discarded and the resultant pellet was re-suspended in 5 per cent TCA (10 ml) and heated on a water bath at 80º C for 30 min. The sample was then cooled, re-centrifugated and each time the supernatant discarded. The pellet finally was washed with distilled water, centrifuged and the residue dissolved in 1N NaOH (10 ml) and left overnight at room temperature.

Total protein content was estimated in an aliquot of 1 ml extract, using the protocol of Lowry *et al.* (1951). A stock solution (1mg/ml) of bovine serum albumin (Sigma Chemicals manufacturing limited) was prepared in 1N NaOH, from which 0.1 to 0.9 ml of aliquots were dispensed in a series of test tubes. The volume was made up to 1 ml by adding distilled water. To each test sample, 5 ml freshly prepared alkaline solution (prepared by mixing 50 ml of 2% Na_2CO_3 in 0.1N NaOH and 1 ml of 0.5% $CuSO_4.5H_2O$ in 1% sodium potassium tartrate) was added at room temperature and left undisturbed for a period of 10 min.

Subsequently, 0.5 ml of Folin-Ciocalteau reagent (prepared by diluting the reagent with distilled water in 1 : 2 ratio just before use) was added to each sample. OD of each was measured at 750 nm after 30 min in a spectrophotometer. Three replicates of each sample were taken and their mean values used to prepare the standard curve. The total protein content in each sample was calculated from the standard curve for Bovine Serum Albumin (BSA). Three replicates were examined for each treatment.

3.3.2.2.4 Lipids

One g of each of the dried and milled test sample was macerated in 10 ml distilled water (Jayaraman, 1981). To this, 30 ml of chloroform : methanol (2 : 1, v/v) was added and mixed thoroughly. The mixture was left overnight at room temperature;

Twenty ml each of chloroform and distilled water was added to the sample and centrifuged. Of the three layers, a clear lower layer of chloroform containing lipids was collected in a pre-weighted beaker. The solvent was allowed to evaporate and the beaker was re-weighed and recorded the amount of lipids and expressed as total lipids/g of the dried sample.

3.3.2.2.5 Phenols and tanins

Dried and milled test samples (200 mg) were homogenized in 80% ethanol (10 ml) for 2 hours and left over night at room temperature. The samples were centrifuged and the supernatants collected individually and the volume of each was made up to 40 ml with 80 per cent ethanol.

Total phenol content was estimated by following the protocol described by Bray and Thorpe (1954). A standard curve of caffeic acid (phenol) was prepared. A stock solution (100 µg/ml) of caffeic acid was prepared in 80 per cent ethanol, from which 0.1 to 0.9 ml aliquots were transferred into a series of test-tubes and the volume was made up to 1 ml with 80 per cent ethanol. To each of these tubes, 1 ml of Folin–Ciocalteau reagent (1: 2 ratio) with 2 ml of 20 per cent Na_2CO_3 solution was added and the content mixed vigorously. The samples were incubated in boiling water bath for 1 min, cooled and diluted to 25 ml with distilled water. The optical density (OD) was recorded at 750 nm using a spectrophotometer against a blank.

Three replicates were taken for each concentration and the average OD was plotted against the respective concentrations to prepare the standard curve. Each test sample was processed in a similar manner. Total amount of phenols was estimated from (with reference to caffeic acid) the standard curve

The amounts of tannin present in the leaves, flowers and pods of different pigeonpea genotypes were estimated by Vanillin-Hydrochloric acid method (Price *et al.*, 1978).

The following reagents were used in the present study;

1. 8 per cent HCl in methanol (v/v): 8 ml concentrated HCl in methanol and made up to 100 ml.

2. In methanol 1 gm of vanillin was dissolved and final volume was made up to 100 ml.

3. Vanillin-hydrochloric acid reagent: Equal volume of solution 1 and 2 are mixed before use.

4. 4 per cent hydrochloric acid in methanol (v/v): 4 ml conc HCl in 96 ml methanol

5. 1 per cent hydrochloric acid in methanol (v/v): 1 ml conc HCl in 99 ml methanol

6. Standard solutions : A stock solution is prepared by dissolving 1 mg of catechin in 1 ml of methanol

From the defatted material, 100 mg was transferred to a centrifuge tube containing 2 ml of 1 per cent acidic-methanol, centrifuged for 10 min and the aliquot transferred to a 5 ml volumetric flask and 1 ml of acidic methanol (1%) was added to this solution. The tannins were extracted from the mixture, was made up to final volume of 4 ml.

From the above extract, 1 ml aliquot was pipetted out into a test tube and freshly prepared Vanillin-hydrochloric acid reagent (1 ml) was added slowly. A blank was also prepared for each extract by adding 5 ml of 4 per cent HCl in methanol to 1 ml aliquot. Finally the absorbance was recorded at 500 nm against the reagent blank in spectrophotometer.

The standard curve was prepared by plotting the average absorbance readings of the duplicate determinations of catechin concentrations and the catechin equivalents (CE) were calculated by using the following formula.

$$CE\ (\%) = \frac{\text{mg catechin/ml}}{\text{Vol. of extract taken}} \times \frac{\text{Volume made up}}{\text{Wt. of sample}} \times 100$$

3.3.2.2.6 Statistical analysis

The data on percentages and insect numbers were transformed using Arcsine and square-root transformation, respectively and subjected to analysis of variance (ANOVA) using GenStat® 13th version statistical analysis program. Biochemical paramaters were correlated with the biology of the *C. chlorideae* and a simple linear

regression analysis was carried out to have the regression equalise. Significance of differences between the treatments was judged by F-test and the means were compared using least significant differences (LSD) at $P \leq 0.05$. Chi-square analysis was performed to test the significance of differences between numbers of wasps that made a choice between the two odour sources offered (a 50:50 probability will be set between the number of wasps walking to the control and the test side in the Y-tube). Wasps that scored as no choice were excluded from statistical analysis.

3.4 Info-chemicals influencing parasitization of *H. armigera* eggs and larvae in pigeonpea

3.4.1 High Performance Liquid Chromatography (HPLC) and Gas Chromotographhy Mass-Spectrophotometer (GCMS) analysis of flowers and pods extracts of different pigeonpea genotpyes

3.4.1.1 Preparation of crude extracts

The pigeonpea flowers and pod surface extracts were prepared by placing the flowers or pods of known surface area into 500 ml of hexane or methanol and stirred for 120 seconds with a glass rod. Each extract was then gravity filtered before being evaporated under vacuum to dryness. Extracts of the pod surfaces were re-dissolved in either hexane or methanol so that 100 µl of solution contained a quantity of extract equivalent to 3.46 cm^2 of flower or pod surface (the area of glass fibre disc). These extracts were then used for the olfactometer and chromatographic studies.

3.4.1.2 Chromatographic analysis

The HPLC system used in this study consisted of Waters® 2695 Separations Module, a automatic injector, integrated system controller, Atlantis® C18 reverse-phase analytical column (250 x 4.6 mm, RP-18, 5-µm particle size) and a Waters® 2995 photo diode array detector with an attached HP analysis computer and data storage system. The gradient elution schedule consisted of an initial 2-min run of 75 per cent of 2 per cent HPLC grade acetic acid and 25 per cent of HPLC grade methanol, followed by a linear gradient to 100 per cent methanol over 55 min at a flow rate of 1 ml/min.

The mobile phase was a mixture of methanol (A) and 2.0 per cent (v/v) acetic acid, with a gradient elution as described in Table 3.

Table 3: HPLC analysis of compounds in hexane and methanol extracts of flowers and pods surface of different pigeonpea genotypes

Time (min)	Methanol (%)	Acetic acid (%)
0	25	75
20	100	0
30	100	0
35	25	75
45	25	75
55	25	75

The flow rate was 1.0 ml/min with a detecting wave length of 254 nm

3.4.2 Olfactometer studies

A Y-tube olfactometer was used to test the choices comprising of.

i) attraction to hexane or methanol extract of flowers,

ii) attraction to hexane or methanol extract of pods and

iii) attraction to volatile and the non-volatile compounds already identified in the pigeonpea flowers/pods to study the behaviour of the egg and larval parasitoids, *T. chilonis* and *C. chlorideae*, respectively.

Erlen meyer flasks (1,000 ml) were used as odor containers. The system consisted of a central tube (10 cm long, 4 cm diameter) and two lateral arms (20 cm long, 4 cm diameter). The arm was divided into basal and terminal segments (10 cm each) connected to each other, with tight glass–glass joints and the terminal segments connected to the flask with Teflon tubing. A white paper was placed under the Y-tube and two fluorescent lamps (each 40 W) were suspended over the arms of the Y-tube to produce a light intensity of 2000 lx. Charcoal-purified and water-humidified air was passed into each flask and then into each arm of the olfactometer at 75 ml/min.

For the testing of single (volatile or non-volatile) compounds, individually, a 10 µl of solution was applied onto a filter paper (1 cm^2) and the filter paper was immediately placed in the flask. A parasitoid was used only once for their orientation. The parasitoids were offered choice between odors of a single compounds and mineral oil (control). Using a smooth fine camel hair brush for *T. chilonis* or two tubes with a cloth mesh between them for *C. chlorideae*, naïve (no experience with hosts plants and tested compounds) female parasitoids were individually released at the base of the central arm of the Y-tube and observed for 5 min. If, a parasitoid did not make a choice after this period, it was removed and recorded as 'no-choice'. Parasitoids that walked to the end of the basal arms or into the terminal arms and stayed there at least 5 s were recorded as having made a choice for the odor. After testing five individuals, the positions of the arms were reversed and the flasks were switched. Then another five parasitoids were tested. During the tests, the room temperature was 25 ± 1°C. The olfactometer and the glass jar were cleaned with water, ethanol and acetone and then kept in an oven at 100° C for 6 hours at the end of each day.

Only one choice test was conducted each day. For choices between single compounds and mineral oil, tested compounds and mineral oil were renewed every 5–10 min (with two to three individuals tested) and each combination was repeated three times on different days. In total, at least 20 parasitoids were tested for each choice test.

For the tests with hexane or methanol extracts of flowers and hexane or methanol extracts of pods, a 10 µl of solution was spotted on 1 cm^2 Whatman's No. 42 paper strips and immediately placed into the flask. Each parasitoid was used only once and the procedure described above was followed. Observations were recorded on the numbers of wasps making a choice and the time taken to reach the target.

3.4.3 Statistical analysis

Number of wasps that entered the treatment arm (+) or the control arm (-) were analysed using the chi-square goodness-of-fit test at $P < 0.05$ (a 50:50 probability was set between the number of wasps walking to the control and the test side in the Y-tube). Wasps that scored as no choice, was excluded from statistical analysis.

4. EXPERIMENTAL RESULTS

Studies on the pigeonpea genotpyes - *Helicoverpa armigera* – Natural enemies interactions were conducted at the International Crops Research Institute for Semi Arid Tropics, Patancheru, Hyderabad between September 2009 and March 2012 and the results of these experiments are elucidated below.

4.1 Identification of pigeonpea genotypes that are hospitable to natural enemies, *Tricogramma chilonis* Ishii and *Campoletis chlorideae* Uchida

4.1.1 Oviposition preference of *H. armigera* on different pigeonpea genotypes

Under no choice conditions, there were significant differences in oviposition preference of *H. armigera* females on different pigeonpea genotypes (Table 4). Number of eggs on ten lower leaf surface were significantly lower on ICPW 125 (1.87), T 21 (5.90), ICPL 87091 (6.07), ICPL 87 (8.13) and ICPL 87119 (11.23). The genotypes ICP 7035 (16.67), ICPL 84060 (16.67), ICPB 2042 (26.33), LRG 41 (28.17) and ICPL 332 WR (32.60) were more preferred for egg laying.

Number of eggs on the upper leaf surface were lower on ICPL 87119 (1.53), ICPW 125 (2.07) and ICPL 87 (4.00) as compared to T 21 (30.70), ICPL 332 WR (32.30) and ICPL 87091 (34.70). ICP 7035 (43.00), ICPL 84060 (45.00) and LRG 41 (53.17) were highly preferred for egg laying by *H. armigera* females (Table 4).

Number of eggs laid on calyx was significantly less on ICPW 125 (2.50), followed by ICPB 2042 (6.00), ICP 7035 (6.00), ICPL 87119 (6.17), ICPL 87091 (7.00) and T 21 (7.20) as compared to LRG 41 (21.00), ICPL 332 WR (21.13), ICPL 84060 (26.87) and ICPL 87 (43.33).

Number of eggs laid on the petal was significantly lower on ICPW 125 (1.33), ICPL 332 WR (2.61), T 21 (6.60), ICPL 87119 (6.63), ICP 7035 (7.17) as compared to other genotypes. Whereas ICPL 84060 has recorded significantly highest number of 42.00 eggs/ petals being on par with ICPL 87 (34.27).

The flower buds of ICPL 125 (1.07 eggs/flower buds) were least preferred for egg laying by *H. armigera* being on par with LRG 41 (1.33), ICPL 87091 (4.27), ICPL 87119 (4.40), ICP 7035 (5.43) and T 21 (6.47). ICPL 87 was highly preferred with highest number of 15.67 eggs/10 flower buds being on par with ICPL 84060 (13.00). In the remaining genotypes the egg load varied from 4.27 to 11.00.

Significantly less numbers of eggs were laid on pods of ICPW 125 (1.17), followed by ICPL 332 WR (6.00). ICPL 87119 (11.00), ICP 7035 (11.00) and T 21 (11.00) were on par with each other. ICPB 2042 (17.50) and LRG 41 (21.67) were on par followed by ICPL 84060 (29.67). The pods of ICPL 87 (42.00) and ICPL 87091 (37.00) were highly but equally preferred for egg laying by *H. armigera* (Table 4).

Under dual-choice conditions, there were significant differences in numbers of eggs laid on lower leaf surface, when test genotypes were compared with the susceptible check, ICPL 87. The test genotypes had significantly lower number of eggs on the lower leaf surface (1.90 to 5.92 eggs/ 10 leaves) than the susceptible check, ICPL 87 (6.22 to 8.14 eggs / 10 leaves) except ICPL 84060 (Table 5).

However, there were no significance differences in egg laying on upper leaf surface between ICPL 87091 (4.58), LRG 41 (4.50) when compared with ICPL 87 (5.14 and 4.76, respectively). ICPL 84060 (7.48) had significantly more eggs than ICPL 87 (5.96). In the remaining genotypes significantly less number of eggs were laid on the upper leaf surface as compared to the susceptible check, ICPL 87 (3.38 to 7.34) (Table 5).

ICPW 125 (1.76) was least preferred for egg laying on calyx compared to ICPL 87 (26.24). In the remaining genotypes also the number of eggs were laid were significantly less as compared to ICPL 87 (15.54 to 26.24 eggs / 10 calyxes) except ICPL 87091 (19.51) and ICPL 87 (20.14) (Table 6).

The oviposition preferences on petals of all test genotypes were significantly lower than ICPL 87. However, ICPW 125 was least preferred with 1.40 eggs/10 petals compared to 13.72 on ICPL 87. Similar trend was observed with respect to number of eggs on flower buds. However, the differences in number of eggs laid on the flower buds of ICPL 87091 (21.40) and ICPL 87 (24.72) were non-significant (Table 5).

Table 4: Oviposition preference of *H. armigera* on different pigeonpea genotypes under no-choice cage conditions[+] (ICRISAT, Patancheru, 2010-2011)

Genotype	No. of eggs on 10 lower leaf surface	No. of eggs on 10 upper leaf surface	No. of eggs on 10 calyxes	No. of eggs on 10 petals	No. of eggs on 10 flower buds	No. of eggs on 10 pods
ICPL 87119	11.23 (3.50)^{bc}	1.53 (1.59)^{e}	6.17 (2.67)^{c}	6.63 (2.76)^{cd}	4.40 (2.32)^{c}	11.00 (3.31)^{d}
ICPL 87	8.13 (3.02)^{c}	4.00 (2.23)^{de}	43.33 (6.65)^{a}	34.27 (5.84)^{ab}	15.67 (4.02)^{a}	42.00 (6.55)^{a}
ICP 7035	16.67 (4.20)^{b}	43.00 (6.63)^{ab}	6.00 (2.64)^{c}	7.17 (2.84)^{cd}	5.43 (2.50)^{c}	11.00 (3.16)^{d}
LRG 41	28.17 (5.39)^{a}	53.17 (7.36)^{a}	21.00 (4.61)^{b}	21.00 (4.73)^{b}	1.33 (1.52)^{d}	21.67 (4.68)^{c}
ICPL 87091	6.07 (2.65)^{cd}	34.70 (5.97)^{bc}	7.00 (2.83)^{c}	8.17 (3.02)^{c}	4.27 (2.29)^{c}	37.00 (6.16)^{a}
ICPL 84060	16.67 (4.19)^{b}	45.00 (6.76)^{ab}	26.87 (5.27)^{b}	42.00 (6.55)^{a}	13.00 (3.73)^{ab}	29.67 (5.15)^{b}
T 21	5.90 (2.62)^{cd}	30.70 (5.61)^{c}	7.20 (2.86)^{c}	6.60 (2.74)^{cd}	6.47 (2.72)^{c}	11.00 (3.45)^{d}
ICPL 332 WR	32.60 (5.80)^{a}	32.30 (5.69)^{c}	21.13 (4.70)^{b}	2.61 (1.90)^{cd}	9.73 (3.26)^{b}	6.00 (2.65)^{e}
ICPB 2042 (Hairy pods)	26.33 (5.22)^{a}	6.33 (2.69)^{d}	6.00 (2.64)^{c}	9.50 (3.24)^{c}	11.00 (3.50)^{b}	17.50 (4.30)^{c}
ICPW 125	1.87 (1.69)^{d}	2.07 (1.73)^{e}	2.50 (1.87)^{d}	1.33 (1.52)^{d}	1.07 (1.44)^{a}	1.17 (1.43)^{f}
SEm±	0.11	0.29	0.24	0.14	0.16	0.20
LSD ($P_{0.05}$)	0.33	0.88	0.72	0.42	0.47	0.60
CV (%)	5.03	11.17	11.48	7.09	10.16	8.59

The values followed by the same letter within a column are not significantly different at $P \leq 0.05$.
Figures in the parentheses are $\sqrt{X+1}$ transformed values

Table 5: Oviposition preference by *H. armigera* towards leaves of different pigeonpea genotypes under dual-choice cage conditions[+] (ICRISAT, Patancheru, 2010-2011)

Genotype	No. of eggs on 10 leaves					
	Lower leaf surface			Upper leaf surface		
	Test genotype	ICPL 87	t-value	Test genotype	ICPL 87	t-value
ICPL 87119	2.88 (1.82)	7.76 (2.87)	8.51*	5.62 (2.46)	7.78 (2.87)	3.67*
ICP 7035	4.98 (2.33)	5.58 (2.46)	2.36*	4.00 (2.11)	5.34 (2.40)	4.10*
LRG 41	5.92 (2.52)	6.66 (2.67)	2.58*	4.50 (2.23)	4.76 (2.28)	1.06 NS
ICPL 87091	5.44 (2.43)	6.52 (2.64)	3.12*	4.58 (2.25)	5.14 (2.37)	1.31 NS
ICPL 84060	14.04 (3.79)	7.18 (2.76)	4.76*	7.48 (2.82)	5.96 (2.54)	4.53*
T 21	4.80 (2.29)	6.22 (2.65)	2.18*	4.98 (2.33)	5.46 (2.43)	2.70*
ICPL 332 WR	3.71 (2.04)	6.86 (2.69)	3.49*	2.40 (1.68)	3.38 (1.96)	5.45*
ICPB 2042	3.82 (1.92)	7.20 (2.69)	3.79*	5.10 (2.26)	5.86 (2.42)	2.35*
ICPW 125	1.90 (1.48)	8.14 (2.93)	5.44*	1.80 (1.50)	7.34 (2.78)	8.36*

* = Significant at $P_{0.05}$
NS = Non-significant.
Figures in the parentheses are $\sqrt{X+1}$ transformed values

Significantly less number of eggs were recorded on the pods of all test genotypes which ranged from 1.68 on ICPW 125 to 11.16 on ICPB 2042 as compared to ICPL 87 (11.68 to 16.84 eggs / 10 pods) (Table 6).

Under multi choice conditions, there were significant differences in oviposition preference of *H. armigera* on different pigeonpea genotypes, in number of eggs laid. Number of eggs laid on lower leaf surface of ICPW 125 (1.65) was lowest followed by ICPL 87091 (8.00) and ICPL 87119 (9.33). Highest numbers of eggs were laid on the lower leaf surface of LRG 41 (21.22) being on par with T 21 (16.00), ICPL 87 (14.33), ICP 7035 (13.33), ICPB 2042 (12.43), ICPL 332 WR (11.67) and ICPL 84060 (9.52) (Table 7).

Number of eggs laid on the upper leaf surface differed significantly among the pigeonpea genotypes. The least number of eggs were laid on the leaves of ICPW 125 (1.43), followed by ICPL 84060 (4.00), ICPL 87119 (5.33), ICP 7035 (7.00) and T 21 (7.32). Whereas in the remaining genotypes the egg laying was more and all being on par with each other.

Signifcantly least number of eggs were laid on the calyxes of ICPW 125 (2.54) and highest on the ICPL 87 (28.67). In the remaining genotypes the egg laying varied from 8.45 on ICPL 87119 to 18.54 on LRG 41.

Number of eggs laid on the petals differed significantly among the pigeonpea genotypes. Least numbers of eggs were recorded on the petals of ICPW 125 (3.54) being on par with ICPL 87091 (7.72), ICPL 84060 (8.00) and ICP 7035 (8.32). Whereas, ICPL 87 was highly preferred for egg laying with 24.00 eggs / 10 petals.

ICPW 125 was least preferred as egg laying was significantly lowest with 1.31/10 flower buds. Whereas, significantly highest number of eggs were laid on ICPL 87 (16.32) being on par with T 21 (13.62), ICPL 84060 (11.00) and ICPL 87119 (9.00).

Least number of eggs were laid on the pods of ICPW 125 (0.67) whereas ICPL 87 was highly preferred for egg laying by the *H. armigera* with maximum of 26.43 being on par with ICPL 87091 (22.00) and T 21 (18.67) (Table 6).

Table 6: Oviposition preference by *H. armigera* females towards reproductive parts of different pigeonpea genotypes under dual-choice cage conditions (ICRISAT, Patancheru, 2010-2011)

Genotype	No. of eggs on 10 calyxes			No. of eggs on 10 petals			No. of eggs on 10 flower buds			No. of eggs on 10 pods		
	Test genotype	ICPL 87	t-value	Test genotype	ICPL 87	t-value	Test genotype	ICPL 87	t-value	Test genotype	ICPL 87	t-value
ICPL 87119	7.20 (2.76)	17.64 (4.23)	4.27*	6.62 (2.65)	13.14 (3.68)	5.85*	7.50 (2.82)	19.44 (4.42)	5.97*	7.04 (2.73)	12.88 (3.65)	11.79*
ICP 7035	5.26 (2.39)	15.54 (3.98)	6.00*	6.50 (2.64)	10.64 (3.33)	9.57*	13.48 (3.72)	21.41 (4.67)	5.36*	7.98 (2.89)	12.82 (3.64)	6.65*
LRG 41	12.16 (3.55)	18.12 (4.29)	6.73*	4.32 (2.18)	11.10 (3.40)	8.03*	13.66 (3.76)	25.30 (5.05)	10.50*	7.76 (4.87)	11.96 (3.52)	7.90*
ICPL 87091	19.52 (4.47)	20.14 (4.54)	2.10 NS	7.50 (2.82)	10.42 (3.29)	4.71*	21.40 (4.67)	24.72 (4.94)	1.78 NS	10.68 (3.34)	11.68 (3.48)	3.30*
ICPL 84060	14.16 (3.82)	18.04 (4.29)	4.37*	5.06 (2.34)	10.34 (3.25)	5.33*	10.22 (3.23)	21.48 (4.64)	3.13*	6.98 (2.71)	13.18 (3.69)	4.94*
T 21	11.78 (3.45)	17.06 (4.26)	2.17*	6.48 (2.64)	10.48 (3.30)	4.94*	8.82 (3.05)	19.92 (4.45)	3.62*	9.16 (3.10)	11.76 (3.49)	3.61*
ICPL 332 WR	8.58 (3.01)	20.44 (4.56)	8.50*	3.19 (1.91)	11.16 (3.40)	7.27*	5.36 (2.41)	21.84 (4.70)	9.87*	6.54 (2.64)	11.96 (3.53)	6.80*
ICPB 2042	18.66 (4.32)	21.42 (4.63)	4.89*	9.50 (3.08)	11.98 (3.46)	4.40*	12.46 (3.50)	21.98 (4.67)	3.45*	11.16 (3.81)	15.72 (3.57)	2.15*
ICPW 125	1.76 (1.49)	26.24 (5.16)	15.04*	1.40 (1.33)	13.72 (3.75)	8.02*	1.46 (1.39)	30.84 (5.59)	64.15*	1.68 (1.46)	16.84 (4.15)	14.46*

*= Significant at $P_{0.05}$
NS = Non-significant.
Figures in the parentheses are $\sqrt{X+1}$ transformed values

Table 7: Oviposition preference by *H. armigera* on different pigeonpea genotypes under multi-choice cage conditions (ICRISAT, Patancheru, 2010-2011)

Genotype	No. of eggs on 10 lower leaf surface	No. of eggs on 10 upper leaf surface	No. of eggs on 10 calyxes	No. of eggs on 10 petals	No. of eggs on 10 flower buds	No. of eggs on 10 pods
ICPL 87119	9.33 (2.97)^{bc}	5.33 (2.46)^{cd}	8.45 (3.04)^{c}	10.00 (3.28)^{bcd}	9.00 (3.15)^{abcd}	10.22 (3.30)^{d}
ICPL 87	14.33 (3.87)^{ab}	13.54 (3.77)^{a}	28.67 (5.41)^{a}	24.00 (4.98)^{de}	16.32 (4.14)^{a}	26.43 (5.19)^{a}
ICP 7035	13.33 (3.79)^{ab}	7.00 (2.79)^{cd}	13.34 (3.78)^{bc}	8.32 (3.00)a^{bc}	7.24 (2.86)^{cd}	14.00 (3.85)^{bcd}
LRG 41	21.22 (4.66)^{a}	13.76 (3.82)^{a}	18.54 (4.39)^{b}	15.67 (4.05)^{bcde}	5.66 (2.54)^{d}	13.67 (3.81)^{bcd}
ICPL 87091	8.00 (2.93)^{bc}	12.00 (3.58)^{ab}	13.67 (3.81)^{bc}	7.72 (2.93)^{ab}	8.71 (3.10)^{bcd}	22.00 (4.78)^{ab}
ICPL 84060	9.32 (3.21)^{ab}	4.00 (2.21)^{de}	13.00 (3.69)^{bc}	8.00 (2.95)^{ab}	11.00 (3.42)^{abcd}	12.23 (3.61)^{cd}
T 21	16.00 (4.07)^{ab}	7.32 (2.85)^{bcd}	16.7 (4.18)^{b}	16.00 (4.11)^{cde}	13.62 (3.74)^{abc}	18.67 (4.43)^{abc}
ICPL 332 WR	11.67 (3.39)^{ab}	9.54 (3.18)^{abc}	15.66 (4.05)^{b}	18.00 (4.19)^{de}	7.45 (2.88)^{cd}	10.00 (3.27)^{d}
ICPB 2042 (Hairy pods)	12.43 (3.62)^{ab}	13.00 (3.73)^{a}	18.00 (4.32)^{b}	17.00 (4.19)^{de}	15.00 (3.95)^{ab}	14.67 (3.93)^{bcd}
ICPW 125	1.65 (1.62)^{c}	1.43 (1.52)^{e}	2.54 (1.48)^{d}	3.54 (2.06)^{a}	1.31 (1.52)^{e}	0.67 (1.27)^{e}
SEm±	0.50	0.26	0.30	0.39	0.32	0.31
LSD ($P_{0.05}$)	1.48	0.76	0.89	1.16	0.94	0.92
CV (%)	25.63	14.91	13.65	19.09	17.65	14.48

The values followed by the same letter within a column are not significantly different at $P \leq 0.05$.
Figures in the parentheses are $\sqrt{X+1}$ transformed values

4.1.2 Parasitisation of *Helicoverpa armigera* eggs by *T. chilonis* on different pigeonpea genotypes

4.1.2.1 No-choice and multi-choice condition

The percentage parasitisation of *H. armigera* eggs by *T. chilonis* under no-choice condition showed significant differences in all the parts of the plant, except on lower leaf surface and flower buds. The per cent egg parasitisation recorded on the lower leaf surface in the descending order was: ICPL 87119 (32.67), T 21 (32.12), LRG 41 (28.42), ICP 7035 (24.12), ICPL 87 (24.00), ICPL 332 WR (21.67), ICPB 2042 (19.67), ICPL 84060 (19.21), ICPL 87091 (17.33) and ICPW 125 (16.67) (Table 8).

The parasitisation of *H. armigera* eggs by *T. chilonis* under multi-choice condition on lower leaf surface did not differ significantly between the different pigeonpea genotypes (Table 8).

There were significant differences among the pigeonpea genotypes in parasitisation of eggs on the upper leaf surface under no choice condition. Highest egg parasitisation was recorded on ICPL 332 WR (66.00) followed by LRG 41 (55.32), T 21 (54.34), ICPB 2042 (49.00), ICPL 87119 (40.00), ICPL 87 (34.00), ICP 7035 (31.63), ICPL 87091 (30.67), ICPL 84060 (27.43) and ICPW 125 (12.67) Table 8).

Under multi choice condition, on upper leaf surface of the leaf the per cent parasitisatioon of *H. armigera* eggs by *T. chilonis* in the descending order was ICPB 2042 (28.00), ICPL 84060 (17.00) ICPL 87119 (15.67), LRG 41 (15.00), ICPL 332 WR (14.33), ICPL 87091 (11.00), ICPL 87 (9.33), T 21 (8.67), ICP 7035 (7.67) and ICPW 125 (5.33) (Table 8).

Parasitisation of eggs on calyx of different pigeonpea genotypes under no choice condition varied significantly and was highest on ICPB 2042 (39.46) followed by T 21 (28.55), ICPL 87091 (19.54), ICPL 332 WR (19.45), LRG 41 (17.00), ICPL 84060 (16.67), ICPL 87 (15.03), ICP 7035 (12.00) and ICPL 87119 (7.33). However, significantly lowest per cent parasitisation was recorded on ICPW 125 (4.60) (Table 8).

Under multi choice conditions, the parasitisation of eggs on the calyx differed significantly among the pigeonpea genotypes under multi choice condition, with highest

of 13.67 on ICPL 84060 being on par with ICPB 2042 (12.00), LRG 41 (11.00) and ICPL 332 WR (9.33). Whereas ICPW 125, recorded significantly lowest of 4.00 per cent parasitisation (Table 8).

High levels of per cent parasitisation of *H. armigera* eggs by *T. chilonis* on the flower petals under no choice condition were recorded on ICPL 332 WR (58.56) and LRG 41 (47.21). In the remaining genotypes the per cent parasitisation in decreasing order was: T 21 (45.44), ICPB 2042 (35.55), ICPL 87119 (34.67), ICPL 87 (30.00), ICPL 87091 (26.00), ICP 7035 (24.23) and ICPL 84060 (23.00). Parasitization was lowest on ICPW 125 (14.67) (Table 8).

Under multi choice condition, egg parasitisation of *H. armigera* by *T. chilonis* on petals did not differ significantly among the pigeon pea genotypes tested.

There were no significant differences in eggs parasitisation of *H. armigera* by *T. chionis* in flower buds of different genotypes both under no choice and multi choice condition (Table 8).

Parasitisation of of *H. armigera* eggs on pod surface of different pigeonpea genotypes under no choice condition differed significantly and was recorded highest on ICPB 2042 (27.71) followed by ICPL 87119 (22.76), ICPL 332 WR (14.32), T 21 (12.42), ICPL 84060 (9.11), ICPL 87 (8.12), LRG 41 (7.04), ICPL 87091 (6.00) and ICP 7035 (4.30). Lowest egg parasitisatin was recorded on ICPW 125 (3.10) (Table 8).

Under multi choice condition, higher egg parasitisation was recorded on the pods of ICPB 2042 (15.33), ICPL 332 WR (9.00), LRG 41 (8.33) and ICPL 84060 (8.00), as compared to that on the susceptible check, ICPL 87. Lowest egg parasitisation was recorded on the pods of ICPW 125 (2.33), followed by ICPL 87 (3.00), ICPL 87091 (4.33), ICPL 87119 (6.33), ICP 7035 (6.67) and T 21 (6.67) (Table 8).

4.1.2.2 Dual-choice condition

Parasitisation of *H. armigera* eggs by *T. chilonis* under dual-choice condition on lower leaf surface showed significant differences between the test genotypes and ICPL 87 (susceptible check). Egg parasitisation on ICPB 2042 (12.38), LRG 41 (11.42), ICPL 84060 (8.58), ICPL 87091 (8.28) was significantly higher than that on ICPL 87.

Table 8: Per cent parasitization of *H. armigera* eggs by *T. chilonis* on different parts of the pigeonpea plant under no-choice and multi-choice cage conditions (ICRISAT, Patancheru, 2010-2011)

Genotype	Lower leaf surface		Upper leaf surface		Calyxes		Petals		Flower buds		Pods	
	No-choice	Multi-choice	No-choice	Multi-choice	No-choice	Multi-choice	No-choice	Multi-choice	No-choice	Multi-choice	No-choice	Multi-choice
ICPL 87119	32.67 (34.61)	12.00 (19.53)	40.00 (39.21)^{cd}	15.67 (22.93)^{ab}	7.33 (15.56)^{ef}	4.60 (11.75)^{ab}	34.67 (36.02)^{bc}	11.67 (18.60)	29.00 (32.14)	6.00 (13.09)	22.76 (28.17)^{b}	6.33 (13.55)^{bc}
ICPL 87	24.00 (28.38)	7.33 (14.94)	34.00 (35.63)^{de}	9.33 (17.46)^{ab}	15.03 (22.60)^{cd}	8.00 (15.12)^{ab}	30.00 (33.18)^{c}	6.00 (13.20)	23.22 (27.84)	10.33 (18.40)	8.12 (16.40)^{de}	3.00 (9.72)^{bc}
ICP 7035	24.12 (29.21)	8.67 (16.62)	31.63 (34.19)^{de}	7.67 (15.55)^{b}	12.00 (20.06)^{de}	7.00 (14.96)^{ab}	24.23 (29.42)^{cd}	8.67 (16.64)	24.67 (29.02)	10.00 (17.92)	4.30 (11.32)^{f}	6.67 (14.38)^{bc}
LRG 41	28.42 (31.16)	11.00 (18.23)	55.32 (48.45)^{b}	15.00 (23.39)^{ab}	17.00 (24.20)^{cd}	11.00 (18.95)^{ab}	47.21 (43.46)^{ab}	18.67 (25.04)	33.00 (34.51)	13.33 (19.89)	7.04 (15.31)^{de}	8.33 (16.65)^{ab}
ICPL 87091	17.33 (24.35)	9.67 (18.09)	30.67 (33.56)^{de}	11.00 (19.33)^{ab}	19.54 (26.01)^{c}	6.33 (14.56)^{ab}	26.00 (30.58)^{c}	7.33 (15.48)	22.00 (27.25)	10.30 (18.38)	6.00 (14.14)^{e}	4.33 (11.99)^{bc}
ICPL 84060	19.21 (24.62)	9.33 (17.07)	27.43 (31.39)^{e}	17.00 (23.89)^{ab}	16.67 (24.04)^{cd}	13.67 (21.44)^{a}	23.00 (28.52)^{cd}	15.33 (22.57)	19.67 (24.75)	9.00 (17.30)	9.11 (17.38)^{d}	8.00 (16.40)^{ab}
T 21	32.12 (32.50)	5.00 (12.64)	54.34 (47.50)^{b}	8.67 (16.22)^{b}	28.55 (32.35)^{b}	4.67 (10.87)^{b}	45.44 (42.29)^{b}	10.00 (18.06)	28.60 (31.93)	10.67 (18.70)	12.42 (20.25)^{c}	6.67 (14.50)^{bc}
ICPL 332 WR	21.67 (25.85)	5.67 (12.79)	66.00 (54.37)^{a}	14.33 (21.84)^{ab}	19.45 (26.22)^{c}	9.33 (17.00)^{ab}	58.56 (50.01)^{a}	9.33 (17.12)	22.22 (27.19)	6.33 (14.43)	14.32 (21.96)^{c}	9.00 (16.82)^{ab}
ICPB 2042 (Hairy pods)	19.67 (25.95)	13.00 (20.88)	49.00 (44.42)^{bc}	28.00 (31.74)^{a}	39.46 (39.01)^{a}	12.00 (19.76)^{ab}	35.55 (36..44)^{bc}	13.67 (20.66)	31.66 (34.15)	16.67 (23.45)	27.71 (31.93)^{a}	15.33 (22.94)^{a}
ICPW 125	16.67 (14.89)	4.33 (11.05)	12.67 (20.79)^{f}	5.33 (13.26)^{b}	4.60 (12.41)^{f}	4.00 (14.28)^{ab}	14.67 (22.44)^{d}	5.33 (12.50)	12.21 (20.39)	7.33 (14.98)	3.10 (9.88)^{f}	2.33 (8.46)^{c}
SEm ±	6.24	3.39	1.94	3.87	1.78	3.01	2.42	3.85	6.02	3.42	0.90	2.35
LSD ($P_{0.05}$)	NS	NS	7.81	15.59	7.19	12.13	9.74	NS	NS	NS	3.63	9.47
CV (%)	18.67	16.00	8.63	11.87	12.77	13.33	11.89	17..02	20.05	13.54	8.38	18.04

NS = Non-significant.
Values in parentheses are Arcsine transformed.
The values followed by the same letter within a column are statistically non-significant at $p \leq 0.05$.

Whereas, ICPL 87 recorded higher egg parasitisation compared to ICPL 87119 (8.54), ICP 7035 (7.22), T 21 (5.80) and ICPL 332 WR (5.56). Lowest parasitisation was recorded on ICPW 125 (2.22) as compared to ICPL 87 (5.76) (Table 9).

Eggs parasitisation on the upper leaf surface compared to ICPL 87 was highest on ICPB 2042 (18.02 vs 7.60), followed by ICPL 332 WR (13.22 vs 10.68), ICPL 87091 (11.40 vs 9.24), ICPL 84060 (7.48 vs 5.96) and ICP 7035 (7.18 vs 6.26). There were no significant differences between ICPL 87119 and LRG 41 and ICPL 87. ICPW 125 and T 21 had lowest egg parasitisation as compared to ICPL 87 (Table 9).

Egg parasitisation on calyx was highest on, ICPB 2042 (11.26), LRG 41 (10.56), ICPL 332 WR (9.16) and ICPL 84060 (8.84) than on the susceptible check, ICPL 87 (6.46 to 8.44% parasitization). Parasitisation was significantly lower on ICPW 125 (3.98), T 21 (4.36), ICPL 87091 (6.44) and ICP 7035 6.86) as compared to the check genotype, ICPL 87 (7.04 to 8.72%). The per cent parasitisation of *H. armigera* eggs by *T. chilonis* on ICPL 87119 (8.62) and ICPL 87 (6.72) was same as revealed by non-sgnificant differences between two genotypes (Table 10).

On petals, the egg parasitisation was significantly higher on ICPL 87119 (15.22), ICPL 84060 (14.06), ICPL 332 WR (9.10), T 21 (8.80), ICP 7035 (8.74), ICPL 87091 (7.38), and as compared to the susceptible check, ICPL 87 (5.94 to 9.62% parasitisation). Egg parasitisation was lower on ICPW 125 (4.00) and ICPB 2042 (9.50) as compared to that on ICPL 87 (8.58 and 4.59% parasitisation, respectively). There were no significant differences between LRG 41 (8.22) and ICPL 87 (8.14), and between ICP 7035 (8.74) and ICPL 87 (8.20) (table 10).

Greater egg parasitisation was recorded on the flower buds of ICPB 2042 (14.90) LRG 41 (11.26) and ICP 7035 (9.02) than on the flower buds of the susceptible check, ICPL 87 (5.96 to 10.06% parasitisation, respectively). Egg parasitisation was lower on ICPW 125 (6.40), ICPL 332 WR (7.02), ICPL 84060 (8.32), ICPL 87119 (6.28) and T 21 (8.82) when compared to the susceptible check, ICPL 87. Egg parasitisation on ICPL 87091 (10.42) and ICP 7035 (9.02) did not differ significantly with that on the susceptible check, ICPL 87 (Table 10).

Table 9: Parasitization of *H. armigera* eggs on leaves of pigeonpea plants by *T. chilonis* under dual-choice cage conditions (ICRISAT, Patancheru, 2010-2011)

Genotype	Egg parasitization on leaves (%)					
	Lower			Upper		
	Test genotype	ICPL 87	t-value	Test genotype	ICPL 87	t-value
ICPL 87119	8.54 (16.99)	9.86 (18.25)	2.44*	9.90 (18.19)	8.62 (17.05)	1.21 NS
ICP 7035	7.22 (15.45)	8.74 (16.46)	3.79*	7.18 (15.53)	6.26 (17.18)	5.53*
LRG 41	11.42 (19.71)	8.46 (16.83)	2.71*	10.74 (19.05)	10.48 (18.75)	0.55 NS
ICPL 87091	8.28 (16.70)	6.80 (15.08)	3.45*	11.40 (19.71)	9.24 (17.69)	4.42**
ICPL 84060	8.58 (17.02)	6.70 (15.00)	3.59*	7.48 (15.86)	5.96 (14.12)	4.53*
T 21	5.80 (15.48)	7.38 (16.67)	5.03*	7.14 (13.89)	8.26 (15.76)	4.86*
ICPL 332 WR	5.56 (13.61)	7.90 (16.32)	4.13*	13.22 (21.32)	10.68 (19.01)	2.57*
ICPB 2042	12.38 (20.60)	8.36 (16.80)	8.80*	18.02 (25.10)	7.60 (15.99)	9.35*
ICPW 125	2.22 (8.46)	5.76 (13.86)	11.69*	3.44 (10.64)	7.56 (15.87)	3.98*

* = Significant at $P_{0.05}$. NS = Non-significant
Values in parentheses are Arcsine transformed.

Parasitisation of eggs on pod surface of ICPB 2042 (9.56), LRG 41 (8.46), ICPL 84060 (8.32), ICPL 87119 (5.74) and ICPL 87091 (4.38) was greater than the pods of the susceptible check, ICPL 87 (3.40 to 6.74% parasitisation), but ICPL 332 WR (3.78) and ICPW 125 (4.38) recorded per cent parasitisation lower than that on the susceptible check genotype ICPL 87 (8.16 and 6.76% parasitisation, respectively). Egg parasitisation of eggs on the pod surface of ICP 7035 (3.04) and T 21 (4.34) did not differ significantly than that on the susceptible check, ICPL 87 (3.52 and 4.14% parasitisation, respectively) (Table 10).

4.1.3 Influence of pigeonpea genotypes on parasitism of *Helicoverpa armigera* larvae by *Campoletis chlorideae* under no-choice, multi-choice and dual-choice cage conditions.

Under no-choice cage conditions, there were significant differences in larval parasitization on different pigeonpea genotypes and the highest percentage parasitization was recorded on ICPL 87 (61.74) followed by ICPL 87119 (52.55), ICPL 87091 (41.39), T 21(23.41), ICP 7035 (22.59), LRG 41 (18.47), ICPL 84060 (14.46), ICPL 332WR (7.45), ICPB 2042 (4.50), ICPW 125 (2.00) recorded significantly lower percentage of parasitisation compared to the other genotypes included in the study (Table 11).

Under multi-choice cage conditions, the percentage parasitization was highest on ICPL 87 (53.33) followed by ICPL 87119 (47.67). Significantly lowest parasitisation was recorded on ICPW 125 (0.13) followed by ICPB 2042 (1.32). The per cent parasitisation of *H. armigera* in the remaining genotypes varied from 7.46 to 35.33 (Table 11).

Under dual-choice conditions, when the parasitoid adults 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 (2.08vs 24.62) (Table 12).

The relative parasitisation preference (RPP) by *C. chlorideae* on different test genotypes compared to ICPL 87 ranged from -5.01 to -8.42%. Lowest RPP of -84.2%

Table 10: Parasitization of *H. armigera* eggs on reproductive parts of pigeonpea plants by *T. chilonis* under dual-choice cage conditions (ICRISAT, Patancheru, 2010-2011)

Genotype	Parasitization on calyxes (%)			Parasitization on petals (%)			Parasitization on flower buds (%)			Parasitization on pods (%)		
	Test enotype	ICPL 87	t-value	Test genotype	ICPL 87	t-value	Test genotype	ICPL 87	t-value	Test genotype	ICPL 87	t-value
ICPL 87119	8.62 (16.78)	6.72 (15.04)	0.70 NS	15.22 (22.96)	6.56 (14.80)	8.86*	6.28 (14.51)	9.00 (17.41)	4.64*	5.74 (13.77)	3.50 (10.63)	6.77*
ICP 7035	6.82 (15.13)	8.20 (16.64)	3.43*	8.74 (17.18)	8.20 (16.60)	0.69 NS	9.02 (17.45)	8.88 (17.26)	0.40	3.04 (9.99)	3.52 (10.67)	0.66 NS
LRG 41	10.56 (18.90)	6.46 (14.67)	4.78**	8.22 (16.65)	8.14 (16.53)	0.13 NS	11.26 (19.56)	5.96 (14.11)	2.13*	8.46 (16.88)	6.74 (14.94)	3.38*
ICPL 87091	6.44 (14.69)	8.10 (16.51)	8.16*	7.38 (15.76)	5.94 (14.09)	5.72*	10.42 (18.82)	9.31 (17.85)	1.53 NS	4.38 (12.03)	3.62 (10.85)	1.72 NS
ICPL 84060	8.84 (17.28)	7.14 (15.45)	3.53*	14.06 (21.98)	9.62 (17.88)	4.03*	8.32 (16.76)	9.88 (18.31)	2.79*	8.32 (16.76)	3.66 (10.46)	7.80*
T 21	4.36 (11.96)	7.04 (15.29)	4.41*	8.80 (17.27)	6.02 (26.22)	3.59*	8.82 (11.86)	19.12 (11.63)	1.90*	4.34 (17.24)	4.14 (14.19)	8.27*
ICPL 332 WR	9.16 (17.62)	7.65 (16.07)	5.91*	9.10 (17.56)	7.26 (15.55)	2.40*	7.02 (15.32)	8.94 (17.35)	3.93*	3.78 (11.12)	8.16 (16.59)	5.59*
ICPB 2042	11.26 (19.57)	8.44 (16.88)	3.50*	9.50 (17.97)	11.98 (20.25)	4.45*	14.90 (22.62)	10.06 (18.46)	6.41*	9.56 (17.98)	3.40 (10.56)	7.07*
ICPW 125	3.98 (11.46)	8.72 (17.11)	4.48*	4.00 (11.38)	8.58 (16.86)	3.52*	6.40 (14.59)	7.82 (16.14)	1.98	4.38 (11.94)	6.76 (14.97)	2.94*

* = Significant at $P_{0.05}$. NS = Non-significant
Values in parentheses are Arcsine transformed

Table 11: Influence of different pigeonpea genotypes on parasitisation of *H. armigera* by *Campoletis chlorideae* under no-choice and multi-choice conditions (ICRISAT, Patancheru, 2009-2010)

Genotypes	Parasitisation (%)	
	No choice condition	Multi-choice condition
ICPL 87119	52.55 ± 0.29 (46.46±0.34)[b]	47.67±1.45 (43.66±1.65)[b]
ICPL 87	61.74± 0.94 (51.79±1.19)[a]	53.33±1.76 (46.91±2.08)[a]
ICP 7035	22.59±0.52 (28.37±0.54)[d]	19.26±0.68 (26.02±0.69)[e]
LRG 41	18.47±0.51 (25.45±0.53)[e]	17.16±0.65 (24.46±0.66)[e]
ICPL 87091	41.39±0.73 (40.03±0.81)[c]	35.33±1.20 (36.46±1.28)[c]
ICPL 84060	14.46±0.41 (12.34±0.42)[f]	14.33±0.88 (22.22±0.89)[f]
T 21	23.41±0.43 (28.93±0.44)[d]	23.00±2.08 (28.61±2.14)[d]
ICPL 332 WR	7.45±0.29 (15.83±0.29)[g]	7.46±0.38 (15.83±0.38)[g]
ICPB 2042 (Hairy pods)	4.50±0.61 (11.76±0.62)[h]	1.32±0.06 (6.59±0.06)[h]
ICPW 125	2.00 ± 0.58 (7.94±0.58)[i]	0.13±0.01 (2.03±0.01)[i]
SEm±	0.93	0.73
LSD ($P_{0.05}$)	3.74*	2.96*
CV (%)	5.78	5.04

* = Significant at $P_{0.05}$.
Values in parentheses are Arcsine transformed.
The values followed by the same letter within a column are statistically non-significant at $p \leq 0.05$.

Table 12: Parasitization preference of *Campoletis chlorideae* females towards 2nd instar larvae of *H. armigera* on different pigeonpea genotypes under dual-choice conditions (ICRISAT, Patancheru, 2009-2010)

Genotype	Parasitisation (%)		t- value	RPP (%)
	Test genotype	ICPL 87		
ICPL 87119	49.27 (44.60)	54.46 (47.60)	4.15*	-5.01
ICP 7035	36.44 (37.09)	47.95 (43.84)	5.24*	-13.64
LRG 41	27.50 (31.87)	48.50 (44.39)	6.64*	-27.63
ICPL 87091	25.66 (30.36)	50.84 (45.50)	9.26*	-32.92
ICPL 84060	18.39 (25.35)	53.82 (47.22)	25.67*	-49.07
T-21	21.14 (27.24)	51.94 (46.14)	15.81*	-42.14
ICPL 332 WR	11.43 (19.51)	47.20 (43.41)	17.49*	-61.01
Hairy pods	6.99 (15.09)	27.06 (31.22)	09.94*	-58.96
ICPW 125	2.08 (8.22)	24.62 (29.63)	15.31*	-84.42

*The differences were statistically significant at $P_{0.05}$.
Relative parasitization preference = (No. of larvae parasitized on test variety - No. of larvae parasitized on standard variety) / (No. of larvae parasitized on test variety + No. of larvae parasitized on standard variety) X 100.
Figures in the parentheses are arcsine transformed values

was observed on ICPW 125 compared to check genotype ICPL 87. This was followed by ICPL 332 WR (-61.01%), ICPB 2042 (-58.96%), ICPL 84060 (-49.07%) and T 21 (-42.14%). In the remaining genotypes the RPP varied from -5.01 to -32.92.

Egg + larval period was signifacntly lowest on the ICPL 87 (7.33 days), being on par with ICPL 87119 (8.33 days). Longer egg + larval developmental period was recorded on ICP 7035 (11.00 days), ICPB 2042 (12.00 days), ICPL 332 WR (12.33 days) and ICPW 125 (16.00 days) (Table 13).

The pupal period was shorter on ICPL 87119 (7.68 days), being statistically on par with T 21 (8.07 days), ICPL 87 (8.21 days) and ICPL 87091 (8.64 days) as compared to that on ICPL 332 WR (9.40 days), ICP 7035 (9.57 days), ICPL 84060 (9.83 days) and LRG 41 (9.87 days). Pupal period was much longer on ICPB 2042 (12.17 days) and ICPW 125 (14.48 days) as compared to that on the susceptible check, ICPL 87 (Table 13).

The percentage cocoon formation was relatively better on ICPL 87119 (31.81) and ICP 7035 (33.57). Coccoon formation on ICPL 87 (22.03), T 21 (20.14), ICPL 84060 (19.93), ICPL 87091 (20.25) and LRG 41 (19.91) were on par, followed by ICPB 2042 (14.70) and ICPL 332 WR (14.28), which were on par. Lowest cocoon formation was recorded on ICPW 125 (9.00) (Table 13).

Adult emergence was highest on ICP 7035 (40.33) and LRG 41 (39.67) both being on par with other genotypes. Adult emergence was lowest on ICPW 125 (3.33) and ICPB 2042 (5.33) compared to other genotypes included in the study (Table 13).

Adult longevity of the parasitoid was longest on ICP 7035 (29.00 days) and ICPL 87091 (29.70) both being on par with each other. The adult longevity was lowest on ICPW 125 (10.70 days) and ICPB 2042 (14.33 days). Whereas in the remaining genotypes it varied from 18.00 to 23.00 days (Table 13).

4.1.4 Trichome density on different parts of different pigeonpea genotypes

Mean density (numbers/cm^2) of trichomes on the lower surface of the leaf surface of the leaves was highest in ICPW 125 (9.67) whereas type B trichome was significantly lowest in ICPW 125. The two types of trichomes was uniform in the

Table 13: Biology of the *Campoletis chlorideae* parasitizing 2nd instar *H. armigera* larvae released on different pigeonpea genotypes, collected after 48 hours, and reared on the artificial diet (ICRISAT, Patancheru, 2009-2010)

Genotypes	Egg + larval period (days)	Pupal period (days)	Cocoon formation (%)	Adult emergence (%)	Adult longevity (days)
ICPL 87119	8.33±0.33^{ab}	7.68±0.45^{a}	31.81±0.97 (34.22±1.02)^{a}	34.33±0.88 (35.87±0.94)^{eb}	19.00±1.53^{bc}
ICPL 87	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	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	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	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	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	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	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)	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	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}
SEm± LSD ($P_{0.05}$) CV (%)	0.425 1.264* 6.2	0.404 1.202* 7.1	0.74 2.98* 4.82	1.20 4.83* 7.77	1.718 5.11* 14.8

Values in parentheses are Arcsine transformed.
The values followed by the same letter within a column are statistically non-significant at $p \leq 0.05$.

remaining genotypes as revealed by non significant differences. Type C trichome was highest on ICPL 332 WR (6.65) followed by ICPL 87119 (3.67), ICPW 125 (3.00) and ICPL 84060 (3.00). Significantly highest number of type D trichome were observed on ICPW 125 (13.35) followed by ICPB 2042 (9.34) and ICPL 332 WR (5.33). In the remaining genotypes trichome density/cm^2 was uniform as indicated by non significant difference. ICPW 125 recorded maximum length of trichome D (4.20 mm) followed by ICPB 2042 (2.61). In the remaining genotypes the length of trichome D ranged from 1.27 to 1.60 (Table 14).

On the upper leaf surface, the type A trichome density was highest in ICPL 332 WR (4.32) and in the remaining genotypes it ranged from 0.65 to 2.67/cm^2. ICPL 87091 recorded highest number of type B trichomes (130.00), ICPL 84060 (98.23) and ICPL 87 (96.67); whereas ICPW 125 had no type B trichomes. Type C trichomes among different genotypes was uniform except LRG 41 which recorded highest number of 10 trichomes/cm^2. Type D trichomes were significantly highest in ICPW 125 (10.00), while in ICP 7035 it was least (0.33). In the remaining genotypes it varied from 1.00 to 2.00. The length of trichome D was uniform in all the genotypes except ICPW 125 which recorded highest length of 3.00 mm (Table 15).

On calyx the type A trichomes were highest in ICPL 87 (6.67) and lowest density of 0.33 trichomes/cm^2 were recorded in ICPL 87, LRG 41, ICPL 84060 and ICPW 125. Type B trichomes were highest in ICPL 87 (10.00) and lowest in ICPW 125 (1.33). Type C trichome was lowest in ICPW 125 (12.7) and highest in ICP 7035 (162.7), ICPL 84060 (155.7) and T 21 (173.7). Type D trichomes were highest in ICPW 125 (8.28) and lowest in ICPL 87091 (2.33) (Table 16).

On pod surface of different genoytpes, type A trichome were highest in ICPL 84060 (10.00) and ICPB 2042 (8.67) whereas on ICPW 125 they were absent. Type B trichome were significantly highest in ICPL 87 (5.00) and ICPL 87091 (4.00), whereas they were lowest in ICPW 125 (0.33). ICPW 125 recorded significantly highest number of 30.33 trichomes /cm^2; while ICPL 87 recorded significantly minimum of 8.67 trichomes and in the remaining genotypes it varied from 18.00 to 26.67. Type D trichomes were significantly highest in ICPW 125 (10.33) followed by ICPB 2042 (6.67) while in ICPL 87 it was minimum (2.00) being statistically on par with ICPL 87091 (2.67) and T 21 (2.67) (Table 17). Pod wall and pod pod length was lowest and pod wall thickness was highest in ICPW 125 (43.73, 3.30 and 0.97 mm, respectively) (Table 18).

Table 14: Mean density and types of trichomes per cm^2 on lower surface of the leaves of different pigeonpea genotypes (2010-2011)

Genotype	Type A	Type B	Type C	Type D	Length of Trichome D (mm)
ICPL 87119	1.67 (1.62)[a]	45.67 (6.78)[b]	3.67 (2.15)[c]	2.00 (1.71)[a]	1.60 (1.61)[bc]
ICPL 87	1.32 (1.52)[a]	84.33 (8.36)[b]	2.33 (1.82)[ab]	1.33 (1.52)[a]	1.32 (1.52)[ab]
ICP 7035	2.00 (1.71)[a]	58.67 (7.68)[b]	1.66 (1.62)[a]	2.32 (1.80)[a]	1.33 (1.46)[a]
LRG 41	1.33 (1.52)[a]	38.67 (6.16)[b]	1.67 (1.62)[a]	1.67 (1.62)[a]	1.67 (1.47)[a]
ICPL 87091	1.67 (1.62)[a]	42.33 (6.57)[b]	2.65 (1.91)[ab]	1.66 (1.62)[a]	1.27 (1.50)[ab]
ICPL 84060	1.32 (1.52)[a]	59.33 (7.77)[b]	3.00 (1.98)[bc]	1.68 (1.60)[a]	1.20 (1.48)[a]
T 21	1.65 (1.62)[a]	48.33 (6.95)[b]	2.64 (1.91)[ab]	1.64 (1.62)[a]	1.97 (1.72)[c]
ICPL 332 WR	2.32 (1.82)[a]	74.32 (8.67)[b]	6.65 (2.76)[d]	5.33 (2.51)[b]	1.43 (1.56)[ab]
ICPB 2042	1.64 (1.62)[a]	52.00 (7.23)[b]	2.65 (1.91)[ab]	9.34 (3.20)[c]	2.61 (1.89)[d]
ICPW 125	9.67 (3.25)[b]	0.00 (1.00)[a]	3.00 (1.98)[bc]	13.35 (3.77)[d]	4.20 (2.28)[e]
SEm±	0.12	1.01	0.10	0.14	0.38
LSD ($P_{0.05}$)	0.35	2.99	0.30	0.44	0.11
C V (%)	11.79	16.16	9.07	12.34	3.98

Values followed by same letter within a column are not significantly different at $P \leq 0.05$.
Figures in the parentheses are $\sqrt{X+1}$ transformed values

Table 15: Mean density and types of trichomes per cm^2 on upper surface of the leaves of different pigeonpea genotypes (2010-2011)

Genotype	Type A	Type B	Type C	Type D	Length of Trichome D (mm)
ICPL 87119	0.65 (1.28) [a]	72.67 (8.52) [bcd]	3.00 (2.00) [a]	2.00 (1.73) [c]	2.00 (1.73) [ab]
ICPL 87	1.00 (1.414) [a]	96.67 (9.86) [de]	3.00 (2.00) [a]	1.00 (1.414) [b]	1.50 (1.58) [ab]
ICP 7035	0.66 (1.28) [a]	46.32 (6.52) [b]	1.67 (1.62) [a]	0.33 (1.13) [a]	1.03 (1.53) [ab]
LRG 41	2.33 (1.82) [b]	60.00 (7.75) [bc]	10.00 (3.08) [b]	1.00 (1.414) [b]	1.00 (1.414) [a]
ICPL 87091	1.01 (1.414) [a]	130.00 (11.4) [e]	2.00 (1.71) [a]	1.00 (1.414) [b]	1.10 (1.45) [a]
ICPL 84060	1.00 (1.414) [a]	98.23 (9.89) [de]	2.00 (1.73) [a]	1.00 (1.414) [b]	1.00 (1.414) [a]
T 21	2.67 (1.91) [b]	52.00 (7.22) [bc]	1.00 (1.414) [a]	1.00 (1.414) [b]	1.00 (1.414) [a]
ICPL 332 WR	4.32 (2.30) [c]	68.23 (8.30) [bcd]	0.65 (1.28) [a]	1.00 (1.414) [b]	1.00 (1.414) [a]
ICPB 2042	2.00 (1.73) [b]	89.00 (9.33) [cde]	1.00 (1.414) [a]	2.00 (1.73) [c]	1.20 (1.48) [a]
ICPW 125	0.67 (1.28) [a]	0.00 (1.06) [a]	1.00 (1.414) [a]	10.00 (3.31) [d]	3.00 (2.44) [b]
SEm±	0.97	0.80	0.28	0.44	0.31
LSD ($P_{0.05}$)	0.28	2.36	0.82	0.12	0.93
C V (%)	10.69	10.36	10.22	4.61	3.51

Values followed by same letter within a column are not significantly different at $P \leq 0.05$.
Figures in the parentheses are $\sqrt{X+1}$ transformed values

Table 16: Mean density and types of trichomes per cm^2 on calyx of different pigeonpea genotypes (2010-2011)

Genotype	Type A	Type B	Type C	Type D
ICPL 87119	6.67 (2.76)^{e}	6.67 (2.76)^{de}	74.3 (8.79)^{b}	34.67 (5.97)^{f}
ICPL 87	0.33 (1.13)^{e}	10.00 (3.30)^{g}	95.0 (9.89)^{d}	6.00 (2.64)^{c}
ICP 7035	3.00 (1.98)^{c}	4.67 (2.37)^{bc}	162.7 (12.72)^{f}	7.67 (2.94)^{d}
LRG 41	0.33 (1.13)^{e}	7.67 (2.94)^{ef}	119.0 (11.04)^{e}	3.67 (2.15)^{b}
ICPL 87091	1.33 (1.52)^{b}	8.67 (3.10)^{fg}	105.0 (10.39)^{e}	2.33 (1.82)^{a}
ICPL 84060	0.33 (1.13)^{e}	5.67 (2.58)^{cd}	155.7 (12.59)^{f}	7.00 (2.82)^{cd}
T 21	4.67 (2.37)^{d}	7.00 (2.82)^{def}	173.7 (13.29)^{f}	12.00 (3.60)^{e}
ICPL 332 WR	1.33 (1.52)^{b}	4.00 (2.23)^{b}	61.0 (7.99)^{b}	41.67 (6.53)^{g}
ICPB 2042 (Hairy pods)	2.33 (1.82)^{bc}	3.67 (2.14)^{b}	104.0 (10.34)^{e}	4.67 (2.37)^{b}
ICPW 125	0.33 (1.13)^{a}	1.33 (1.52)^{a}	12.7 (3.95)^{a}	67.67 (8.28)^{h}
SEm±	0.11	0.10	0.43	0.77
LSD ($P_{0.05}$)	0.34	0.31	1.29	0.22
C V (%)	10.23	7.06	7.50	3.40

Values followed by same letter within a column are not significantly different at $P \leq 0.05$.
Figures in the parentheses are $\sqrt{X+1}$ transformed values

Table 17: Mean density and types of trichomes per cm^2 on pod surfaces of different pigeonpea genotypes (2010-2011)

Genotype	Type A	Type B	Type C	Type D
ICPL 87119	2.67 (1.91)^{bc}	1.67 (1.62)^{b}	24.00 (4.99)^{d}	4.00 (2.22)^{c}
ICPL 87	3.67 (2.15)^{c}	5.00 (2.44)^{d}	8.67 (3.10)^{a}	2.00 (1.71)^{a}
ICP 7035	2.00 (1.71)^{b}	2.00 (1.71)^{d}	20.67 (4.65)^{e}	3.67 (2.15)^{bc}
LRG 41	3.67 (2.15)^{c}	2.67 (1.91)^{bc}	26.67 (5.25)^{e}	3.67 (2.15)^{bc}
ICPL 87091	2.67 (1.91)^{bc}	4.00 (2.22)^{cd}	18.67 (4.43)^{bc}	2.67 (1.91)^{ab}
ICPL 84060	10.00 (3.31)^{d}	1.67 (1.62)^{b}	18.00 (4.36)^{bc}	3.67 (2.15)^{bc}
T 21	2.00 (1.71)^{b}	1.67 (1.62)^{b}	23.33 (4.92)^{d}	2.67 (1.91)^{ab}
ICPL 332 WR	1.67 (1.62)^{b}	1.67 (1.62)^{b}	25.00 (5.09)^{d}	4.67 (2.37)^{c}
ICPB 2042 (Hairy pods)	8.67 (3.10)^{d}	3.00 (1.98)^{bc}	18.67 (4.43)^{bc}	6.67 (2.76)^{d}
ICPW 125	0.00 (1.00)^{a}	0.33 (1.13)^{a}	30.33 (5.59)^{f}	10.33 (3.36)^{e}
SEm±	0.11	0.12	0.81	0.10
LSD ($P_{0.05}$)	0.33	0.36	0.24	0.30
C V (%)	9.38	11.93	3.01	7.82

Values followed by same letter within a column are not significantly different at $P \leq 0.05$.
Figures in the parentheses are $\sqrt{X+1}$ transformed values

Table 18. Morphological characters of pods of different pigeonpea genotypes (ICRISAT, Patancheru, 2010-2011)

Genotypes	Pod length (mm)	Pod width (mm)	Pod wall thickness (mm)
ICPL 87119	48.06^{b}	4.50^{bc}	0.54^{a}
ICPL 87	61.11^{c}	5.34^{cd}	0.36^{a}
ICP 7035	72.90^{d}	5.58^{d}	0.45^{a}
LRG 41	60.35^{c}	6.04^{d}	0.66^{ab}
ICPL 87091	71.25^{d}	4.03^{ab}	0.37^{a}
ICPL 84060	44.01^{b}	4.07^{ab}	0.32^{a}
T 21	46.10^{b}	4.46^{bc}	0.41^{a}
ICPL 332 WR	47.43^{b}	6.05^{d}	0.34^{a}
ICPB 2042 (Hairy pods)	43.73^{b}	4.14^{ab}	0.43^{a}
ICPW 125	20.08^{a}	3.30^{a}	0.97^{b}
SEm±	2.62	0.29	0.12
LSD ($P_{0.05}$)	7.77	0.86	0.34
CV (%)	8.8	10.5	41.2

** = Significant at $P_{0.01}$.
The values followed by the same letter within a column are not significantly different at $P \leq 0.005$.

4.1.5 Correlation between trichome density on different parts of pigeonpea genotypes and the oviposition preference by the *Helicoverpa armigera*

Under no-choice conditions, number of type A trichomes were negatively associated with the number of eggs laid on lower leaf surfaces, calyxes, petals and flower buds, but positively correlated with the number of eggs laid on upper leaf surface and pods. Type B and Type C trichomes were negatively correlated with the number of eggs laid on pods but positively correlated with remaining parts of the plant. Type D trichomes were negative correlation between the length of trichome D and the number of eggs laid on both the surfaces of leaves, but the correlation was significant on lower surface (Table 19).

Under dual-choice conditions, type A trichomes were negatively associated with the numbers of eggs laid on upper leaf surfaces, calyxes and flower buds, but positively correlated with the numbers of eggs laid on petals and pods. Type B trichomes were positively correlated with the number of eggs laid on all the parts of plant. Type C trichomes were negatively correlated with the number of eggs laid on lower leaf surface and pods, but positively correlated with the number of eggs laid on upper leaf surface, calyx, petals and flower buds. Type D trichome were significantly negatively correlated the number of eggs laid on calyxes, petals, flower buds and pods. Length of trichome D was negatively correlated with the numbers of eggs laid on lower and upper leaf surfaces (Table 20).

Under multi-choice conditions, type A trichomes were negatively correlated with the numbers of eggs laid on lower leaf surface, calyxes, petals, but positively correlated with the numbers of eggs laid on upper leaf surface, flower buds and pods. Type B trichomes were negatively correlated with the numbers of eggs laid on petals but positively correlated with the other parts of the plant. Type C trichomes were negatively correlated with the numbers of eggs laid on lower leaf surface and pods, but positively correlated with the numbers of eggs laid on upper leaf surface, calyxes, petals and flower buds. Type D trichomes were significant negatively correlated with all the parts of plant but the correlation of non significant with number of eggs on upper leaf surface and petals. Length of trichome D was negatively correlated with the numbers of eggs laid on lower and upper leaf surfaces (Table 21).

Table 19: Correlation coefficient between trichomes and oviposition preference under no-choice conditions

Trichome types	No. of eggs on 10 lower leaf surface	No. of eggs on 10 upper leaf surface	No. of eggs on 5 calyxes	No. of eggs on 10 petals	No. of eggs on 10 flower buds	No. of eggs on 10 pods
Type A	-0.40	0.28	-0.50	-0.45	-0.19	0.31
Type B	0.39	0.14	0.41	0.61	0.02	-0.08
Type C	0.36	0.40	0.25	0.37	0.30	-0.35
Type D	-0.02	-0.51	-0.30	-0.51	-0.36	-0.53
Length of Trichome D	-0.63*	-0.28				

* = Significant at $P_{0.05}$

Table 20: Correlation coefficient between trichomes and oviposition preference under dual-choice conditions

Trichome types	No. of eggs on lower leaf surface	No. of eggs on upper leaf surface	No. of eggs on 10 calyxes	No. of eggs on 10 petals	No. of eggs on 10 flower buds	No. of eggs on 10 pods
Type A	-0.43	-0.31	-0.24	0.16	-0.23	0.35
Type B	0.38	0.63*	0.31	0.10	0.33	0.47
Type C	-0.19	0.15	0.31	0.35	0.36	-0.84**
Type D	-0.49	-0.56	-0.75*	-0.68*	-0.78**	-0.78**
Length of Trichome D	-0.51	-0.49				

*, ** = Significant at P $_{0.05}$ and $_{0.01}$, respectively.

Table 21: Correlation coefficient between trichomes and oviposition preference under multi-choice conditions

Trichome types	No. of eggs on 10 lower leaf surface	No. of eggs on 10 upper leaf surface	No. of eggs on 5 calyxes	No. of eggs on 10 petals	No. of eggs on 10 flower buds	No. of eggs on 10 pods
Type A	-0.58	0.33	-0.23	-0.06	0.18	0.18
Type B	0.47	0.56	0.05	-0.21	0.11	0.45
Type C	-0.28	0.42	0.37	0.12	0.47	-0.82**
Type D	-0.69*	-0.56	-0.68*	-0.36	-0.63*	-0.68*
Length of Trichome D	-0.51	-0.58				

*, ** = Significant at P $_{0.05}$ and $_{0.01}$, respectively.

4.1.6 Correlation coefficient between the eggs laid on different parts of pigeonpea genotypes and the per cent parasitisation

There was no significant correlation in relative preference for eggs laid on different parts of pigeonpea genotypes and parasitisation by *T. chilonis* under no-choice, dual choice and multi-choice conditions (Table 22). Under no choice conditions, there was a positive association in the number of eggs laid on different plant parts, except on pods. Under dual-choice condition there was positive correlation between the number of eggs laid on the leaf surfaces and pods and parasitisation by *T. chilonis* and the correlation was negative between eggs laid on calyxes, petals, flower buds and parasitisation by *T. chilonis*. Under multi-choice conditions, there was positive correlation between the eggs laid on different parts of the plant and the parasitisation by *T. chilonis* suggesting that egg density largely influenced by the parasitisation by the egg parasitoid (Table 22).

4.1.7 Correlation coefficient between the trichomes on different parts of pigeonpea genotypes and the percentage parasitisation

Under no-choice conditions, there was postitive correlation between the type A trichomes and the per cent parasitisation on all the parts of the plant except lower leaf surface where it was significantly negative. Further there was postitive correlation between type B trichomes and per cent parasitisation on all parts of plant except calyxes and petals where the correlation was negative. There was positive correlation between the type C trichome and per cent parasitisation on all the parts of the pigeonpea plant except lower leaf surface and pods where the correlation was negative. Type D trichomes present on all parts of the pigeonpea plant had negative correlatin with the per cent parasitisation, but the correlation was significant with lower leaf surface, flower buds and pods (Table 23). The length of trichome D present on both the surfaces of leaves had negative significant correlation with the per cent parasitisation.

Under dual choice-conditions (Table 23), type A trichome present on lower leaf surface, calyx and flower buds had negative correlation with the per cent parasitisation, but the correlation was positive with that on upper leaf surface, petals and pods. Type B trichomes present on all parts of the pigeonpea plant had positive correlation with per cent parasitisation by *T. chilonis*. There was negative correlation between type C

Table 22: Correlation coefficient between eggs laid by *H. armigera* on different parts of pigeonpea genotypes and per cent parasitisation by *T. chilonis* under different choice conditions

	No-choice	Dual-choice	Multi-choice
Lower leaf surface	0.26	0.20	0.28
Upper leaf surface	0.37	0.28	0.11
Calyxes	0.40	-0.04	0.39
Petals	0.10	-0.19	0.19
Flower buds	0.44	-0.04	0.54
Pods	-0.05	0.26	0.16

Table 23: Correlation coefficient between different types of trichomes on various parts of pigeonpea genotypes and per cent parasitisation by *T. chilonis* under no-choice conditions

	Lower leaf surface	Upper leaf surface	Calyxes	Petals	Flower buds	Pods
Type A	-0.73**	0.87**	0.044	0.19	0.45	0.42
Type B	0.45	0.15	-0.098	-0.24	0.17	5
Type C	-0.08	0.22	0.40	0.097	0.45	-0.07
Type D	-0.73**	-0.57	-0.53	-0.096	-0.61*	-0.65*
Length of Trichome D (mm)	-0.61*	-0.63*				

*, ** = Significant at $P_{0.05}$ and $_{0.01}$, respectively.

trichomes and per cent parasitisation of *H. armigera* present on lower leaf surface and pods, but was positively correlated with other parts of the plant. Type D trichomes present on all parts of the plant had negative correlation with the per cent parasitisation. But this correlation was significant with calyx, flower buds and pods. The length of trichome D present on the leaves had significant negative correlation with per cent parasitisation (Table 24).

Correlation coefficient between different types of trichomes on various parts of pigeonpea genotypes and per cent parasitisation by *T. chilonis* under multi-choice conditions (Table 25) showed no significant difference, except on the trichome type D of calyx, flower buds and pods which showed significant negative correlation and type A trichome on the pods showed significant positive correlation with per cent parasitisation by *T. chilonis*. The length of trichome D on leaves had significant negative correlation with per cent parasitisation (Table 25).

4.2 Attractant/ Repellent effect and influence of pigeonpea genotypes on *T. chilonis* and *C. chlorideae*

4.2.1 Attractant/ Repellent properties of host genotypes on the *T. chilonis* and *C. chlorideae*

Response of the egg parasitoid, *T. chilonis* was more to the odors from ICP 7035 (17 wasps) than to the natural air, but the reverse was true in case of ICPL 84060 (4 wasps) and ICPL 87091 (7 wasps) (Table 26). Odors from the flowers of remaining genotypes were as attractive as the natural air (Table 26).

Under dual choice conditions, significantly more *T. chilonis* wasps were attracted to the odors from the flowers of ICP 7035 (16 wasps), but the odors from the flowers of ICPW 125 (4 wasps) and ICPL 84060 (5 wasps) exhibited a significant repellent effect when compared with the odors from the flowers of ICPL 87. There was no significant difference in the attraction of the parasitoids towards other genotypes compared to the susceptible check CPL 87 (Table 27).

More number of *C. chlorideae* (15-18 mated females) were attracted towards the stimuli from the flowers of all the pigeonpea genotypes, suggesting that, odors from the host plants play a significant role in host finding by the parasitoid females (Table 28).

Table 24: Correlation coefficient between different types of trichomes on various parts of pigeonpea genotypes and per cent parasitisation by *T. chilonis* under dual-choice conditions

	Lower leaf surface	Upper leaf surface	Calyxes	Petals	Flower buds	Pods
Type A	-0.71**	0.46	-0.10	0.51	-0.21	0.81
Type B	0.32	0.54	0.02	0.38	0.07	0.41
Type C	-0.34	0.04	0.06	0.34	0.33	-0.08
Type D	-0.35	-0.45	-0.61*	-0.24	-0.70**	-0.64*
Length of Trichome D (mm)	-0.62	-0.60				

** = Significant at $P_{0.01}$.

Table 25: Correlation coefficient between different types of trichomes on various parts of pigeonpea genotypes and per cent parasitisation by *T. chilonis* under multi-choice conditions

	Lower leaf surface	Upper leaf surface	Calyxes	Petals	Flower buds	Pods
Type A	-0.54	0.24	-0.49	0.01	-0.19	0.63*
Type B	0.13	0.44	0.21	0.49	0.13	0.38
Type C	-0.30	0.07	0.30	0.39	0.39	0.01
Type D	-0.23	-0.30	-0.68*	-0.42	-0.66*	-0.65
Length of Trichome D (mm)	-0.31	-0.37				

* = Significant at $P_{0.05}$.

Table 26: Response of *T. chilonis* females to odor stimuli from flowers of different pigeonpea genotypes in comparision to natural air (ICRISAT, Patancheru, 2009-2010)

Genotype	No. of females attracted		χ^2-test
	Test genotype	Natural air	
ICPL 87119	9	11	0.05
ICPL 87	11	9	0.05
ICP 7035	17	3	8.45 **
LRG 41	11	9	0.05
ICPL 87091	7	13	1.25
ICPL 84060	4	16	6.05 *
T 21	12	8	0.45
ICPL 332 WR	11	9	0.05
ICPB 2042 (Hairy pods)	14	6	2.45
ICPW 125	10	10	0.05

*, ** The differences were statistically significant at $P_{0.05}$ and $_{0.01}$, respectively
Total number of wasps = 20.

Table 27: Response of *T. chilonis* females to odor stimuli from flowers of different pigeonpea genotypes compared to the susceptible check, ICPL 87 under dual-choice conditions (ICRISAT, Patancheru, 2009-2010)

Genotype	No. of females attracted		^{2}-test
	Test genotype	ICPL 87	
ICPL 87119	11	9	0.05
ICP 7035	16	4	6.05**
LRG 41	13	7	1.25
ICPL 87091	12	8	0.45
ICPL 84060	5	15	4.05*
T 21	6	14	2.45
ICPL 332 WR	14	6	2.45
Hairy pods	8	12	2.45
ICPW 125	4	16	6.05**

*, ** The differences were statistically significant at $P_{0.05}$ and $_{0.01}$, respectively

Table 28: Response of *C. chlorideae* females to odor stimuli from flowers of different pigeonpea genotypes in comparision to natural air (ICRISAT, Patancheru, 2009-2010)

Genotype	No. of females attracted		χ^2-test
	Test genotype	Natural air	
ICPL 87119	19	1	14.45**
ICPL 87	18	2	11.25**
ICP 7035	16	4	6.05*
LRG 41	18	2	11.25**
ICPL 87091	18	2	11.25**
ICPL 84060	18	2	11.25**
T 21	18	2	11.25**
ICPL 332 WR	17	3	08.45**
ICPB 2042 (Hairy pods)	18	2	11.25**
ICPW 125	15	5	04.05*

*, ** The differences were statistically significant at $P_{0.05}$ and $_{0.01}$, respectively
Total number of wasps = 20.

In dual-choice tests significantly more number of parasitoids were attracted to the odors from the flowers of ICPL 87119 (17 wasps) than to flowers of ICPL 87 (3 wasps), but the reverse was true in case of ICPL 84060 (1 vs 19 wasps) and ICPW 125 (3 vs 17wasps). The odors from the flowers of ICP 7035 and ICPB 2042 were repellent to the females of *C. chlorideae*. There were no significant differences in relative response of *C. chlorideae* females between other test genotypes and the susceptible check, ICPL 87 (Table 29).

4.2.2 Influence of pigeonpea genotypes on the biology of *C. chlorideae* via *H. armigera*

Egg + larval period (days) of the *C. chlorideae* when parasitized *H. armigera* larvae was reared on leaves and flowers and on artificial diet containing lyophilized pod powder of different pigeonpea genotypes differed significantly. Egg + larval period was shortest when the *H. armigera* larvae were fed on the leaves of LRG 41 (8.3) and ICP 7035 (8.7), followed by ICPL 84060 (11.00) and ICPL 87 (11.7). The egg + larval period of *C. chlorideae* was relatively longer when the *H. armigera* were fed on the leaves of ICPL 87119 (12.70), ICPL 87091 (12.7) and T 21 (12.7). The egg + larval period of *C. chlorideae* was significantly prolonged when the *H. armigera* larvae were fed on the leaves of ICPW 125 (15.7), ICPL 332 WR (14.33) and ICPB 2042 (14.00) (Table 30).

When the *H. armigera* larvae were reared on flowers, shortest egg + larval period of *C. chlorideae* was recorded on ICPL 332 WR (6.3), ICP 7035 (6.3) and ICPL 87119 (6.8). The egg + larval period of *C. chlorideae* was significantly prolonged when the *H. armigera* larvae were fed on flowers of ICPW 125 (14.6), ICPB 2042 (13.6) and ICPL 87091 (12.6) (Table 29).

Longest egg + larval period of the parasitoid was recorded when the *H.armigera* larvae were fed on pods of ICPW 125 (11.33) and shortest on *H. armigera* larvae fed on pods of ICPL 84060 (6.83). The parasitoid egg + larval period in the remaining genotypes varied from 8.90 to 9.97 (Table 30).

Table 29: Response of *C. chlorideae* females to odor stimuli from flowers of different pigeonpea genotypes as compared to the susceptible check, ICPL 87 under dual-choice conditions (ICRISAT, Patancheru, 2009-2010)

Genotype	No. of females attracted		χ^2-test
	Test genotype	ICPL 87	
ICPL 87119	17	3	8.45**
ICP 7035	4	16	6.05*
LRG 41	14	6	2.45
ICPL 87091	13	7	1.25
ICPL 84060	1	19	14.45**
T-21	10	10	0.05
ICPL 332 WR	13	7	1.25
ICPB 2042 (Hairy pods)	5	15	4.05*
ICPW-125	3	17	8.45**

*, ** The differences were statistically significant at $P_{0.05}$ and $_{0.01}$, respectively

When the larvae of *H. armigra* reared on leaves, the pupal period of *C. chlorideae* was lowest on ICPL 84060 (6.3), followed by LRG 41 (6.7); whereas pupal period was longest on ICP 7035 (10.30). No parasitoid adults emerged from *H. armigera* larvae reared on ICPL 87 and ICPL 332 WR. When the *H. armigera* larvae were fed on the flowers of different pigeonpea genotypes, the pupal period of the parasitoid was shortest on ICPL 84060 (5.7), followed by ICPL 87091 (6.5), T 21 (6.6), ICP 7035 (7.0), ICPL 332 WR (7.3) and ICPL 87119 (7.5); whereas it was longest on ICPW 125 (9.8), LRG 41 (9.5), ICPB 2042 (8.8) and ICPL 87 (8.7). When the *H. armigera* larvae were reared on artificial diet having lyophilized pod powder, the pupal period was shortest on ICPL 87 (7.4), followed by ICPB 2042 (7.5), LRG 41 (7.7) and ICP 7035). The parasitoid pupal period was relatively longer on *H. armigera* larvae reared on diets with pod powder of ICPW 125 (10.00), followed by ICPL 87091 (9.1) (Table 31).

There was no cocoon formation of the parasitoid when the *H. armigera* larvae were reared on ICPL 332 WR leaves. Lowest cocoon formation was recorded on ICPW 125 (4.90). Highest cocoon formation was recorded on *H. armigera* larvae reared on LRG 41 (62.55), followed by those reared on ICP 7035 (39.77). Among the *H. armigera* larvae reared on flowers of different pigeonpea genotypes, cocoon formation was lowest on ICPW 125 (18.67), followed by ICPL 87119 (36.67). Cocoon formation was highest on ICPB 2042 (86.33) and LRG 41 (82.10) (Table 30).

Lowest cocoon formation was recorded when the *H. armigera* larvae were reared on artificial diets with lyophilized pod powder of LRG 41 (26.40), followed by ICPW 125 (26.53). Highest cocoon formation was recorded on T 21 (47.37) being on par with the remaining genotypes.

There was no adult emergence of *C. chlorideaae* on the *H. armigera* larvae reared on the leaves of ICPL 87119, ICPL 87 and ICPL 332 WR. Adult emergence was quite low on ICPW 125 (4.33), followed by ICPB 2042 (8.89), ICPL 87091 (11.94) and T 21 (15.62). The parasitoid adult emergence was significantly greater on ICP 7035 (37.00).

When the *H. armigera* larvae were reared on the flowers of different pigeonpea genotypes, lowest adult emergence of the parasitoid was recorded on on ICPW 125 (15.43), followed by ICPL 84060 (18.97) and ICPL 87091 (20.47). Adult emergence was highest on LRG 41 (69.44), ICPL 332 WR (66.22) and ICPB 2042 (65.80). Parasitoid adult emergence was lowest on *H. armigera* reared on the pods of ICPW 125 (23.03), whereas it was highest on ICPB 2042 (37.12) followed by ICPL 332 WR (35.20) (Table 30).

Lowest longevity of the parasitoid females was recorded on leaves of ICPW 125 (9.74), ICPB 2042 (10.66) and ICPL 87091 (10.93). Adult longevity was highest on the larvae fed on LRG 41 (34.71) and ICP 7035 (32.67). Adult longevity was lowest on *H. armigera* larvae reared on flowers of ICPW 125 (12.0), T 21 (15.8) and ICPL 332 WR (15.9). Parasitoid adult longevity was longest on ICPL 87 (35.3) followed by LRG 41 (32.4) and ICPL 84060 (31.2) (Table 30).

4.2.3 Consumption and utilisation of food by the parasitized and unparasitised larvae of *H. armigera*

4.2.3.1 Leaves

Consumption and utilization of leaves of different pigeonpea genotypes by the parasitized and unparasitized 4th instar larvae of *H. armigera* showed significant differences among the genotypes tested. Consumption index of the parasitized larvae was greater than that of the unparasitized larvae. Parasitized and unparasitized larvae of *H. armigera* reared on leaves of ICPW 125 had the lowest consumption index (0.42 and 0.29, respectively) and highest on ICPL 84060 (0.95) and LRG 41 (0.86), respectively (Table 31).

Approximate digestibility (AD%) of unparasitized larvae and parasitized larvae was lowest when fed on ICPW 125 (13.54 and 21.36, respectively). The AD of parasitized larvae differed significantly and in increasing order was: ICPL 87 (33.23) < ICPL 87119 (45.18) < ICPB 2042 (48.38) < ICPL 87091 (54.72) < T 21 (55.63) < LRG 41 (71.74) < ICP 7035 (73.20) < ICPL 84060 (78.38) < ICPL 332 WR (79.08). AD of the unparasitized larvae in the increasing order was; ICPB 2042 (46.36), followed by ICPL 87091 (48.65), ICPL 84060 (50.09), T 21 (52.10), ICPL 87 (52.47), ICPL 332

Table 30: Biology of *Campoletis chlorideae* parasitizing *H. armigera* larvae fed on leaves, flowers and lyophilized pod powders of different pigeonpea genotypes (ICRISAT, Patancheru, 2010-2011)

Genotypes	Egg + larval period (days)			Pupal period (days)		
	Leaves	Flowers	Lyophilized pod powder	Leaves	Flowers	Lyophilized pod powder
ICPL 87119	12.7 ± 0.33^{bc}	6.8 ± 0.17^{a}	9.97 ± 0.35^{bc}	7.8 ± 0.01^{b}	7.5 ± 0.09^{abc}	8.43 ± 0.47^{abcd}
ICPL 87	11.7 ± 0.34^{b}	11.9 ± 0.09^{d}	9.21 ± 0.60^{b}	--	8.7 ± 0.08^{bc}	7.4 ± 0.32^{a}
ICP 7035	8.7 ± 0.33^{a}	6.3 ± 0.09^{a}	9.33 ± 0.81^{bc}	10.3 ± 0.34^{d}	7.0 ± 0.12^{ab}	8.3 ± 0.07^{abcd}
LRG 41	8.3 ± 0.33^{a}	7.6 ± 0.12^{b}	9.73 ± 0.43^{bc}	6.7 ± 0.33^{a}	9.5 ± 0.27^{bc}	7.7 ± 0.17^{abc}
ICPL 87091	12.7 ± 0.88^{bc}	12.6 ± 0.14^{e}	9.14 ± 0.26^{b}	7.8 ± 0.17^{b}	6.5 ± 2.52^{ab}	9.1 ± 0.40^{de}
ICPL 84060	11.0 ± 1.16^{b}	8.7 ± 0.12^{c}	6.83 ± 0.7^{a}	6.3 ± 0.33^{a}	5.7 ± 0.18^{a}	8.6 ± 0.52^{bcd}
T 21	12.7 ± 0.88^{bc}	7.5 ± 0.15^{b}	9.03 ± 1.11^{b}	8.0 ± 0.01^{b}	6.6 ± 0.12^{ab}	8.7 ± 0.49^{cd}
ICPL 332 WR	14.33 ± 0.01^{c}	6.3 ± 0.09^{a}	9.76 ± 0.9^{bc}	--	7.3 ± 0.15^{ab}	8.7 ± 0.60^{cd}
ICPB 2042 (Hairy pods)	14.0 ± 0.01^{c}	13.6 ± 0.30^{f}	8.90 ± 0.06^{b}	8.00 ± 0.01^{b}	8.8 ± 0.15^{bc}	7.5 ± 0.13^{ab}
ICPW 125	15.7 ± 0.34^{c}	14.6 ± 0.30^{g}	11.33 ± 0.58^{c}	9.67 ± 0.16^{c}	9.8 ± 0.24^{bc}	10.0 ± 0.24^{e}
SEm±	0.60	0.17	0.63	0.21	0.81	0.34
LSD ($P_{0.005}$)	1.78	0.51	1.86	0.61	2.42	1.00
CV (%)	4.5	3.1	11.6	1.00	8.2	6.9

The values followed by the same letter within a column are not significantly different at $P \leq 0.005$.

Contd….

Table 30 Contd….

Genotypes	Cocoon formation (%)			Adult Emergence (%)		
	Leaves	Flowers	Lyophilized pod powder	Leaves	Flowers	Lyophilized pod powder
ICPL 87119	27.97 ± 0.36 (31.92 ± 0.60)^{c}	36.67 ± 2.03 (37.25 ± 2.18)^{d}	34.53 ± 7.06 (35.79 ± 7.61)^{ab}	0.00 ± 0.00 (0.00 ± 0.00)^{g}	27.67 ± 3.38 (31.64 ± 3.51)^{d}	30.87 ± 3.35 (33.68 ± 3.51)^{abcd}
ICPL 87	27.70 ± 0.74 (31.75 ± 0.69)^{c}	52.10 ± 1.16 (46.20 ± 1.36)^{c}	35.60 ± 8.67 (36.33 ± 9.40)^{ab}	0.00 ± 0.00 (0.00 ± 0.00)^{g}	33.24 ± 0.58 (35.20 ± 0.61)^{c}	32.87 ± 1.45 (34.97 ± 1.54)^{abc}
ICP 7035	39.77 ± 0.71 (39.09 ± 0.96)^{b}	50.67 ± 2.91 (45.38 ± 3.40)^{c}	29.47 ± 4.85 (32.73 ± 5.10)^{ab}	37.00 ± 1.84 (37.44 ± 1.86)^{a}	35.17 ± 0.44 (36.37 ± 0.47)^{bc}	30.50 ± 1.10 (33.51 ± 1.15)^{abcd}
LRG 41	62.55 ± 2.38 (52.28 ± 3.34)^{a}	82.10 ± 1.24 (64.99 ± 2.18)^{a}	26.40 ± 3.76 (30.80 ± 3.92)^{b}	31.03 ± 1.18 (33.84 ± 1.26)^{b}	69.44 ± 0.84 (56.44 ± 1.18)^{a}	26.70 ± 0.70 (31.10 ± 5.56)^{bcd}
ICPL 87091	21.53 ± 0.99 (27.63 ± 0.90)^{d}	59.67 ± 0.88 (50.57 ± 1.10)^{b}	41.40 ± 8.25 (39.88 ± 0.09)^{ab}	11.94 ± 0.91 (20.19 ± 0.89)^{d}	20.47 ± 0.79 (26.88 ± 0.80)^{e}	27.11 ± 2.33 (31.33 ± 2.42)^{bcd}
ICPL 84060	27.04 ± 1.06 (31.32 ± 1.25)^{c}	66.00 ± 1.01 (54.32 ± 1.34)^{a}	32.47 ± 3.31 (34.68 ± 3.52)^{ab}	33.00 ± 1.00 (35.20 ± 2.98)^{b}	18.97 ± 0.31 (25.81 ± 0.31)^{e}	24.47 ± 2.18 (29.59 ± 2.25)^{cd}
T 21	23.48 ± 2.57 (28.92 ± 2.82)^{cd}	51.79 ± 0.91 (46.02 ± 1.07)^{c}	47.37 ± 4.89 (43.48 ± 5.62)^{a}	15.62 ± 0.90 (23.26 ± 0.89)^{c}	38.06 ± 0.78 (38.09 ± 0.84)^{b}	26.63 ± 5.31 (30.87 ± 5.56)^{bcd}
ICPL 332 WR	0.00 ± 0.00 (0.00 ± 0.00)^{g}	64.55 ± 2.28 (53.47 ± 2.95)^{b}	37.63 ± 4.50 (37.78 ± 4.91)^{ab}	0.00 ± 0.00 (0.00 ± 0.00)^{g}	66.22 ± 0.62 (54.46 ± 0.82)^{a}	35.20 ± 1.89 (36.37 ± 2.01)^{ab}
ICPB 2042 (Hairy pods)	10.13 ± 0.95 (18.52 ± 1.00)^{e}	86.33 ± 2.73 (68.48 ± 2.28)^{a}	42.73 ± 1.51 (40.81 ± 1.67)^{ab}	8.89 ± 0.81 (17.30 ± 0.89)^{e}	65.80 ± 0.99 (54.21 ± 1.31)^{a}	37.12 ± 1.71 (37.52 ± 1.85)^{a}
ICPW 125	4.90 ± 1.07 (12.63 ± 1.24)^{f}	18.67 ± 2.40 (25.50 ± 2.44)^{e}	26.53 ± 2.31 (30.96 ± 2.40)^{b}	4.33 ± 1.20 (11.74 ± 1.20)^{f}	15.43 ± 0.43 (23.12 ± 0.43)^{f}	23.03 ± 2.67 (28.60 ± 2.70)^{d}
SEm±	0.96	1.28	3.27	0.89	0.80	1.65
LSD ($P_{0.005}$)	3.86	5.17	13.17	3.59	3.25	6.65
CV (%)	6.07	4.52	15.60	9.59	3.67	8.74

Values in parentheses are arcsine transformed.
The values followed by the same letter within a column are not significantly different at $P \leq 0.005$.

Contd…

Table 30 Contd….

Genotypes	Adult Longevity of females (days)		
	Leaves	Flowers	Lyophilized pod powder
ICPL 87119	-	22.0 ± 0.58^{d}	21.9 ± 0.4^{ab}
ICPL 87	--	35.3 ± 1.19^{g}	21.7 ± 1.4^{ab}
ICP 7035	32.67 ± 2.52^{d}	28.7 ± 0.88^{e}	21.0 ± 0.7^{ab}
LRG 41	34.71 ± 1.64^{d}	32.4 ± 0.32^{f}	23.6 ± 2.1^{bc}
ICPL 87091	10.93 ± 0.43^{a}	23.1 ± 0.59^{d}	26.7 ± 0.6^{cd}
ICPL 84060	26.33 ± 1.53^{c}	31.2 ± 0.50^{f}	21.0 ± 0.8^{ab}
T 21	14.84 ± 1.44^{b}	15.8 ± 0.10^{b}	26.4 ± 1.9^{cd}
ICPL 332 WR	--	15.9 ± 0.19^{b}	28.2 ± 0.8^{d}
ICPB 2042 (Hairy pods)	10.66 ± 1.21^{a}	19.7 ± 0.39^{c}	24.6 ± 2.4^{bcd}
ICPW 125	9.74 ± 0.65^{a}	12.0 ± 1.15^{a}	17.8 ± 1.0^{a}
SEm±	0.89	0.68	1.31
LSD ($P_{0.005}$)	2.74	2.02	3.89
CV (%)	8.8	5.0	9.7

The values followed by the same letter within a column are not significantly different at $P \leq 0.005$.

WR (55.75), ICPL 87119 (56.73), LRG 41 (58.87) and ICP 7035 (60.28). The unparasitized larvae exhibited lower AD than the parasitized larvae, except on ICPL 87119 and ICPL 87.

Efficiency of conversion of ingested food into body matter (ECI%) of parasitized and unparasitized *H. armigera* larvae varied significantly among the pigonpea genotypes tested. ECI of the unparasitized larvae was greater than that of the parasitized larvae. ECI of the parasitized larvae was lower on ICPW 125 (8.35), followed by ICPL 87119 (8.87), ICPL 87091 (8.87) and ICPL 332 WR (9.05) compared to the larvae fed on remaining genotypes. ECI of the unparasitized larvae was least on ICPL 332 WR (10.17) and highest on T 21 (29.81). ECI in the remaining genotypes I increasing order was: ICPL 87091 (13.90) < ICPB 2042 (17.57) and ICPL 87 (17.83) < ICPL 84060 (19.51) < ICP 7035 (23.47) < ICPL 87119 (28.07).

Efficiency of conversion of digested food into body matter (ECD%) of unparasitized larvae was greater than that of the parasitized larvae, except on ICP 7035. ECI of parasitized and unparasitized larvae was least on the leaves of ICPW 125 (9.40 and 12.10, respectively) and highest on the leaves of T 21 (35.39 and 57.22, respectively). ECD of parasitized larvae on ICPL 332 WR (10.17) was on par with ICPW 125 (Tsble 31).

4.2.3.2 Flowers

Consumption and utilization of flowers of different pigeonpea genotypes by the parasitized and unparasitized larvae differed significantly and it was least on ICPW 125 (1.33 and 2.06, respectively). The CI of the unparasitized larvae was greater than the parasitized larvae on different genotypes except ICPL 87, ICPL 87091 and LRG 41. CI of the parasitized larvae in increasing order was: ICPL 332 WR (1.93) < ICPB 2042 (2.20) = ICPL 87119 (2.29) < ICP 7035 (2.76) = T 21 (2.83) < LRG 41 (3.19) < ICPL 87091 (3.56) = ICPL 87 (3.72) = ICPL 84060 (3.81). CI of the unparasitized larvae in increasing order was: ICPL 332 WR (2.41) < ICP 7035 (2.78) = ICPB 2042 (2.85) = ICPL 87119 (3.03) < LRG 41 (3.11) < T 21 (3.37) < ICPL 87091 (3.46) = ICPL 87 (3.53) < ICPL 84060 (4.38) (Table 32).

Approximate digestibility (AD%) was better in the parasitized than the unparasitized larvae when reared on the flowers of different pigeonpea genotypes except on ICPL 84060 and ICPW 125. Least AD was recorded on ICPW 125 for the parasitized (46.41) and unparasitized (46.93) larvae. The AD in parasitized larvae in increasing order was on; ICPL 87119 (53.21), ICPL 332 WR (66.74), LRG 41 (72.27), ICPL 87091 (75.60), T 21 (76.19), ICPL 87 (79.84), ICPB 2042 (81.12), ICP 7035 (86.26) and ICPL 84060 (95.02). Similarly, in unparasitised larvae the AD in increasing order was on; ICPL 87119 (50.75), ICPL 332 WR (66.25), LRG 41 (69.75), ICPL 87091 (74.12), ICPL 87 (74.58), T 21 (75.69), ICPB 2042 (80.26), ICP 7035 (84.77) and ICPL 84060 (95.08).

Efficiency of conversion of ingested food into body matter (ECI%) of the parasitized larvae was lowest on T 21 (10.45) and ICPL 84060 (11.41) followed by ICPL 87091 (15.44) and ICPW 125 (18.35). The ECI values in the remaining genotypes in increasing order was ICPL 332 WR (21.02), ICPL 87 (21.73), ICPB 2042 (21.79), LRG 41 (25.11), ICP 7035 (26.44) and ICPL 87119 (26.46). ECI of the unparasitized larvae was lowest on ICPL 84060 (12.63). ECI in the remaining genotypes in increasing order was ICPL 87091 (17.90), ICPW 125 (19.96), T 21 (23.14), followed by ICPL 87 (24.05) and ICPB 2042 (24.66), LRG 41 (24.96), ICPL 332 WR (28.27), ICPL 87119 (28.84) and ICP 7035 (29.70) (Table 32).

Efficiency of conversion of digested food into body matter (ECD%) of the parasitized larvae was lowest on ICPL 84060 (11.76), followed by T 21 (13.10), ICPL 87091 (13.42) and ICPL 87 (14.10). ECD of unparasitised larvae was significantly lowest on ICPL 84060 (12.30), and the values in increasing order was; ICPL 87 (14.27) < ICPL 87091 (14.71) which was on par with T 21 (14.87) < LRG 41 (15.63) < ICPW (16.69) < ICPB 2042 (20.09) < ICPL 87119 (21.57) < ICPL 332 WR (22.01) < ICP 7035 (22.43) (Table 31).

4.2.3.3 Lyophilized pod powder

Consumption and utilization of lyophilized pod powder of different pigeonpea genotypes by the parasitized and unparasitized 4th insatr larvae of *H. armigera* diferred significantly among the pigeonpea genotypes tested. Consumption index (mg/mg/day) of the parasitized larvae was lowest on ICPW 125 (0.62) being on par with ICPL 332

WR (0.73), ICPL 84060 (1.04), ICP 7035 (1.13) and T 21 (1.14). CI of unparasitized larvae was lowest on ICPW 125 (0.74) which was on par with ICPL 332 WR (0.82). The CI in the remaining genotypes in increasing order were on; LRG 41 (1.34), T 21 (1.40), ICPL 84060 (1.45), ICP 7035 (1.54), ICPB 2042 (1.88) and ICPL 87091 (2.41), ICPL 87119 (2.57) and ICPL 87 (2.57). CI of parasitized larvae was lower than that of the unparasitied larvae except LRG 41 (Table 32).

Approximate digestibility (AD%) of the parasitized larvae was lowest on ICPW 125 (25.03) followed by ICPL 332 WR (43.18), ICPL 84060 (47.47), T 21 (55.18), ICPL 87119 (55.52) and LRG 41 (56.15). AD of the unparasitized larvae was lowest on ICPW 125 (26.62). The AD in remaining genotypes were on par with each other except ICPB 2042 (61.41), ICPL 87091 (64.10) and ICPL 87 (66.55). AD of the unparasitized larvae was greater than that of the parasitized larvae, and reverse in other genotypes ICPL 87, ICPL 87091, ICPB 2042 and ICPW 125.

ECI of the parasitized larvae was lowest on ICPW 125 (11.69), being on par with ICPL 332 WR (13.00), ICPL 84060 (15.48), LRG 41 (17.81) and ICPB 2042 (19.33). ECI of the unparasitized larvae was lowest on ICPW 125 (13.24), which was statistically on par with ICPL 332 WR (15.01), LRG 41 (18.88) and T 21 (22.52). ECI of the unparasitized larvae was greater than that of the parasitized larvae.

ECD of the unparasitized larvae was greater than that of the parasitized larvae and lowest ECD values of parasitized larvae were recorded on ICPW 125 (6.21) which was on par with ICPL 332 WR (7.56), ICPL 84060 (8.99) and LRG 41 (9.27). ECD of the unparasitized larvae was lowest on ICPW 125 (7.26) followed by ICPL 332 WR (9.36), LRG 41 (11.95), ICP 7035 (12.28), ICPL 84060 (12.67) and ICPL 87119 (12.68) (Table 33).

4.2.3.4 Biochemical composition of pigeonpea genotypes

The amounts of carbohydrate, total soluble sugars, starch, proteins, lipids, phenols and tannins differed in leaves, flowers and pods significantly across the genotypes tested. Lowest amount of carbohydrates were recorded in the leaves of susceptible genotype ICPL 87 (14.2 mg/g dw), followed by ICPL 87119 (29.4), T 21 (37.8), LRG 41 (48.5) and ICPL 87091 (68.2). The flowers of ICPW 125

Table 31: Consumption and utilization of leaves of different pigeonpea genotypes by the parasitized and unparasitized 4th instar larvae of *H. armigera* (ICRISAT, Patancheru, 2010-2011)

Genotypes	CI (mg/mg/day)		AD (%)		ECI (%)		ECD (%)	
	Parasitised larvae	Unparasitised larvae	Parasitised larvae	Unparasitised larvae	Parasitised larvae	Unparasitised larvae	Parasitised larvae	Unparasitised larvae
ICPL 87119	0.49^{ab}	0.53^{abcd}	45.18^{c}	56.73^{e}	8.87^{a}	28.07^{g}	14.96^{bc}	49.18^{i}
ICPL 87	0.53^{abc}	0.38^{ab}	33.23^{b}	52.47^{d}	12.18^{b}	17.83^{d}	14.64^{bc}	37.47^{h}
ICP 7035	0.84^{cd}	0.69^{cde}	73.2^{h}	60.28^{f}	20.85^{d}	23.47^{f}	33.21^{f}	32.84^{g}
LRG 41	0.79^{bcd}	0.86^{e}	71.74^{g}	58.87^{ef}	12.21^{b}	12.15^{b}	18.18^{de}	26.03^{f}
ICPL 87091	0.74^{abcd}	0.67^{cde}	54.72^{e}	48.65^{bc}	8.87^{a}	13.90^{c}	20.38^{e}	24.83^{e}
ICPL 84060	0.95^{d}	0.78^{de}	78.38^{i}	50.09^{cd}	14.94^{c}	19.51^{e}	16.91^{cd}	19.07^{d}
T 21	0.54^{abc}	0.37^{a}	55.63^{f}	52.10^{d}	19.80^{d}	29.81^{h}	35.39^{f}	57.22^{j}
ICPL 332 WR	0.59^{abc}	0.43^{abc}	79.08^{j}	55.75^{e}	9.05^{a}	10.17^{a}	10.92^{a}	17.15^{b}
ICPB 2042 (Hairy pods)	0.68^{abcd}	0.64^{bcde}	48.38^{d}	46.36^{b}	15.64^{c}	17.57^{d}	14.04^{b}	17.86^{c}
ICPW 125	0.42^{a}	0.29^{a}	21.36^{a}	13.54^{a}	8.35^{a}	12.06^{b}	9.40^{a}	12.10^{a}
SEm±	0.09	0.08	0.20	1.11	0.51	0.26	0.78	0.006
LSD ($P_{0.05}$)	0.29	0.25	0.60	3.26	1.51	0.78	2.32	0.019
CV (%)	26.1	25.4	0.6	3.8	6.7	2.5	7.2	4.1

The values followed by the same letter within a column are not significantly different at P≤0.05.
CI = Consumption index; AD = Approximate digestibility; ECI = Efficiency of conversion of ingested food into body matter; and ECD = Efficiency of conversion of digested food into body matter.

Table 32: Consumption and utilization of flowers of different pigeonpea genotypes by the parasitized and unparasitized 4th instar larvae of *H. armigera* (ICRISAT, Patancheru, 2010-2011)

Genotypes	CI (mg/mg/day)		AD (%)		ECI (%)		ECD (%)	
	Parasitised larvae	Unparasitised larvae	Parasitised larvae	Unparasitised larvae	Parasitised larvae	Unparasitised larvae	Parasitised larvae	Unparasitised larvae
ICPL 87119	2.29^{bc}	3.03^{c}	53.21^{b}	50.75^{b}	26.46^{e}	28.84^{g}	20.29^{g}	21.57^{g}
ICPL 87	3.72^{e}	3.54^{e}	79.84^{f}	74.58^{e}	21.73^{d}	24.05^{e}	14.10^{b}	14.27^{b}
ICP 7035	2.76^{cd}	2.78^{c}	86.26^{g}	84.77^{g}	26.44^{e}	29.70^{h}	22.03^{h}	22.43^{i}
LRG 41	3.19^{de}	3.11^{cd}	72.27^{d}	69.75^{d}	25.11^{e}	24.96^{f}	15.23^{c}	15.63^{d}
ICPL 87091	3.56^{e}	3.46^{e}	75.60^{e}	74.12^{e}	15.44^{b}	17.90^{b}	13.42^{b}	14.71^{c}
ICPL 84060	3.81^{e}	4.38^{f}	95.02^{h}	95.08^{h}	11.41^{a}	12.63^{a}	11.76^{a}	12.30^{a}
T 21	2.83^{cd}	3.37^{de}	76.19^{e}	75.69^{e}	10.45^{a}	23.14^{d}	13.10^{b}	14.87^{c}
ICPL 332 WR	1.93^{ab}	2.41^{b}	66.74^{c}	66.25^{c}	21.02^{d}	28.27^{g}	18.89^{f}	22.01^{h}
ICPB 2042 (Hairy pods)	2.20^{bc}	2.85^{c}	81.12^{f}	80.26^{f}	21.79^{d}	24.66^{ef}	17.45^{e}	20.09^{f}
ICPW 125	1.33^{a}	2.06^{a}	46.41^{a}	46.93^{a}	18.35^{c}	19.96^{c}	16.35^{d}	16.69^{e}
SEm±	0.22	0.11	0.91	0.51	0.66	0.28	0.34	0.14
LSD ($P_{0.05}$)	0.66	0.32	2.71	1.52	1.95	0.84	1.01	0.40
CV (%)	13.8	6.0	2.2	1.2	5.7	2.1	3.6	1.3

The values followed by the same letter within a column are not significantly different at P≤0.05.
CI = Consumption index; AD = Approximate digestibility; ECI = Efficiency of conversion of ingested food into body matter; and
ECD= Efficiency of conversion of digested food into body matter.

Table 33: Consumption and utilization of artificial diet containing lyophilized pod powders of different pigeonpea genotypes by the parasitized and unparasitized 4th instar larvae of *H. armigera* (ICRISAT, Patancheru, 2010-2011)

Genotypes	CI (mg/mg/day)		AD (%)		ECI (%)		ECD (%)	
	Parasitised larvae	Unparasitised larvae	Parasitised larvae	Unparasitised larvae	Parasitised larvae	Unparasitised larvae	Parasitised larvae	Unparasitised larvae
ICPL 87119	1.48 cde	2.57 d	55.52 bcd	54.88 bc	25.44 d	28.50 c	11.29 cde	12.68 abc
ICPL 87	1.73 de	2.57 d	66.38 d	66.55 c	26.45 d	30.40 c	14.11 e	16.75 c
ICP 7035	1.13 abcd	1.54 bc	58.10 cd	56.33 bc	23.96 cd	26.21 bc	11.14 bcde	12.28 abc
LRG 41	1.39 bcd	1.34 b	56.15 bcd	54.03 bc	17.81 abcd	18.88 abc	9.27 abcd	11.95 abc
ICPL 87091	2.07 e	2.41 d	60.29 cd	64.10 c	25.59 d	28.93 c	14.03 e	15.03 c
ICPL 84060	1.04 abc	1.45 bc	47.47 bc	43.51 b	15.48 abc	26.90 bc	8.99 abc	12.67 abc
T 21	1.14 abcd	1.40 bc	55.18 bcd	54.25 bc	22.44 bcd	22.52 abc	13.45 e	14.30 bc
ICPL 332 WR	0.73 ab	0.82 a	43.18 b	41.43 b	13.00 ab	15.01 ab	7.56 ab	9.36 ab
ICPB 2042 (Hairy pods)	1.30 bcd	1.88 c	58.73 cd	61.41 c	19.33 abcd	27.69 c	12.84 de	16.14 c
ICPW 125	0.62 a	0.74 a	25.03 a	26.62 a	11.69 a	13.24 a	6.21 a	7.28 a
SEm±	0.2	0.16	4.03	4.71	3.32	3.71	1.12	1.67
LSD ($P_{0.05}$)	0.60	0.47	11.97	13.98	9.8	11.02	3.33	4.97
CV (%)	17.6	16.6	13.3	15.6	18.6	17	17.9	12.6

The values followed by the same letter within a column are not significantly different at P≤0.005. CI = Consumption index; AD = Approximate digestibility; ECI = Efficiency of conversion of ingested food into body matter; and ECD= Efficiency of conversion of digested food into body matter

(48.9 mg/g dw) had the lowest amounts of carbohydrates, followed by ICPL 87119 (59.6), ICPL 87 (72.3), ICP 7035 (97.4), ICPL 87091 (107.1) and ICPB 2042 (108.40). Carbohydrate amounts in the pods of T 21 (146.6) were the lowest followed by ICPL 87119 (189.7), ICPL 87091 (201.0) and ICPL 87 (212.9) (Table 34).

Total soluble sugar (TSS) content was lowest in the leaves of T 21 (8.1) followed by LRG 41 (10.3), ICPL 87 (11.5), ICPL 87091 (13.9), ICPL 87119 (24.1) and ICPW 125 (26.7). Leaves of ICP 7035 (28.9) and ICPL 84060 (29.2) had similar amounts of TSS, followed by ICPB 2042 (33.5) and ICPL 332 WR (71.0). Lowest amount of TSS were recorded in the flowers of ICPW 125 (12.4), followed by ICP 7035 (19.6), ICPB 2042 (20.9), ICPL 87091 (21.3). Whereas ICPL 87119 recorded highest TSS of 130.8 followed by ICPL 87 (112.4). Lowest amounts of TSS were recorded were recorded in the pods of T 21 (64.9), followed by ICPL 87119 (83.78) and ICPL 87091 (87.9). There were no significant differences in TSS content of the pods of ICPL 87 (94.4), ICPL 332 WR (95.4), LRG 41 (96.1), ICPW 125 (97.5) and ICPB 2042 (98.0).

Leaves of ICPB 2042 (40.7) and ICPL 84060 (41.9) had the lowest quantity of starch, followed by ICPL 332 WR (46.4), ICPL 87091 (49.2), T 21 (52.1), LRG 41 (55.4) and ICPW 125 (57.4). Flowers of ICPW 125 (38.6) had lowest starch conent, followed by T 21 (60.4), ICPL 87119 (60.5), ICPL 332 WR (60.5) and LRG 41 (61.8). Pods of T 21 (99.2), ICPL 87 (99.9), ICPL 87119 (100.6) and ICPW 125 (100.0) had significantly lower amounts of starch content, as compared to that of ICPB 2042 (102.6), ICPL 332 WR (104.0), ICPL 84060 (104.8), ICPL 87091 (105.3), ICP 7035 (105.9) and LRG 41 (106.4).

Protein content was lowest in the leaves of ICPL 87 (5.3), followed by ICPL 84060 (6.2), ICPL 87091 (6.7), ICPL 332 WR (6.9) and ICPL 87119 (7.1). Protein content in the flowers of the genotypes did not differ significantly (2.5 to 6.2 mg/g dw), except ICPW 125 (9.13), which had higher protein content. Pods of ICPL 87091 (31.1) had the lowest protein content followed by ICPL 332 WR (34.2), LRG 41 (34.6), ICPL 84060 (35.2), ICP 7035 (35.5) and ICPL 87 (43.6).

ICPW 125 (70.6) leaves had the lowest lipid content, followed by T 21 (76.2), ICPB 2042 (85.7), ICPL 87 (90.0), ICP 7035 (96.0), ICPL 84060 (96.8) and LRG 41 (114.1). Lipid content in the flowers of ICPW 125 (0.7), ICPB 2042 (0.7), ICP 7035 (0.8), ICPL 84060 (0.8) and ICPL 332 WR (0.8) did not differ significantly. Pods of ICP 7035 (41.9) and LRG 41 (41.9) had lower lipid content, than other genotypes tested (Table 34).

Phenol content (mg/g dw) of leaves was lowest in ICPL 87119 (2.5) and ICPL 87 (2.5), followed by LRG 41 (15.3), ICPB 2042 (16.0) and ICPL 87091 (16.1) while flowers of T 21 (4.8) and ICPL 87091 (4.9) had lower phenol content. Whereas ICP 7035 (18.8) and ICPL 87119 (18.4) had higher phenol content. Pods of T 21 (15.0) had the lowest phenol content, followed by ICPW 125 (26.5); whereas it was highest in ICP 7035 (53.8) and ICPL 87091 (57.7) (Table 35).

Leaves of ICPL 87 (16.7) and ICPB 2042 (17.1) had lowest tannin content, followed by ICPL 87119 (21.3), LRG 41 (22.1), ICPL 84060 (22.3), T 21 (23.3) and ICPL 332 WR (23.3) had the lowest tannin content in the flowers, followed by T 21 (23.0), ICPL 87119 (26.8), ICPL 87091 (27.1), ICPB 2042 (31.1) and ICPW 125 (31.7). Pods of ICPB 2042 (30.7) and ICPW 125 (31.1) had lower tannin content than in ICPL 332 WR (38.2), ICPL 84060 (45.7), LRG 41 (45.7), ICPL 87 (54.5), ICP 7035 (54.5), ICPL 87119 (62.8) and T 21 (78.4) (Table 35).

4.3 Info-chemicals influencing parasitization of *H. armigera* (Hübner) eggs and larvae in pigeonpea

The odors from hexane extract of ICPB 2042 (2 vs 18 wasps) flowers exhibited a significant repellent effect on the egg parasitoid *T. chilonis* whereas in the remaining genotypes no significant differences were found in the response of the egg parasitoid, *T. chilonis* females to odor stimuli from the hexane extract of flowers of pigoenpea genotypes in comparision to the natural air (Table 36).

Table 34: Biochemical composition of different parts of pigeonpea genotypes

Genotype	Carbohydrate (mg/g dw)			Total soluble sugar (mg/g dw)			Starch (mg/g dw)			Protein (mg/g dw)			Lipids (mg/g dw)		
	Leaves	Flowers	Pods	Leaves	Flowers	Pods	Leaves	Flowers	Pods	Leaves	Flowers	Pods	Leaves	Flowers	Pods
ICPL 87119	29.4^{b}	59.6^{b}	189.7^{b}	24.1^{e}	130.8^{g}	83.78^{b}	76.8^{f}	60.5^{b}	100.6^{b}	7.1^{c}	6.2^{b}	64.28^{e}	124.3^{g}	1.4^{b}	57.3^{d}
ICPL 87	14.2^{a}	72.3^{c}	212.9^{d}	11.5^{c}	112.4^{f}	94.4^{d}	80.1^{g}	120.2^{e}	99.9^{ab}	5.3	4.2^{ab}	43.6^{c}	90.0^{d}	2.3^{c}	48.1^{b}
ICP 7035	141.1^{g}	97.4^{d}	229.0^{f}	28.9^{g}	19.6^{b}	101.0^{f}	61.5^{e}	67.8^{c}	105.9^{ef}	8.3^{e}	4.4^{ab}	35.5^{b}	96.0^{e}	0.8^{ab}	41.9^{a}
LRG 41	48.5^{d}	261.3^{h}	219.4^{e}	10.3^{b}	52.3^{e}	96.1^{de}	55.4^{d}	61.8^{bc}	106.4^{f}	12.9^{g}	4.5^{ab}	34.6^{b}	114.1^{f}	2.9^{c}	41.9^{a}
ICPL 87091	68.2^{e}	107.1^{e}	201.0^{c}	13.9^{d}	21.3^{b}	87.9^{c}	49.2^{bc}	105.1^{d}	105.3^{def}	6.7^{bc}	4.4^{ab}	31.1^{a}	123.8^{g}	2.5^{c}	74.6^{e}
ICPL 84060	141.6^{g}	150.3^{g}	231.2^{f}	29.2^{g}	31.1^{d}	102.7^{f}	41.9^{a}	63.3^{bc}	104.8^{de}	6.2^{b}	3.3^{ab}	35.2^{b}	96.8^{e}	0.8^{ab}	51.2^{c}
T 21	37.8^{c}	128.4^{f}	146.6^{a}	8.1^{a}	25.6^{c}	64.9^{a}	52.1^{c}	60.4^{b}	99.2^{a}	10.5^{f}	2.5^{a}	44.8^{c}	76.2^{b}	2.8^{c}	78.4^{f}
ICPL 332 WR	348.6^{i}	128.4^{f}	220.5^{e}	71.0^{i}	25.7^{c}	95.4^{de}	46.4^{b}	60.5^{b}	104.0^{d}	6.9^{c}	3.5^{ab}	34.2^{b}	132.3^{h}	0.8^{ab}	56.5^{d}
ICPB 2042	162.6^{h}	108.4^{e}	218.4^{de}	33.5^{h}	20.9^{b}	98.0^{e}	40.7^{a}	67.9^{c}	102.6^{c}	7.7^{d}	5.2^{ab}	47.7^{d}	85.7^{c}	0.7^{a}	76.0^{e}
ICPW 125	130.3^{f}	48.9^{a}	222.3^{e}	26.7^{f}	12.4^{a}	97.5^{e}	57.4^{d}	38.6^{a}	101.0^{b}	13.8^{h}	9.13^{c}	79.3^{f}	70.6^{a}	0.7^{a}	57.9^{d}
SEm±	0.57	0.51	1.91	0.27	0.58	0.87	1.07	2.15	0.43	0.2	1.0	0.59	1.06	0.21	0.66
LSD ($P_{0.005}$)	1.7	1.52	5.68	0.82	1.71	2.57	3.17	6.39	1.26	0.5	3.0	1.8	3.1	0.6	1.9
CV (%)	0.9	0.8	1.6	1.9	2.3	1.6	3.3	5.3	0.7	3.5	13.7	2.3	1.8	23.1	2.0

The values followed by the same letter within a column are not significantly different at $P \leq 0.05$.
g dw = gram dry weight.

Table 35: Amounts of secondary metabolites of different parts of pigeonpea genotypes

Genotype	Phenol (mg/gdw)			Condensed Tannin (mg/gdw)		
	Leaves	Flowers	Pods	Leaves	Flowers	Pods
ICPL 87119	2.5[a]	18.4[e]	37.8[c]	21.3[b]	26.8[c]	62.8[e]
ICPL 87	2.5[a]	11.8[c]	49.1[e]	16.7[a]	49.5[f]	54.5[d]
ICP 7035	22.0[d]	18.8[e]	53.8[f]	45.4[f]	19.0[a]	54.5[d]
LRG 41	15.3[b]	14.7[d]	44.5[d]	22.1[bc]	19.1[a]	45.7[c]
ICPL 87091	16.1[bc]	4.9[a]	57.7[g]	26.0[d]	27.1[c]	63.4[e]
ICPL 84060	18.2[c]	15.2[d]	44.4[d]	22.3[bc]	39.7[e]	45.7[c]
T 21	18.2[c]	4.8[a]	15.0[a]	23.3[c]	23.0[b]	78.4[f]
ICPL 332 WR	18.3[c]	11.7[c]	42.2[d]	23.3[c]	66.7[g]	38.2[b]
ICPB 2042	16.0[bc]	5.7[b]	36.0[c]	17.1[a]	31.1[d]	30.7[a]
ICPW 125	24.3[e]	11.7[c]	26.5[b]	28.8[e]	31.7[d]	31.1[a]
SEm±	0.73	0.17	1.27	0.6	0.69	0.51
LSD ($P_{0.005}$)	2.2	0.5	3.8	1.8	2.0	1.5
CV (%)	8.3	2.5	5.4	4.2	3.6	1.8

The values followed by the same letter within a column are not significantly different at $P \leq 0.05$.
gdw = gram dry weight.

Table 36: Response of *T. chilonis* females to the odor stimuli from the hexane extract of flowers of different pigeonpea genotypes in comparison to natural air (ICRISAT, Patancheru, 2011-2012)

Genotypes	No. of females attracted		χ^2-test
	Hexane extract of flowers	Natural air	
ICPL 87119	11	9	0.05
ICPL 87	9	11	0.05
ICPL 7035	12	8	0.45
LRG 41	12	8	0.45
ICPL 87091	14	6	2.45
ICPL 84060	6	14	2.45
T 21	10	10	0.05
ICPL 332 WR	11	9	0.05
ICPB 3042 (Hairy pods)	2	18	11.25 **
ICPW 125	14	6	2.45

** Significant at $P_{0.01.}$
No. of observations = 20

There was a significant repellent effect of the methanol extract of flowers of ICPB 2042 (5 vs 15 wasps), ICPL 87119 (5 vs 15 wasps) and LRG 41 (7 vs 19 wasps) towards the *T. chilonis* females, however, the odors from the flowers of ICPL 84060 (15 vs 5 wasps) attracted significantly more numbers of *T. chilonis* females as compared to the natural air (Table 37).

Hexane extract of flowers of ICPB 2042 attracted significantly more numbers of *C. chlorideae* mated females (17 vs 3 wasps) as compared to the natural air, but the hexane extract of flowers of remaining genotypes had no significant effect as compared to the natural air (Table 38).

Response of the laraval parasitod, *C. chlorideae* mated females to odor stimuli from the methanol extract of flowers of ICPL 87 (17 vs 3 wasps), ICPL 87119 (16 vs 4 wasps) and ICPW 125 (15 vs 5 wasps) exhibited an attractant effect; whereas methanol extract of flowers of other genotypes had no attraction/ repellent effect as compared to the natural air (Table 39).

Odor stimuli from the hexane extract of ICPB 2042 (17 vs 3) and ICPL 87119 (16 vs 4) pods had the attraction effect on the females of *T. chilonis*, but the hexane extract of pods of ICPL 84060 (4 vs 16) had the repellent effect on the females of *T. chilonis* (Table 40).

Response of the laraval parasitod, *C. chlorideae* mated females to odor stimuli from the hexane extract of pods of ICPL 87 (2 vs 18 wasps) and ICPL 84060 (4 vs 16 wasps) exhibited a repellent effect; However, there was no effect of hexane extract pods of remaining genotypes as compared to the natural air in their relative attraction of the mated females of *C. chlorideae* (Table 41).

Response of the parasitoid, *T. chilonis* females to odour stimuli from the methanol extract of pods of different genotypes in comparison to natural air showed neither attraction nor repellent effect in the genotypes ICPL 87, ICPL 332 WR, ICPB 2042, LRG 41 and ICP 7035. There was more attraction of the egg parasitoids towards the genotypes T 21, ICPL 84060, ICPL 87091 and ICPL 87119 but the ICPW 125 had the repellent effect (4 vs 16) (Table 42).

Table 37: Response of *T. chilonis* females to the odor stimuli from the methanol extract of flowers of different pigeonpea genotypes in comparison to natural air (ICRISAT, Patancheru, 2011-2012)

Genotypes	No. of females attracted		χ^2 test
	Methanol extract of flowers	Natural air	
ICPL 87119	5	15	4.05 *
ICPL 87	6	14	2.45
ICPL 7035	9	12	0.25
LRG 41	7	19	6.05 **
ICPL 87091	16	14	0.05
ICPL 84060	15	5	4.05 *
T 21	12	12	0.05
ICPL 332 WR	15	9	2.05
ICPB 3042 (Hairy pods)	5	15	4.05 *
ICPW 125	9	11	0.05

*, ** Significant at $P_{0.05}$ and $_{0.01}$, respectively.
No. of observations = 20

Table 38: Response of *C. chlorideae* females to the odor stimuli from the hexane extract of flowers of different pigeonpea in comparison to natural air (ICRISAT, Patancheru, 2011-2012)

Genotypes	No. of females attracted		χ^2 test
	Hexane extract of flowers	Natural air	
ICPL 87119	10	10	0.05
ICPL 87	10	10	0.05
ICPL 7035	11	9	0.05
LRG 41	14	6	2.45
ICPL 87091	8	12	0.45
ICPL 84060	11	9	0.05
T 21	9	10	0.05
ICPL 332 WR	10	10	0.05
ICPB 3042 (Hairy pods)	17	3	8.45 **
ICPW 125	8	12	0.45

** Significant at $P_{0.01.}$
No. of observations = 20

Table 39: Response of *C. chlorideae* females to the odor stimuli from the methanol extract of flowers of different pigeonpea genotypes genotypes in comparison to natural air (ICRISAT, Patancheru, 2011-2012)

Genotypes	No. of females attracted		χ^2 test
	Methanol extract of flowers	Natural air	
ICPL 87119	16	4	6.05*
ICPL 87	17	3	8.45**
ICPL 7035	7	13	1.25
LRG 41	12	8	0.45
ICPL 87091	14	6	2.45
ICPL 84060	12	8	0.45
T 21	6	14	2.45
ICPL 332 WR	13	7	1.25
ICPB 3042 (Hairy pods)	12	8	0.45
ICPW 125	15	5	4.05*

* Significant at $P_{0.05}$.
No. of observations = 20

Table 40: Response of *T. chilonis* females to odor stimuli from the hexane extract of pods of different pigeonpea genotypes in comparision to natural air (ICRISAT, Patancheru, 2011-2012)

Genotype	No. of females attracted		χ^2 test
	Hexane extract of pods	Natural air	
ICPL 87119	16	4	6.05*
ICPL 87	10	10	0.05
ICPL 7035	10	10	0.05
LRG 41	10	10	0.05
ICPL 87091	13	7	1.25
ICPL 84060	4	16	6.05*
T 21	7	13	1.25
ICPL 332 WR	12	8	0.45
ICPB 2042 (Hairy pods)	17	3	8.45**
ICPW 125	13	7	1.25

*, ** = Significant at $P_{0.005}$ and $_{0.001}$, respectively.
No. of observations = 20

Table 41: Response of *C. chlorideae* females to odor stimuli from the hexane extract of pods of different pigeonpea genotypes in comparision to natural air (ICRISAT, Patancheru, 2011-2012)

Genotype	No. of females attracted		χ^2 test
	Hexane extract of pods	Natural air	
ICPL 87119	10	10	0.05
ICPL 87	2	18	11.25**
ICPL 7035	10	10	0.05
LRG 41	6	14	2.45
ICPL 87091	11	9	0.05
ICPL 84060	4	16	6.05*
T 21	12	8	0.45
ICPL 332 WR	13	7	1.25
ICPB 2042 (Hairy pods)	13	7	1.25
ICPW 125	11	9	0.05

*, ** = Significant at P $_{0.005}$ and $_{0.001}$, respectively.
No. of observations = 20

Table 42: Response of *T. chilonis* females to odour stimuli from the methanol extract of pods of different pigeonpea genotypes in comparision to natural air (ICRISAT, Patancheru, 2011-2012)

Genotype	No. of females attracted		χ^2 test
	Methanol extract of pods	Natural air	
ICPL 87119	16	4	6.05 **
ICPL 87	13	7	1.25
ICPL 7035	12	8	0.05
LRG 41	12	8	2.05
ICPL 87091	17	3	8.45**
ICPL 84060	15	5	4.05 **
T 21	15	5	4.05 **
ICPL 332 WR	9	6	2.05
ICPB 2042 (Hairy pods)	8	12	0.45
ICPW 125	4	16	6.05 **

*, ** Significant at $P_{0.05}$ and $_{0.01}$, respectively.
No. of observations = 20

Larval parasitoid, *Campoletis chlorideae* females attracted towards odour stimuli from the methanol extract of pods of ICPL 87, ICPL 87119 and ICPL 87091, while in other genotypes neither the attraction nor the repellent effect was seen (Table 43) .

4.3.1 HPLC fingerprints of hexane extract of surface of the flowers of different pigeonpea genotypes

Hexane extracts of flowers of genotype ICPL 87 had maximum number of six peaks at peak 1, peak 2, peak 3, peak 5, peak 6 and peak 8, followed by five peaks in T 21 at peak 3, peak 4, peak 7, peak 10 and peak 12. Three peaks were observed in genotypes 87091 (peak 6, peak 7 and peak 11), ICPB 2042 (peak 6, peak 10 and peak 12) and ICPW 125 (peak 5, peak 10 and peak 12). Whereas minimum number of two peaks were recorded in ICP 7035 (peak 5 and peak 12), LRG 41 (peak 5 and peak 6), ICPL 84060 (peak 8 and peak 9) and ICPL 332 WR (peak 8 and peak 9) (Table 44).

4.3.2 HPLC fingerprints of methanol extract of surface of flowers of different pigeonpea genotypes

Methanol extracts of flowers of ICPL 87119 and ICPB 2042 had maximum number of ten peaks followed by nine in ICPL 87, ICP 7035 and T 21. ICPL 87091 had totally eight peaks. ICPW 125 had six peaks followed by four peaks in ICPL 84060 and three peaks in LRG 41. Lowest number of peaks were observed in ICPL 332 WR at peak 15 and peak 17 (Table 45).

4.3.3 HPLC fingerprints of hexane extract of pod surface of different pigeonpea genotypes

Hexane extract of pod surface of different pigeonpea genotypes indicated maximum of eight peaks in LRG 41, followed by five in ICPL 87091, T 21 and ICPL 332 WR. ICPL 87119, ICPL 87, ICP 7035 and ICPB 2042 had four peaks. ICPL 84060 and ICPW 125 had total number of two peaks, respectively (Table 46).

Table 43: Response of *C. chlorideae* females to odour stimuli from the methanol extract of pods of different pigeonpea genotypes in comparision to natural air (ICRISAT, Patancheru, 2011-2012)

Genotype	No. of females attracted		χ^2 test
	Methanol extract of pods	Natural air	
ICPL 87119	15	5	4.05 *
ICPL 87	15	5	4.05*
ICPL 7035	13	7	1.25
LRG 41	12	8	0.45
ICPL 87091	16	4	6.05 **
ICPL 84060	8	12	0.45
T 21	14	6	2.45
ICPL 332 WR	7	13	1.25
ICPB 2042 (Hairy pods)	12	8	0.45
ICPW 125	7	13	1.25

*, ** Significant at $P_{0.05}$ and $_{0.01}$, respectively.
No. of observations = 20

Table 44: HPLC finger prints of hexane extract of flower surface of different pigeonpea genotypes (ICRISAT, Patancheru, 2011-2012)

Genotype	Peak 1	Peak 2	Peak 3	Peak 4	Peak 5	Peak 6	Peak 7	Peak 8	Peak 9	Peak 10	Peak 11	Peak 12
	Retention time											
	0-1 min	1 - 2 min	2 - 2.5 min	2.5 - 3.0 min	3 - 3.5 min	3.5 - 4.0 min	5 - 6 min	17 - 18 min	23 - 24 min	40 - 41 min	45 - 46 min	50 -51 min
	Area	Area	Area	Area	Area	Area	Area	Area	Area	Area	Area	Area
ICPL 87	38740	30721	28997	00	285795	555336	00	414202	00	00	00	00
ICP 7035	00	00	00	00	608189	00	00	00	00	00	00	34704
LRG 41	00	00	00	00	275167	645641	00	00	00	00	00	00
ICPL 87091	00	00	00	00	00	1896221	827774	00	00	00	94695	00
ICPL 84060	00	00	00	00	00	00	00	116450	31057	00	00	00
T 21	00	00	47834	399938	00	00	7188	00	00	35930	00	54187
ICPL 332 WR	00	00	00	00	00	00	00	91513	17518	00	00	00
ICPB 2042	00	00	00	00	00	571056	00	00	00	29738	00	57918
ICPW 125	00	00	00	00	465015	00	00	00	00	20855	00	55143

Table 45: HPLC finger prints of methanol extract of flower surface of different pigeonpea genotypes (ICRISAT, Patancheru, 2011-2012)

Genotype	Peak 1	Peak 2	Peak 3	Peak 4	Peak 5	Peak 6	Peak 7	Peak 8	Peak 9	Peak 10	Peak 11
	Retention time										
	3 - 3.5 min	7 - 8 min	8 - 9 min	9 - 9.5 min	9.5 - 10 min	10 - 10.5 min	10.5 - 11 min	11 - 11.5 min	11.5 - 12 min	12 - 12.5 min	12.5 - 13 min
	Area	Area	Area	Area	Area	Area	Area	Area	Area	Area	Area
ICPL 87119	1536876	00	00	00	00	00	00	416049	601964	00	365287
ICPL 87	10584114	00	00	00	00	2533958	00	5774396	3873944	00	1736692
ICP 7035	2618926	00	00	00	00	639912	00	1680909	00	627787	247758
LRG 41	00	00	00	00	00	00	00	00	00	00	00
ICPL 87091	1654991	00	00	00	00	471162	00	1214735	00	313585	00
ICPL 84060	00	00	00	00	00	00	00	00	00	00	38726
T 21	1251335	00	00	00	00	240881	00	639671	569372	00	444460
ICPL 332 WR	00	00	00	00	00	00	00	00	00	00	00
ICPB 2042	2161165	109421	1318895	385327	781656	439988	280755	888168	00	750650	358810
ICPW 125	170137	00	00	575749	1341305	00	00	00	00	148983	00

Contd….

Table 45 contd…

Genotype	Peak 12	Peak 13	Peak 14	Peak 15	Peak 16	Peak 17	Peak 18
	Retention time						
	13 - 13.5	13.5 - 14	14 - 15	17 - 18	19 - 20	21 - 22	22 -23
	Area	Area	Area	Area	Area	Area	Area
ICPL 87119	225988	260279	1064139	00	232769	457291	732698
ICPL 87	00	1428865	3635609	00		2654936	4990951
ICP 7035	00	00	254059	00	411212	491173	791107
LRG 41	00	00	00	50070		31195	56058
ICPL 87091	00	253719	981485	00	00	216838	473514
ICPL 84060	00	00	00	14568	00	31746	55917
T 21	00	422846	953895	00	00	419587	579688
ICPL 332 WR	00	00	00	63879	00	31228	00
ICPB 2042	00	00	00	00	00	00	00
ICPW 125	387892	440446	00	00	00	00	00

Table 46: HPLC finger prints of hexane extract of pod surface of different pigeonpea genotypes (ICRISAT, Patancheru, 2011-2012)

Genotype	Peak 1	Peak 2	Peak 3	Peak 4	Peak 5	Peak 6	Peak 7	Peak 8	Peak 9	Peak 10	Peak 11	Peak 12	Peak 13	Peak 14
	Retention time													
	3 - 4.0	13 - 13.5	13.5 - 14	14 - 15	16 - 17	17 - 18	19 - 20	21 - 21.5	21.5 - 22	22 -23	23 - 24	24 -25	27 - 28	33 -34
	Area	Area	Area	Area	Area	Area	Area	Area	Area	Area	Area	Area	Area	Area
ICPL 87119	00	00	00	108049	00	00	00	99443	00	156480	00	31948	00	00
ICPL 87	00	00	100369	447934	00	00	00	205853	00	124566	00	00	00	00
ICP 7035	29403	00	00	00	34798	24236	00	22906	00	00	00	00	00	00
LRG 41	00	00	13622	46131	00	30870	00	45080	277	46507	25149	38926	00	00
ICPL 87091	00	76553	127603	652871	00	00	00	101209	00	163445	00	00	00	00
ICPL 84060	00	00	00	178653	00	00	00	56012	00	83422	00	00	00	00
T 21	00	00	120995	856854	00	00	00	181218	71241	177155	00	00	00	00
ICPL 332 WR	00	00	00	179123	00	00	32560	200044	74735	267978	00	00	00	00
ICPB 2042	00	00	00	114656	00	00		00	00	00	00	195630	21680	262171
ICPW 125	00	00	00	00	00	100098	48540	00	00	00	00	00	00	00

4.3.4 HPLC fingerprints of methanol extract of pod surface of different pigeonpea genotypes

HPLC fingerprints of methanol extract of pod surface of different pigeonpea genotypes indicated highest number of peaks in T 21 and ICPL 332 WR followed by 11 peaks in ICPL 87. ICP 7035 and LRG 41 had nine peaks followed by eight peaks in ICPL 87119, ICPL 84060, ICPB 2042 and ICPW 125. Lowest number of seven peaks were observed in ICPL 87091 (Table 47).

4.3.5 Responsse of *T. chilonis* and *C. chlorideae* females to volatile compounds

Egg parasitoid, *T. chilonis* and the larval parasitoid, *C. chlorideae* responded positively towards the volatile compounds (E)-Alpha-Farnesene (17 and 16 wasps, respectively), Methylbenzoate (15 and 15 wasps, respectively) (Z)-3-Hexenanol (16 and 18 wasps, respectively) and Linalool (18 and 19, wasps respectively) but there was neither attraction nor repellent effect towards the benzaldehyde (9 and 9 wasps, respectively) and Acetaldehyde (12 and 12 wasps, respectively). ß-Caryophyllene attracted the egg parasioid, *T. chilonis* (19 wasps), but not the larval parasitoid, *C. chlorideae* (12 wasps) (Table 48 and 49).

Table 47: HPLC finger prints of methanol extract of pod surface of different pigeonpea genotypes (ICRISAT, Patancheru, 2011-2012)

Genotype	Peak 1	Peak 2	Peak 3	Peak 4	Peak 5	Peak 6	Peak 7	Peak 8	Peak 9
	Retention time								
	3 - 4.0	4.0 - 5.0	6 - 7	8 - 8.5	8.5 - 8.7	8.7 - 9.0	9 - 9.5	9.5 - 11	11 - 11.5
	Area	Area	Area	Area	Area	Area	Area	Area	Area
ICPL 87119	307843	00	00	60291	00	00	255312	00	150919
ICPL 87	510807	00	00	103883	189850	115018	170455	142759	464268
ICP 7035	473203	00	145411	77277	131493	00	00	78592	707527
LRG 41	668429	00	00	98823	153255	00	114316	68150	798492
ICPL 87091	394667	00	00	00	00	00	00	00	00
ICPL 84060	176188	00	00	00	00	00	89238	70162	140101
T 21	370497	00	00	68285	99095	67036	171211	73060	180955
ICPL 332 WR	316747	00	00	55856	99852	72712	353785	174997	145931
ICPB 2042	61140	00	00	00	00	00	00	53401	43111
ICPW 125	52123	30604	29285	00	00	00	28508	44305	41283

Contd…

Table 47 contd….

Genotype	Peak 10	Peak 11	Peak 12	Peak 13	Peak 14	Peak 15	Peak 16
	Retention time						
	13 - 13.5	13.5 – 14.5	14.5 - 15.00	16 - 17	19 - 20	21 - 21.5	22 -23
	Area	Area	Area	Area	Area	Area	Area
ICPL 87119	00	00	834561	00	206967	415392	741796
ICPL 87	00	302049	1020945	00	00	244203	475903
ICP 7035	00	00	241203	00	00	155752	237963
LRG 41	00	00	00	00	190017	275030	474852
ICPL 87091	215006	276337	1361139	00	172456	333725	567844
ICPL 84060	00	00	498154	00	218262	330395	575233
T 21	00	165008	1284383	187852	110028	450510	668370
ICPL 332 WR	00	90621	635029	101771	467833	731339	1241432
ICPB 2042	00	86874	548704	00	163570	376703	669388
ICPW 125	00	55023	137975	00	00	00	00

Table 48: Response of *T. chilonis* females to odor stimuli from the volatiles in comparison to natural air (ICRISAT, Patancheru, 2010-2011)

Volatile compounds	Number of females attracted		χ^2-test
	Compounds	Natural air	
(E)-Alpha-Farnesene	17	3	8.45**
Benzaldehyde	9	11	0.05
Methylbenzoate	15	5	4.05*
Acetyldehyde	12	9	0.25
Beta-Caryophyllene	19	1	14.45**
(Z)-3-Hexenanol	16	4	6.05*
Linalool	18	2	11.25**

*, **= Significant at $P_{0.05}$ and $P_{o.01}$, respectively. N=20

Table 49: Response of *C. chlorideae* females to odor stimuli from the volatiles in comparison to natural air (ICRISAT, Patancheru, 2010-2011)

Volatile compounds	Number of females attracted		χ^2-test
	Compounds	Natural air	
(E)-Alpha-Farnesene	16	4	6.05*
Benzaldehyde	9	11	0.05
Methylbenzoate	15	5	4.05*
Acetyldehyde	12	9	0.25
Beta-Caryophyllene	12	9	0.25
(Z)-3-Hexenanol	18	2	11.25**
Linalool	19	1	14.45**

*, **= Significant at $P_{0.05}$ and $P_{o.01}$, respectively. N=20

5. DISCUSSION

Within a given plant, plant parts may vary in their physical and chemical attributes such as trichome types and densities, biochemical components present in the plant and the associated allelochemicals, or infochemicals. Chemical and physical attributes (e.g. surface indumentums and structural profile or growth habit) that may vary influence plant attractively may vary even within species, depending on factors such as the number of trichomes, biochemical composition, concentration and presence or absence of volatiles and growth habit of the genotypes.

The increased use of parasitoids in biological control programme has led to numerous studies on factors influencing parasitoid-pest interaction system. Physical, chemical and antogenic factors largely elaborated by plants and insects both have been reported to be of vital significance in eliciting host seeking action in number of natural enemies. Information regarding tritrophic interaction between pod borer, parasitoids, and accessions was essential in pigeonpea in which there are meager studies. Tritrophic interaction is an integral part of biological control programme and in turn the integrated pest management.

The results obtained on the tritropic interactions between pigeonpea genotypes, *H. armigera* and natural enemies are discussed in the context of the earlier published information

5.1 Identification of pigeonpea genotypes that are hospitable to *T. chilonis* and *C. chlorideae*

5.1.1 Oviposition preference by *Helicoverpa armigera*

Under no-choice conditions (Fig. 1), the overall egg laying by *H. armigera* on the inflorescence irrespective of plant parts was minimum in ICPW 125 (10.01) followed by ICPL 87119 (40.96) exhibiting antixenosis effect on these genotypes. Sujana et al. (2008) reported high levels of antixenosis for oviposition on ICPW 125 under no choice, dual choice and multi choice conditions which is in agreement with the present findings. The very dense non-gandular trichomes (Type D) and longer length of

type D trichomes provided a physical barrier for the adult *H. armigera* to lay the eggs on ICPW 125, which agrees with the findings of Peter et al. (1995). Irrespective of the genotypes flower buds were least preferred by *H. armigera* for oviposition followed by petals and calyxes; whereas, leaves and pods were highly preferred for oviposition by *H. armigera*, which corroborated with the findings of Zibtz (2006) who report that the leaves were least preferred for egg laying by *H. armigera*. In the present study the leaves of ICPL 87 were for egg laying compared to other genotypes included in the study, which agrees with the findings of Zibtz (2006) but contradict with the eggs laid on the pods of ICPL 332 WR in the present study as it was least preferred.

Oviposition under no choice condition (Fig. 1) by *H. armigera* was higher on all pigeonpea genoytpes in general compared to multi choice condition. This was mainly because the adult females were forced to lay eggs on the particular genotypes as there was no choice for egg laying. The correlation between the egg laying and trichome density was non-significant under no choice conditions except on lower leaf surface where the length of the trichome D and egg laying was significant negative correlation with egg laying. Under dual choice conditions all the test genotypes were least preferred for egg laying by *H. armigera* compared to ICPL 87 (susceptible check).

Under multi choice conditions, there was no significant correlation between egg laying and the trichomes except type D trichomes on upper leaf surface, and there was negative significant correlation between type D trichomes and egg laying by *H. armigera* on all the parts of plant except on the leaf surface. Egg laying was minimum on ICPW 125 and higher on ICPL 87 (susceptible check) which agrees with the findings of Sujana et al. (2008). In general more number of eggs were laid on the lower (abaxial) leaf surface due to more numbr of type C trichomes than the upper leaf surface (adaxial) which was in corroboration with the findings of Navesero and Ramaswawmy (1991) who reported that the reasons for increased oviposition on the abaxial surface was probably due to higher densities of trichomes. This was not true in case of no-choice conditions in most of the genotypes may be due to the difference in the conditions with that in the multi choice conditions wherein, volatiles emitted by other genotypes or change in vision or variation in total number of plant parts available or the blend of volatiles may influence the stimuli for egg laying by the *H. armigera*.

Under no choice, dual choice and multi choice (Fig. 1 – 4) conditions egg laying was more on ICPL 87 and less on ICPL 332 WR and ICPW 125. This may be due to higher number of volatile compounds present in the hexane extract of flowers of ICPL 87 and less number of volatiles present in the hexane extract of flowers in resistant genotypes i.e. ICPL 332 WR and ICPW 125 as observed in the HPLC data. ICPW 125 was least preferred by *H. armigera* which may be due to lower number of volatile compounds both of hexane and methanol extract of flowers as seen in the HPLC data. This was also supported by the findings of Navasero and Ramaswamy (1991) who reported that in field cages, plants with erect growth habitat (cultivated pigeonpea genotypes) were more acceptable to females than with the procumbent (ICPW 125) growth habitat. Acceptability of erect type may be partially due to the larger size (height and spread), which increases the likelihood of contact by the insect and they also suggested that the involvement of vision in host discrimination was based on use of structural profile.

ICPW 125 recorded lower number of type A trichome on pod surface, which was not preferred for egg laying by the *H. armigera* and ICPL 87 recorded the higher number of type A trichomes on pod surface which was preferred by the *H. armigera* (Table 17). Conversely, type C trichome on pod surface was lower on ICPL 87 than on ICPW 125. Higher number of type C trichome on ICPW 125 was not preferred for egg laying and the lower number of type C trichomes on ICPL 87 was preferred for egg laying by the *H. armigera* (Table 17).

5.1.2 Influence of pigeonpea genotypes on parasitisation of *H. armigera* eggs by *T. chilonis*

Parasitisation of *H. armigera* eggs by *T. chilonis* on different pigeonpea genotypes differed under no-choice, dual-choice and multi-choice conditions (Fig. 5 – 8). In general higher egg parasitisation was recorded under no-choice conditions (Fig. 5) as compared to multi-choice conditions (Fig. 6). This was due to the forced searching of eggs by *T. chilonis* for parasitization and absence of other genotypes under no choice condition which may be having repellent effect on *T. chilonis*.Under no choice conditions, LRG 41, T 21, ICPL 332 WR and ICPB 2042 recorded more than 30 per cent parasitisation. Under multi choice conditions ICPB 2042, LRG 41 and ICPL 84060 recorded higher percentage of parasitisation compared to other genotypes.

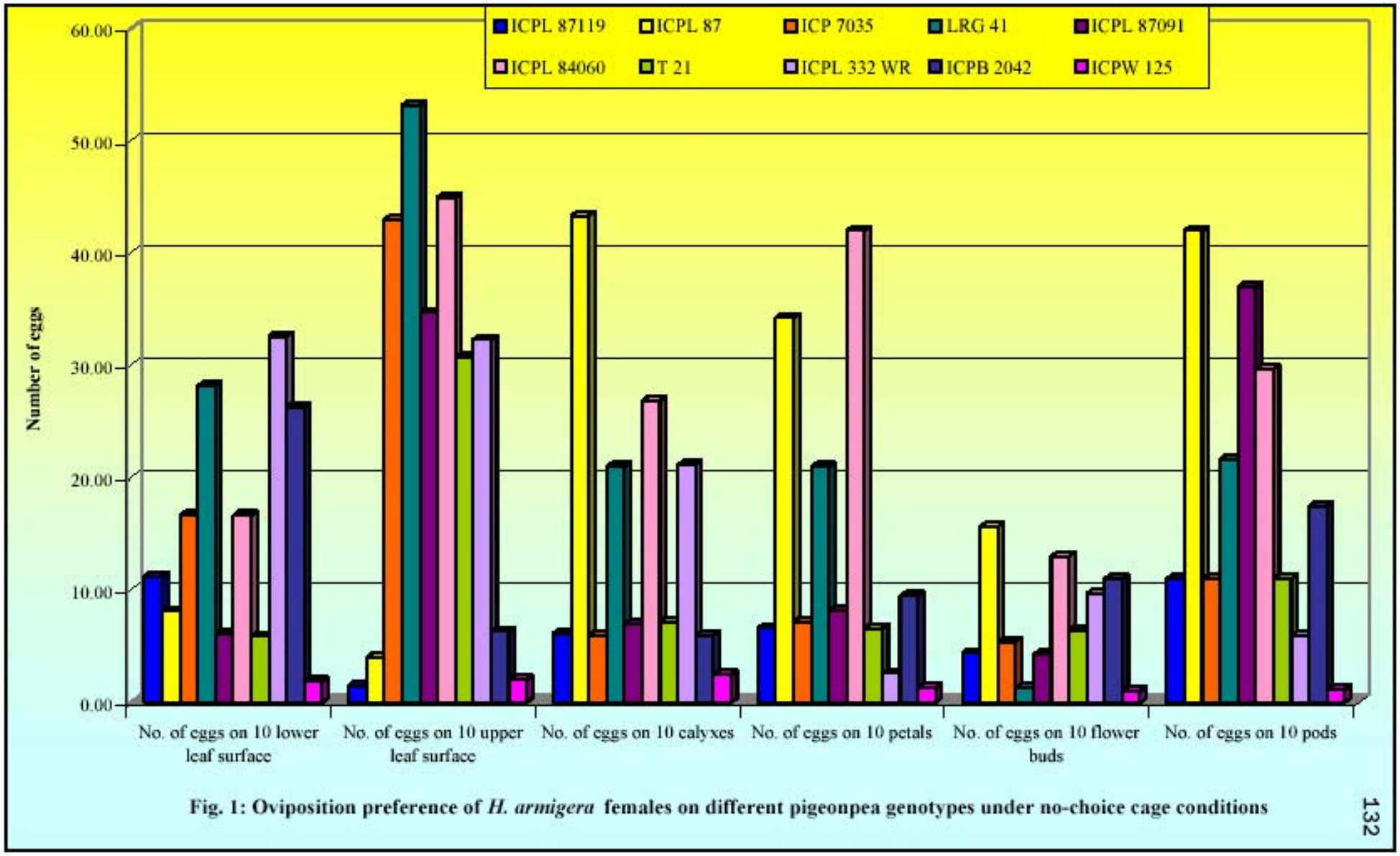


Fig. 1: Oviposition preference of *H. armigera* females on different pigeonpea genotypes under no-choice cage conditions

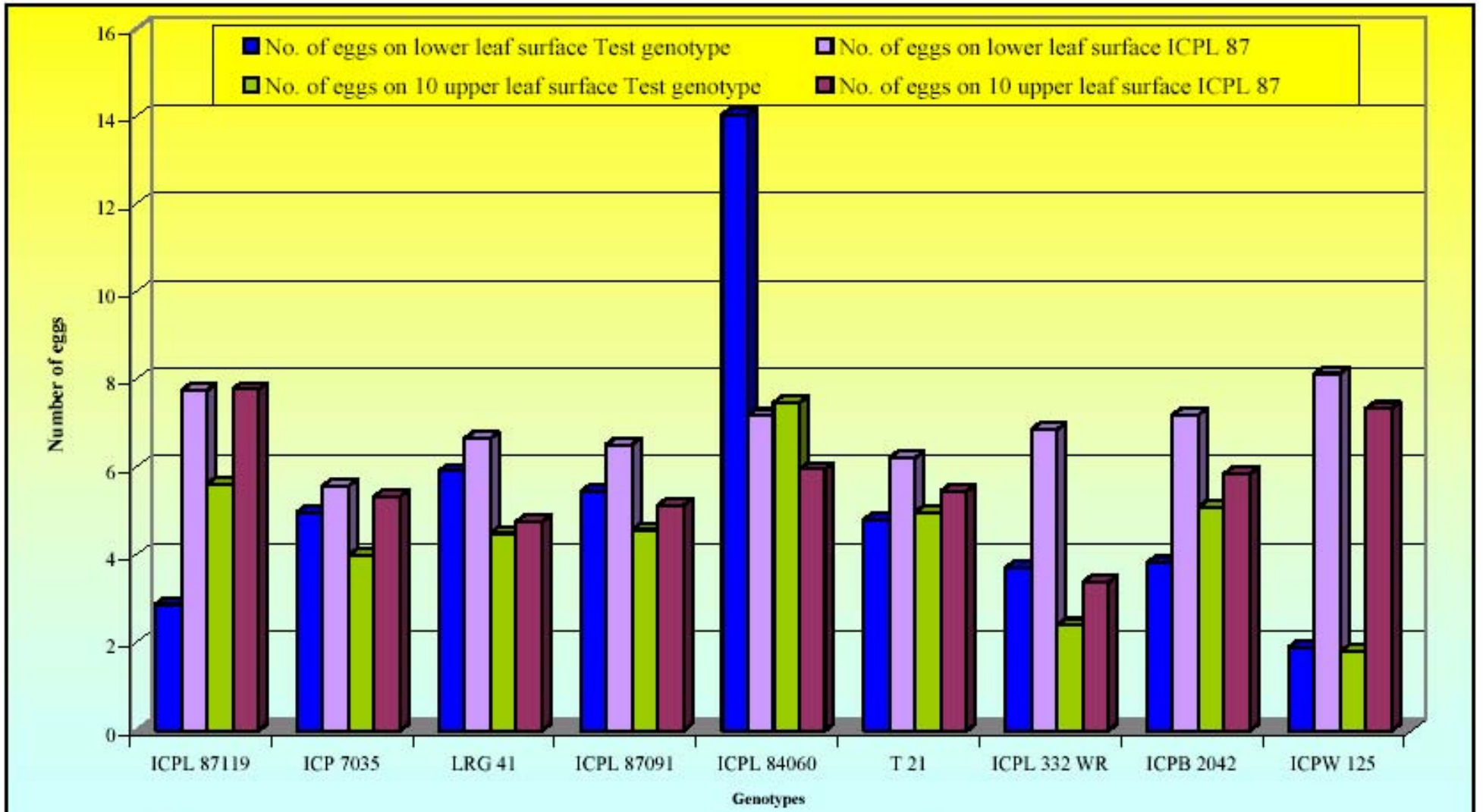


Fig. 2: Oviposition preference by *H. armigera* females towards leaf surface of different pigeonpea genotypes under dual-choice cage conditions

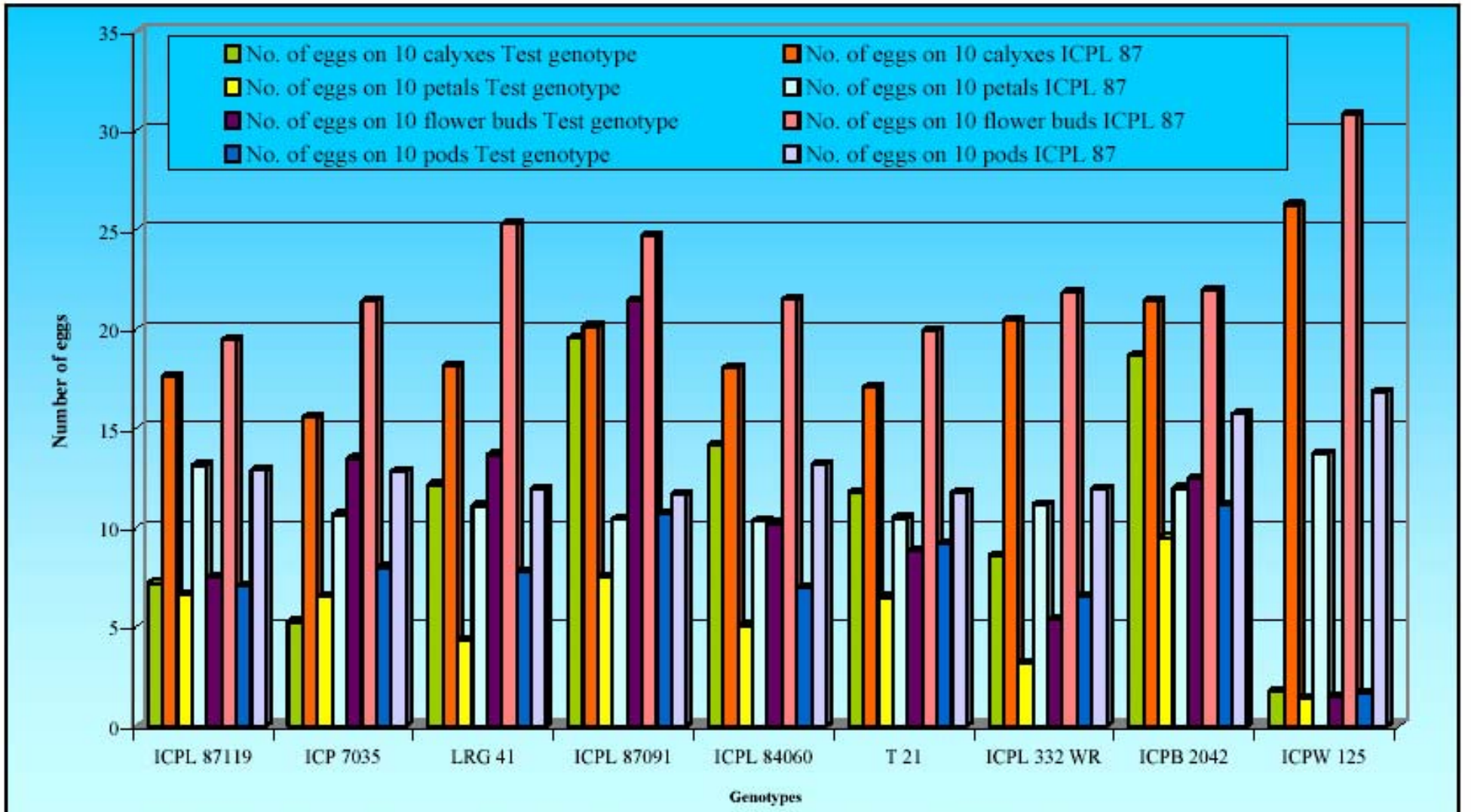


Fig. 3: Oviposition preference by *H. armigera* females towards reproductive parts of different pigeonpea genotypes under dual-choice cage conditions

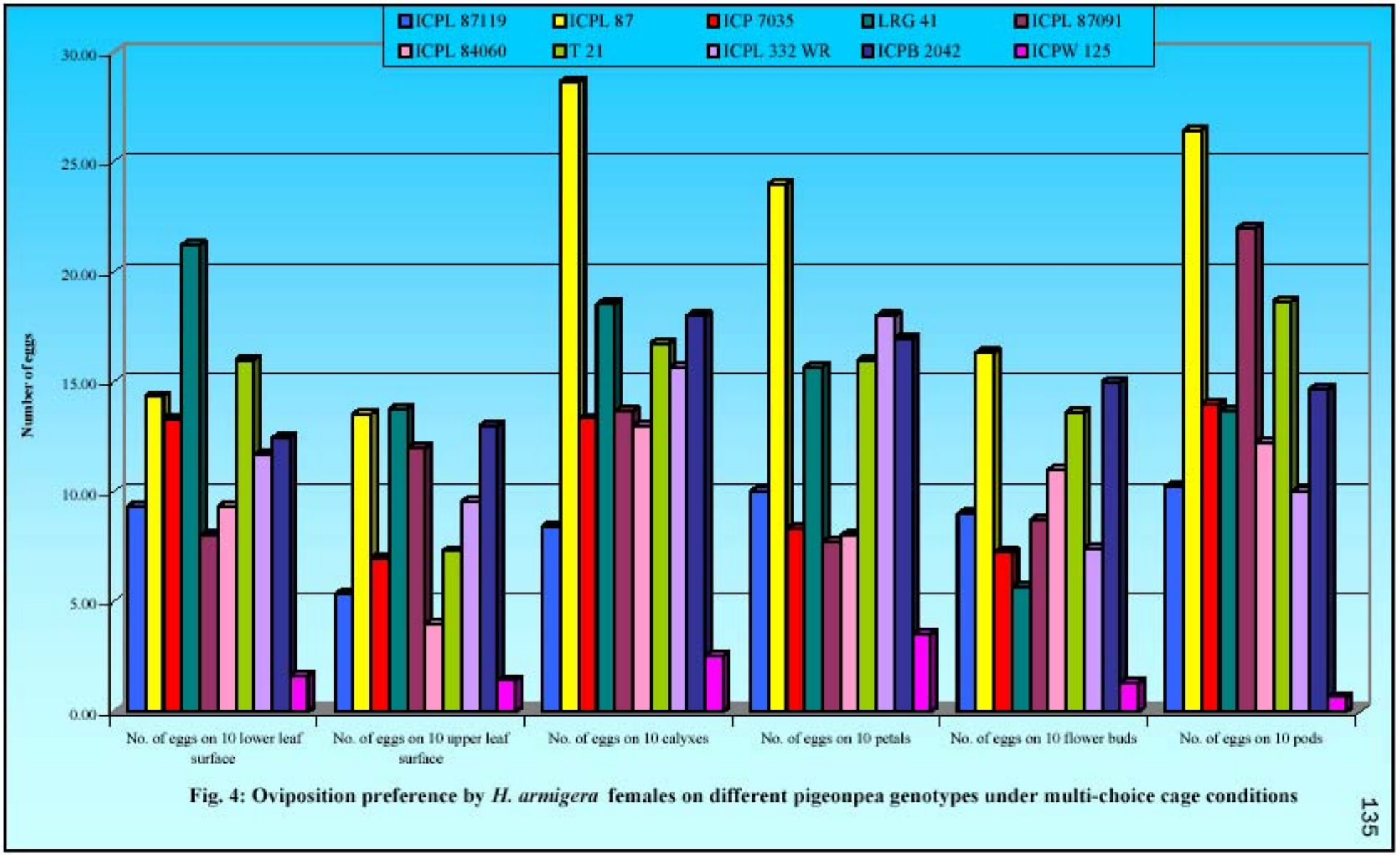


Fig. 4: Oviposition preference by *H. armigera* females on different pigeonpea genotypes under multi-choice cage conditions

Under no choice and multi choice conditions (Fig. 5 – 6), LRG 41, T 21 and ICPB 2042 recorded higher percentage of parasitisation of *H. armigera* eggs by *T. chilonis* which was due to the higher attraction of the parasitoids to the flowers of these genotypes as revealed by the olfactometer study (Table26).

Both under no and multi choice conditions (Fig. 5 – 6), ICPW 125 had least parasitisation of *H. armigera* eggs by *T. chilonis* compared to other genotypes which may be due to the higher trichome density and longer length of trichome D and also interlocking of dense type D trichome which acts as a physical barrier for the movement of *T. chilonis*, as reported by Romies et al. (1996)

Under dual choice conditions (Fig. 7), the parasitisation of eggs on lower leaf surface was higher on test genotypes viz., ICPB 2042, ICPL 87091, ICPL 84060 and LRG 41 compared to susceptible check, ICPL 87. On upper leaf surface, the percentage parasitisation was higher on test genotypes viz., ICPB 2042, ICPL 87091, ICPL 332 WR, ICP 7035, ICPL 84060, ICPL 87119 and LRG 41 compared to ICPL 87 (susceptible check). The higher percentage of parasitisation on the before mentioned genotypes compared to ICPL 87 may be due to lower density of type B trichomes than that on ICPL 87, except ICPL 84060 on upper leaf surface, which is in agreement with the findings of Romies et al. (1996). More number of type B trichomes on ICPL 87 inhibits the walking behavior or even trap the searching parasitoids, thus, inhibiting the ability to locate a host (Kauffman and Kennedy, 1989a, 1989b; kashyap et al., 1991).

Under dual choice condition (Fig. 8), the per cent parasitistion on the reproductive parts of the pigeonpea plant viz., calyxes, flower buds and pods was higher on ICPB 2042 compared to ICPL 87 (susceptible check), which is due to lower number of type B trichomes on calyxes and pods of ICPB 2042.

Under multi choice conditions (Fig. 6), ICPL 84060 recorded higher percentage of parasitisation (12.05), which may due to less number of type B trichomes (glandular and secretes sticky substance), making the movement and searching of *H. armigera* eggs for parasitistion by *T. chilonis* genotypes easier. These findings are in agreement with the work of Tandon and Baktavatsalam (2003).

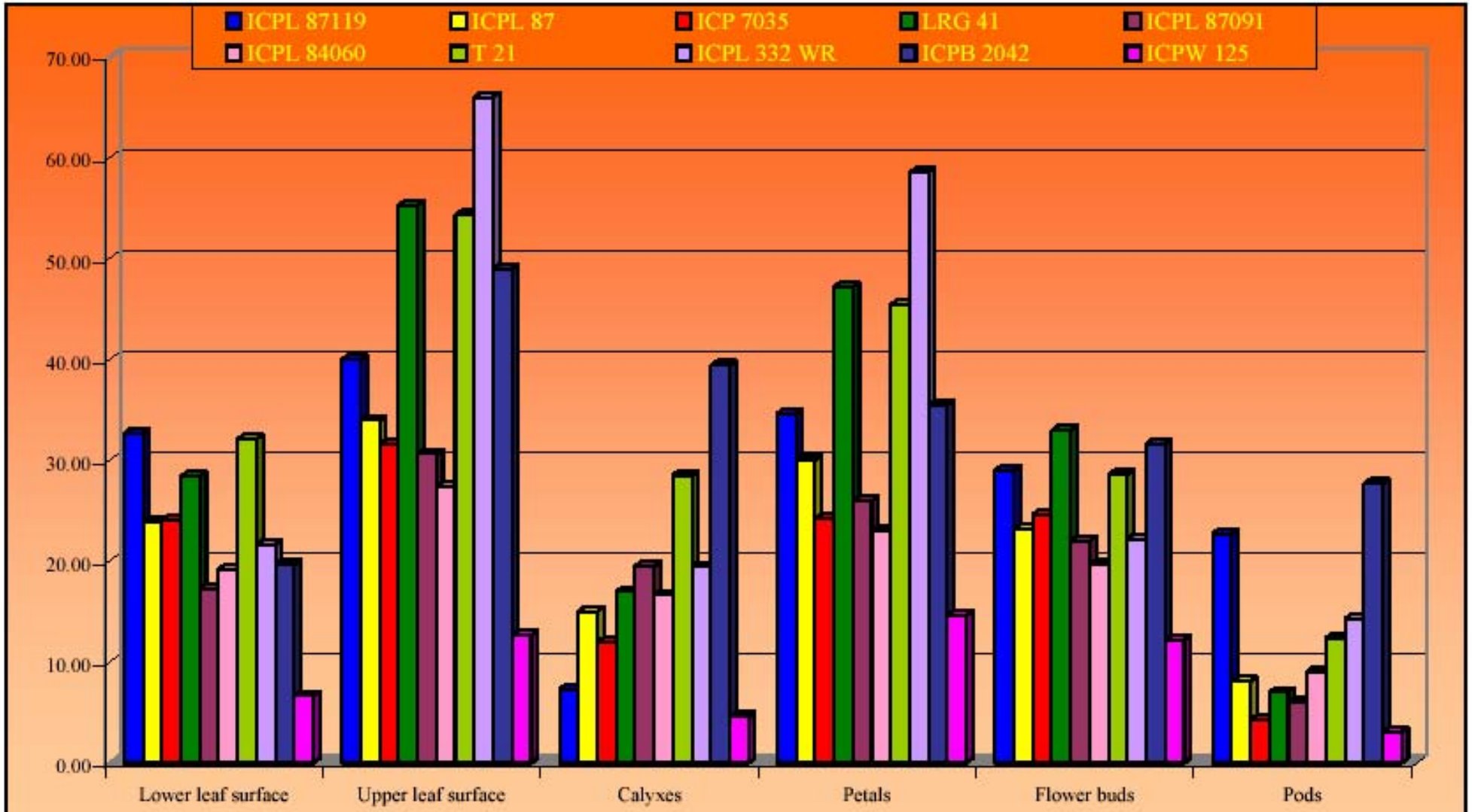


Fig. 5: Per cent parasitization of *H. armigera* eggs by *T. chilonis* on different parts of the pigeonpea plant under no-choice cage conditions

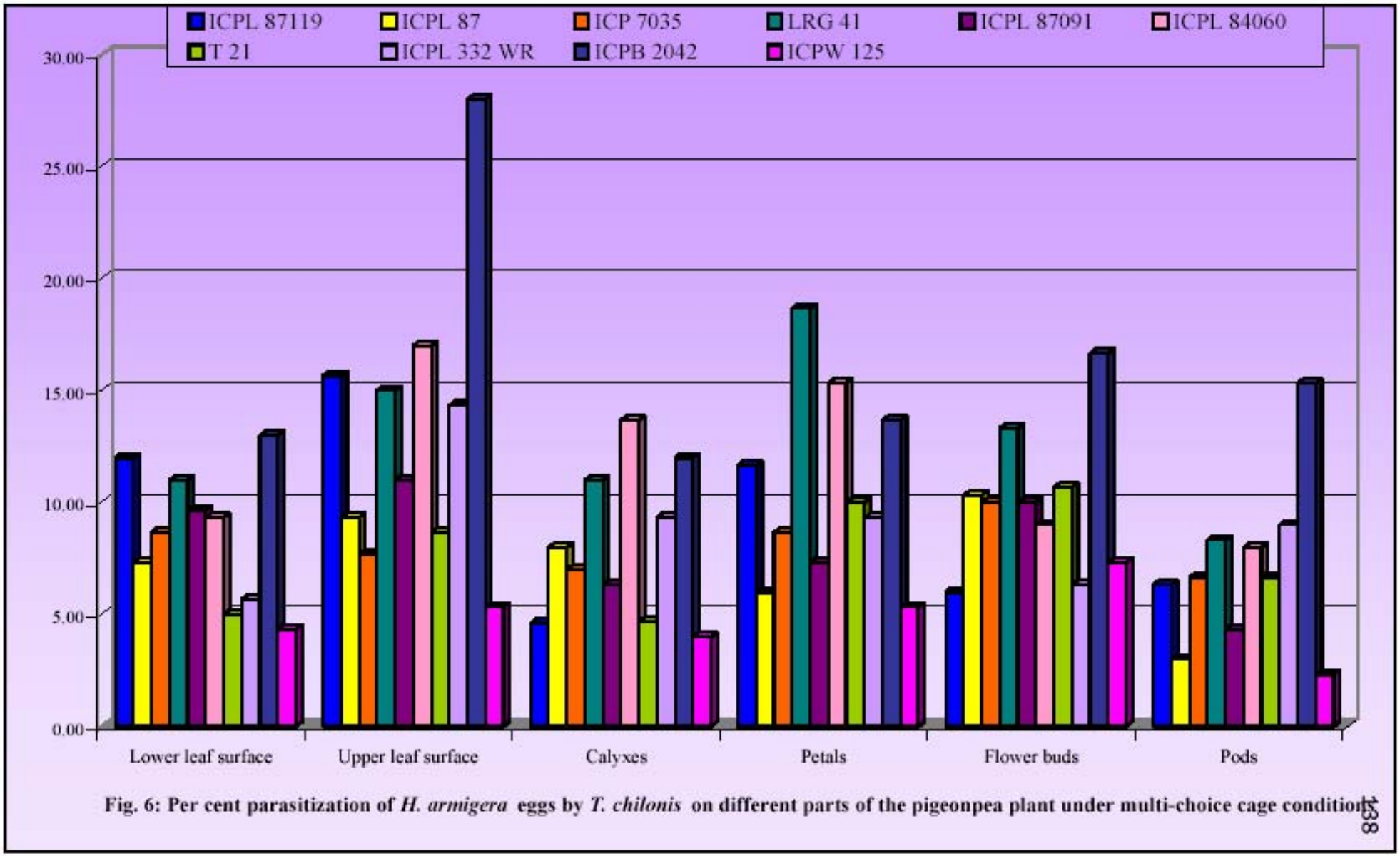


Fig. 6: Per cent parasitization of *H. armigera* eggs by *T. chilonis* on different parts of the pigeonpea plant under multi-choice cage condition

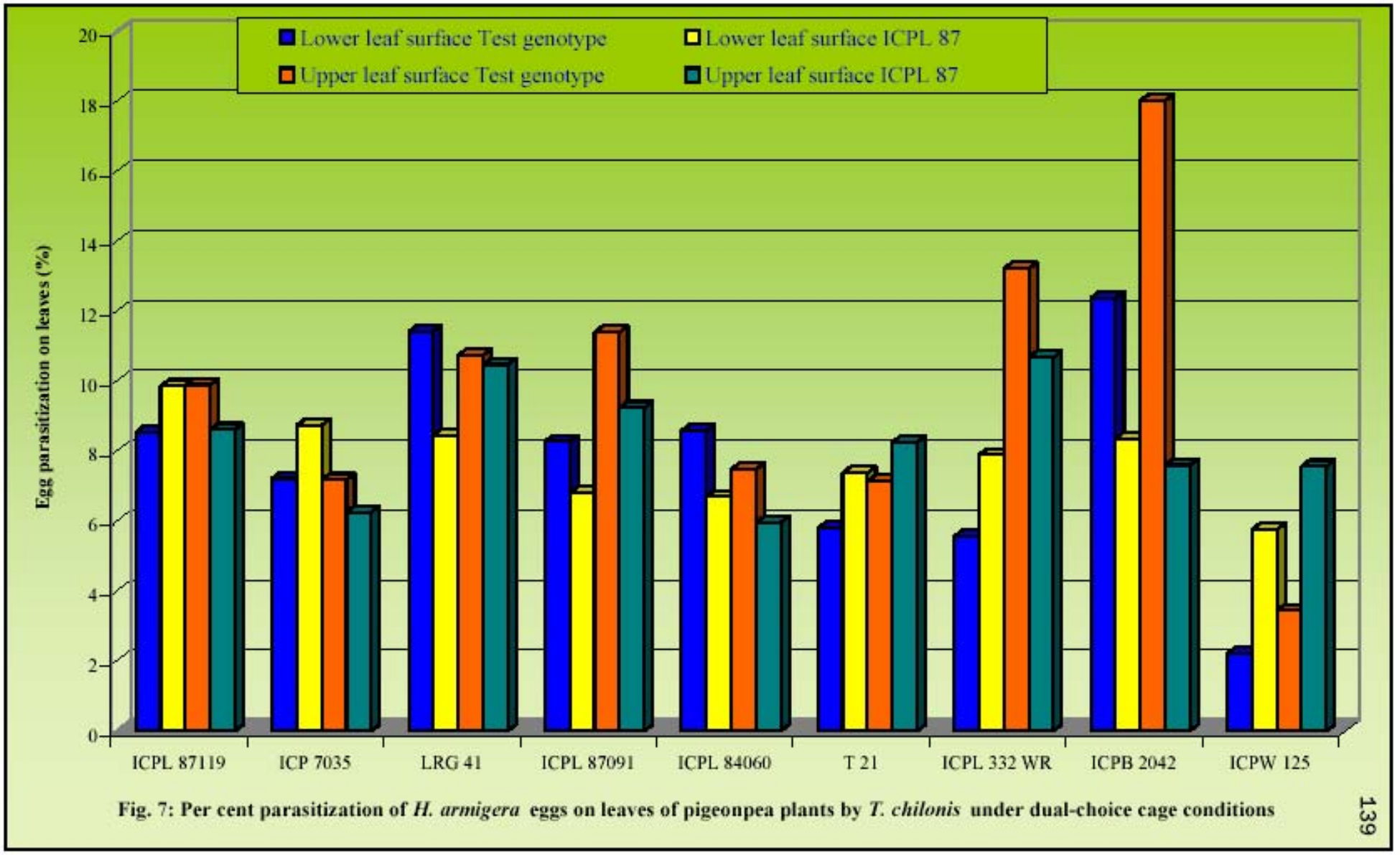


Fig. 7: Per cent parasitization of *H. armigera* eggs on leaves of pigeonpea plants by *T. chilonis* under dual-choice cage conditions

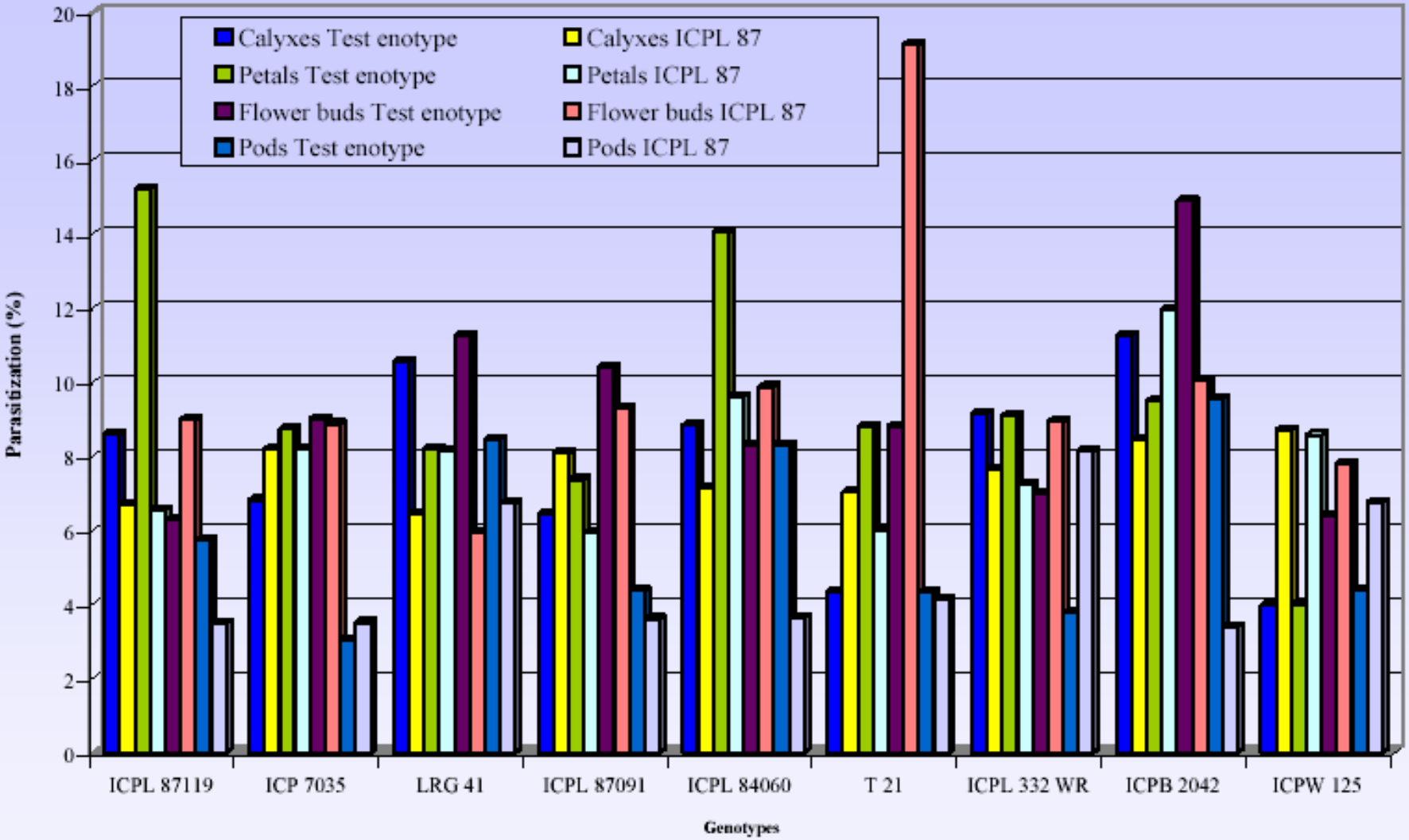


Fig. 8: Per cent parasitization of *H. armigera* eggs on reproductive parts of pigeonpea plants by *T. chilonis* under dual-choice cage condition

5.1.3 Influence of pigeonpea genotypes on parasitisation of *Helicoverpa armigera* larvae by *C. chlorideae*

Plants release large quantities of volatiles in response to herbivore attack (Dicke et al., 1990; Turlings et al., 1990), which play a significant role in insect host location by the parasitoids (Turlings et al., 1990). The present study showed significant influence of host genotypes on the parasitisation potential, development and survival of *C. chlorideae*. Parasitoids have their preferences for different genotyps within the same crop. When compared between the no-choice and multiple-choice conditions (Fig. 9 and 10), percentage parasitisation was greater on no choice condition due to the non availability of other host genotypes to *C. chlorideae*. Also, the volatiles emitted by the single genotype under no choice conditions vary with the mixed complex odour blends of volatiles emitted from the genotypes under multi choice conditions. Similarly, Randlkofer et al. (2007) showed that in the laboratory conditions parasitoids respond only to pure host plant odours but not to complex odour blends. When the parasitoids are given a choice of all the test genotypes and proportionally the number of parasitoids released are more under multi choice conditions compared to no choice condition, the overall larval parasitisation under multi choice conditions was less than in no choice condition, which may be due to the alteration of the proportion of parasitoids in each area by the number of competitors and interference as was reported by Sirot and Bernstein (1996).

Under no choice, dual choice and multi choice conditions (Fig. 9 – 11), it was evident that the susceptible genotype ICPL 87 attracted *C. chlorideae* more than the other genotypes. It was due to the survival of more number of larvae on the susceptible genotype and increase in the induced response from this genotype due to more damage than the other genotypes. Similarly, Kaur et al. (2004) reported that as the incidence of pest increases the parasitoid activity also increases.

Longer pods of ICPL 87 (Table 18) and clustering type of habitat provided more surface area for the movement of the *H. armigera* larvae, rendering more prone to parasitisation. ICPL 87119 which has more pod wall thickness hindered the entry of the larvae into the pods making it more prone to the parasitization by *C. chlorideae*.

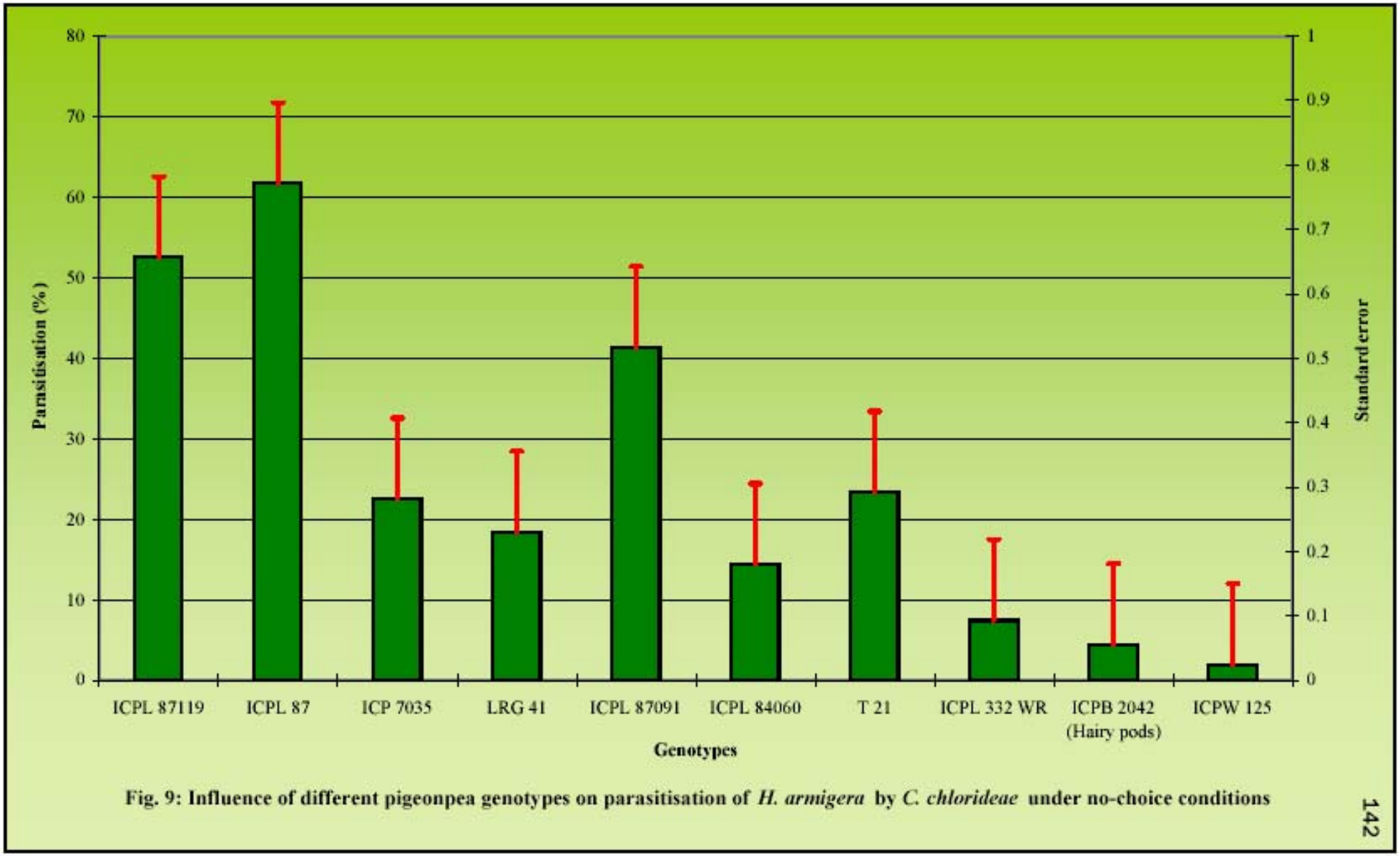


Fig. 9: Influence of different pigeonpea genotypes on parasitisation of *H. armigera* by *C. chlorideae* under no-choice conditions

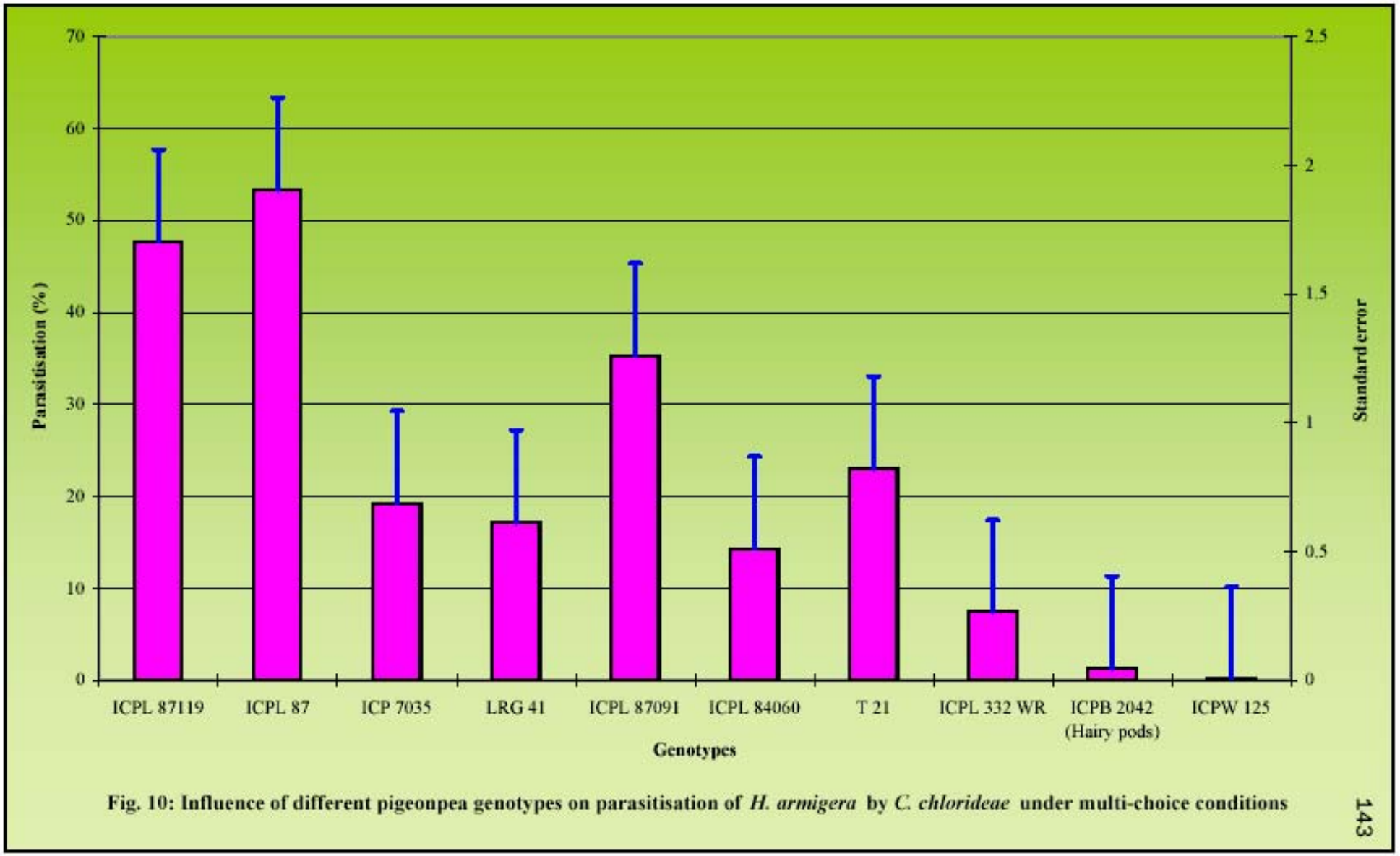


Fig. 10: Influence of different pigeonpea genotypes on parasitisation of *H. armigera* by *C. chlorideae* under multi-choice conditions

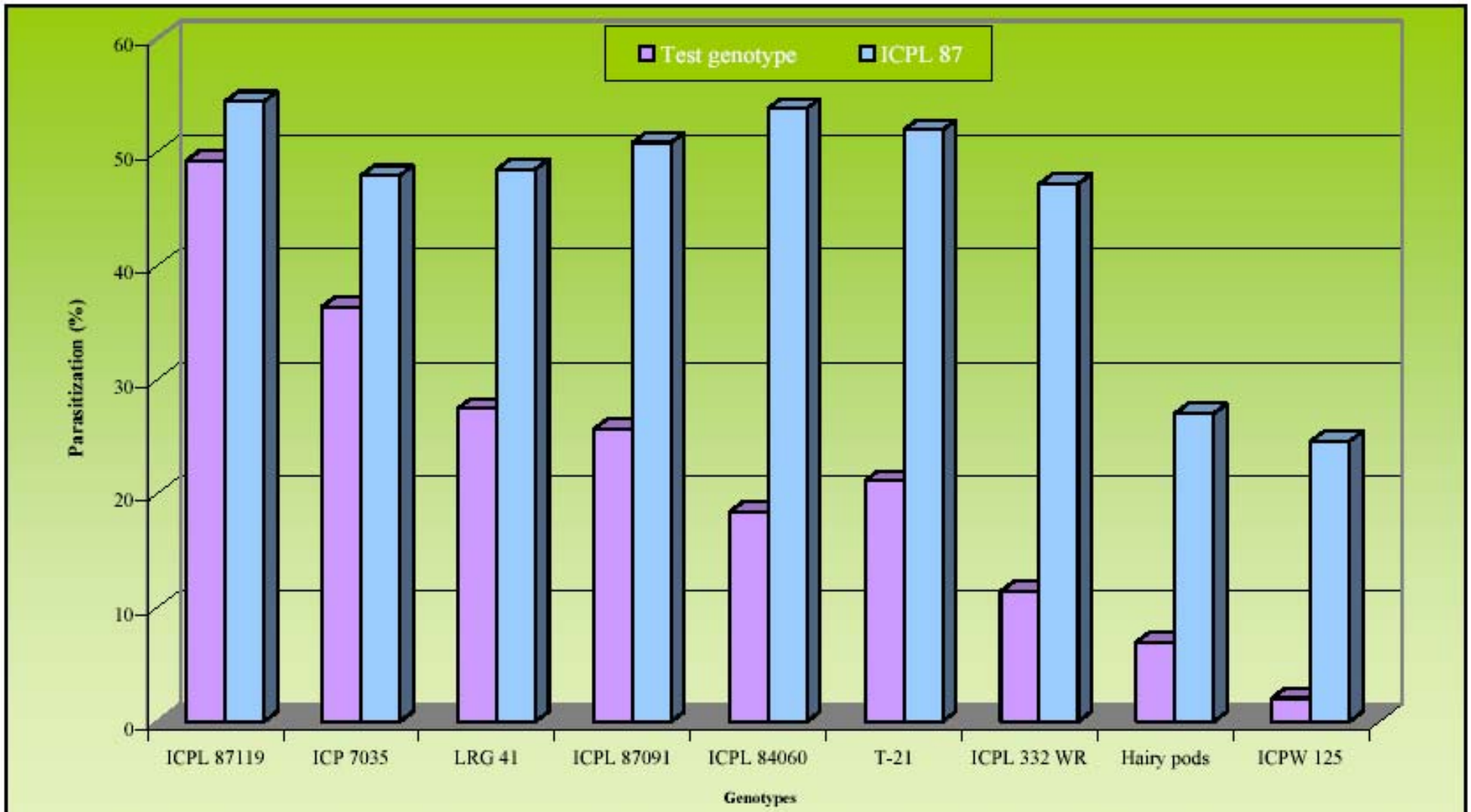


Fig. 11: Per cent parasitization by *C, chlorideae* females towards 2nd instar larvae of *H. armigera* on different pigeonpea genotypes under dual-choice conditions

Creeping type with thick plant canopy of ICPW 125 recorded lowest parasitization under no choice, dual choice and mulit choice conditions, which may be due to hiding of *H. armigera* larvae from being parasitized.

Influence of the genotypes on the biology of the *C. chlorideae* parasitizing second instar *H. armigera* larvae released on different genotypes collected after 48 h, and reared on the artificial diet (Fig. 12) showed that egg + larval period (16 daya), pupal period (14 days) of the parasitoid was highest on the resistant wild genotype ICPW 125 and least on the susceptible genotype ICPL 87. This proved that when the larvae were kept for 48 h on the test genotypes and reared on the artificial diet, the antibiotic components ingested by the larvae in the initial stage also affected the biology of the parasitoid. But cocoon formation, adult emergence and adult longevity was less from the larvae collected from the resistant genotype (ICPW 125 and ICPL 332 WR) than the susceptible genotype (ICPL 87). This may be due to the changes in biochemical composition of host plants in response to herbivory which also affected the growth and survival of herbivores (Gange and Brown, 1989; Whitman et al., 1991), which in turn influenced the activity and abundance of natural enemies (Bloem and Duffey, 1990). This showed that the ICPW 125 and ICPL 332 WR are not compatible with the larval parasitoid *C. chlorideae*. Similarly, sithanantham et al. (1982) observed that parasitism of *H. armigera* larvae in chickpea was lower on the resistant genotypes than on the susceptible ones.

5.2 Attractant/ Repellent effect and influence of pigeonpea genotypes on *T. chilonis* and *C. chlorideae*

5.2.1 Attractant/ Repellent properties of host genotypes on the parasitoids, *T. chilonis* and *C. chlorideae*

Odors from the flowers of ICP 7035 were more attractive to the egg parasitoid, *T. chilonis*, followed by ICPB 2042 as compared to the natural air (Fig. 13). When compared to ICPL 87 (susceptible check) also ICP 7035 (Fig. 14) attracted significantly more number of *T. chilonis* which may be due to the slight purple colour of flower compared to all other genotypes where the flower colour was yellow. In addition ICP 7035 hexane extract of flowers (Table 44) containing blend of volatiles present at peak

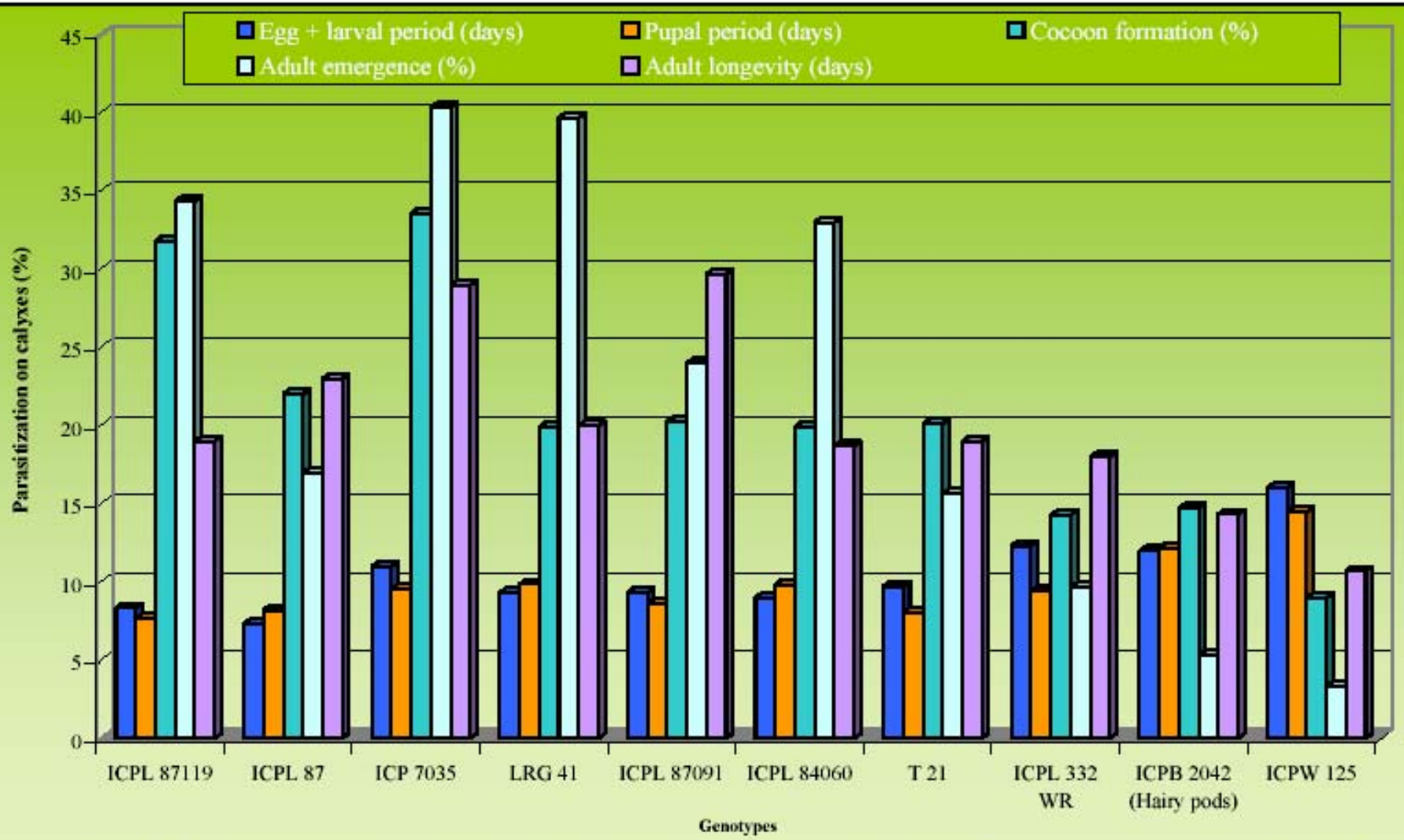


Fig. 12: Biology of *C. chlorideae* parasitizing 2nd instar *H. armigera* larvae released on different pigeonpea genotypes, collected after 48 hours, and reared on the artificial diet

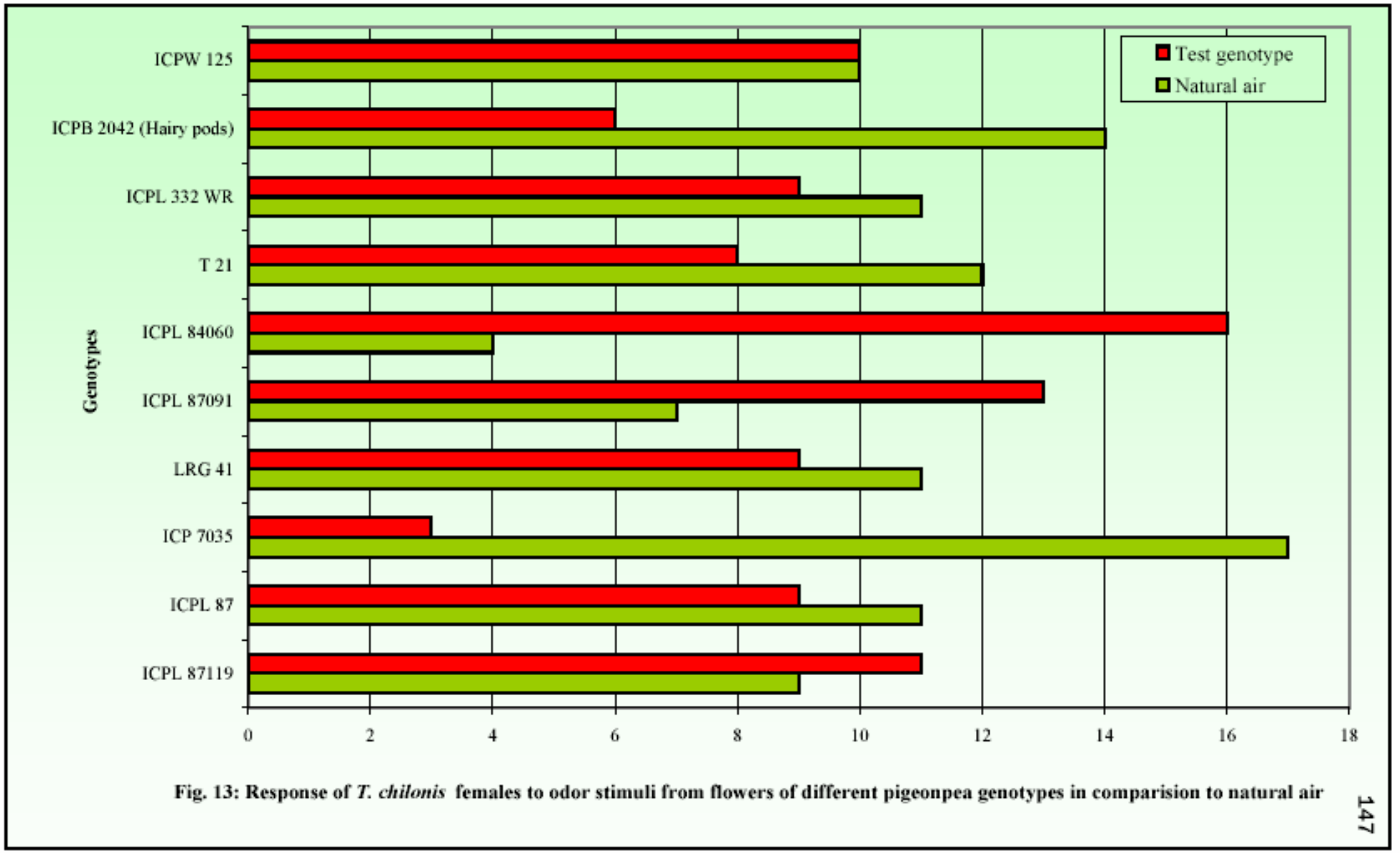


Fig. 13: Response of *T. chilonis* females to odor stimuli from flowers of different pigeonpea genotypes in comparision to natural air

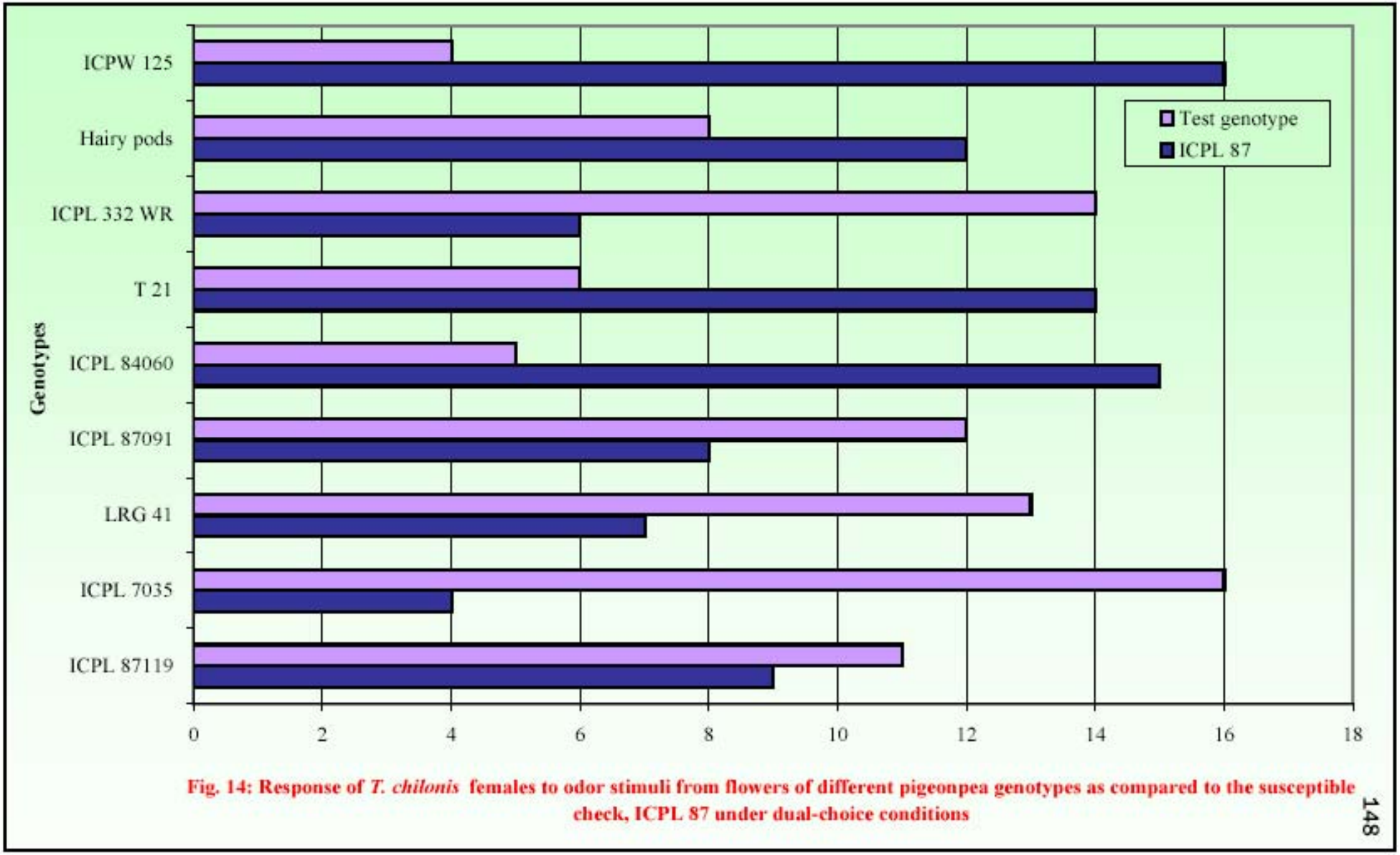


Fig. 14: Response of *T. chilonis* females to odor stimuli from flowers of different pigeonpea genotypes as compared to the susceptible check, ICPL 87 under dual-choice conditions

5 and peak 12 might have attracted the parasitoids in more numbers; whereas ICPL 84060 and ICPW 125 repelled *T. chilonis* to the odours of the flowers of these genotypes

Odors from the flowers of all the pigeonpea genotypes were attractive to the larval parasitoid, *C. chlorideae* when compared with natural air (Fig. 15), which may be due to the presence of nectarines and the blend of volatiles. Compared to ICPL 87, ICPL 87119 attracted more number of *C. chlorideae*, whereas, ICP 7035, ICPB 2042, ICPL 84060 and ICPW 125 were repulsive to the parasitoids (Fig. 16), which may be due to lack of some specific volatile. The attractiveness of *C. chlorideae* towards the flower odour of ICPL 87119, may be due to the presence of some specific volatile compounds. Price et al. (1980) mentioned that the plant attractants like floral and extrafloral nectarines and various volatiles factors originating directly from the plant influence the parasitoid's ability to find its host.

5.2.2 Influence of pigeonpea genotypes on the biology of *C. chlorideae* via *H. armigera*

Host plant influences the feeding, growth and development of phytophagous insects, and can have profound effects on trirophic ineractions involving plants, herbivores and their natural enemies (Price et al., 1980 and 1986). Parasitoids encounter variable nutritional suitability of their host insects. The host is a finite food source that may, because of its size and nutritional history, affect parasitoid development (Vinson and Iwanstsh, 1980).

Campoletis chlorideae via *Helicoverpa armigera* exhibited better life history performance on flowers than on lyophilized pods and leaves (Fig. 17 - 19). Egg + larval period was shorter (Fig. 17a) when the insects were reared on flowers due to the presence of appropriate amount of protein in the flowers, except for ICPW 125 (Fig. 21), which had toxic amount of proteins. Protein quality is a critical factor influencing the growth and development of insects (Bernays and Chapman, 1978; Mattson, 1980; Murugan et al., 1997), and in the lepidopteran and hymenopteran species, the optimal proportion of linoleic and linolenic acids is quite important (Dadd, 1985; Parnanen and Turunen, 1987). Similarly, shorter Egg + larval period was observed when the insects were reared on lyophilized pod powder incorporated into the

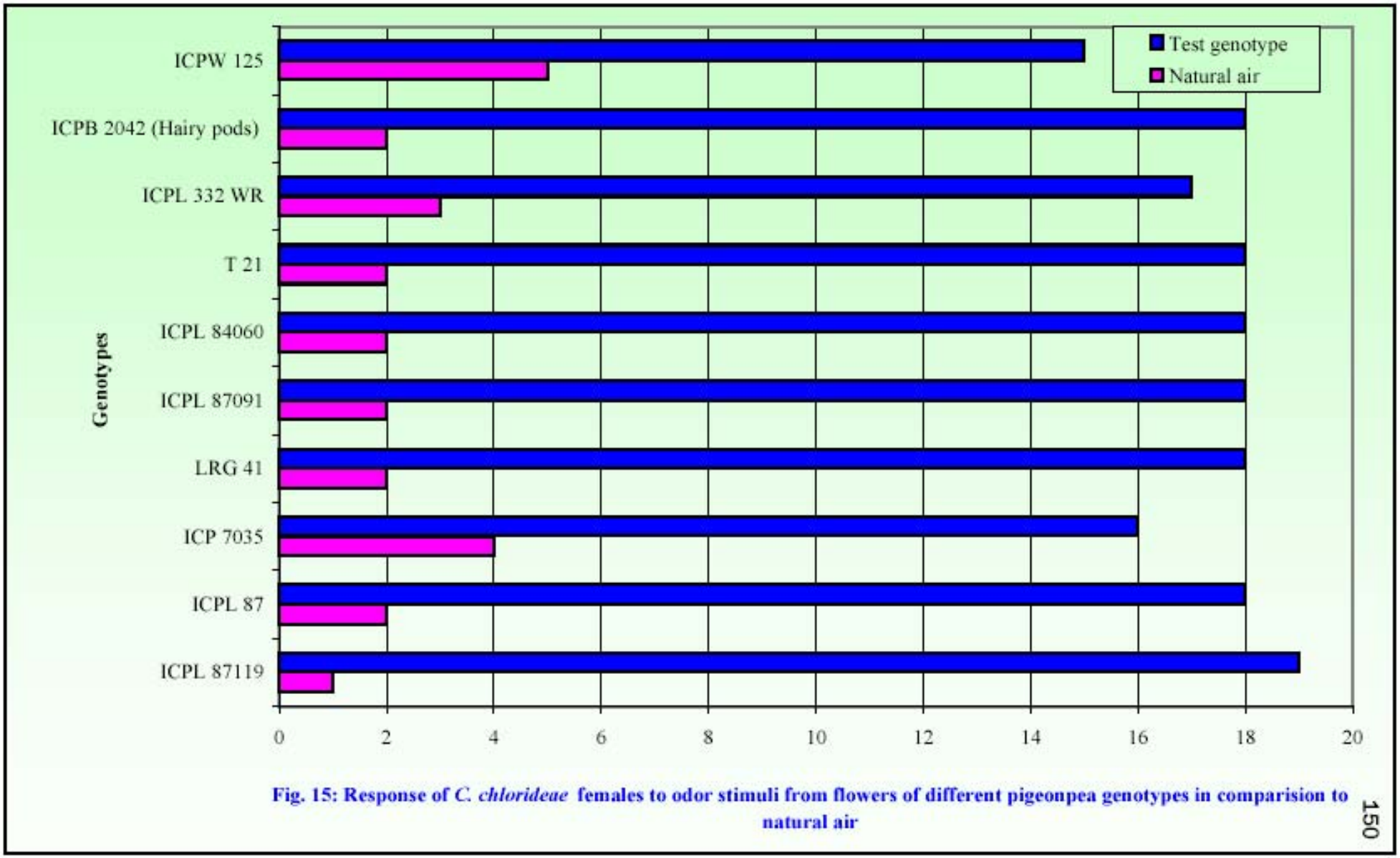


Fig. 15: Response of *C. chlorideae* females to odor stimuli from flowers of different pigeonpea genotypes in comparision to natural air

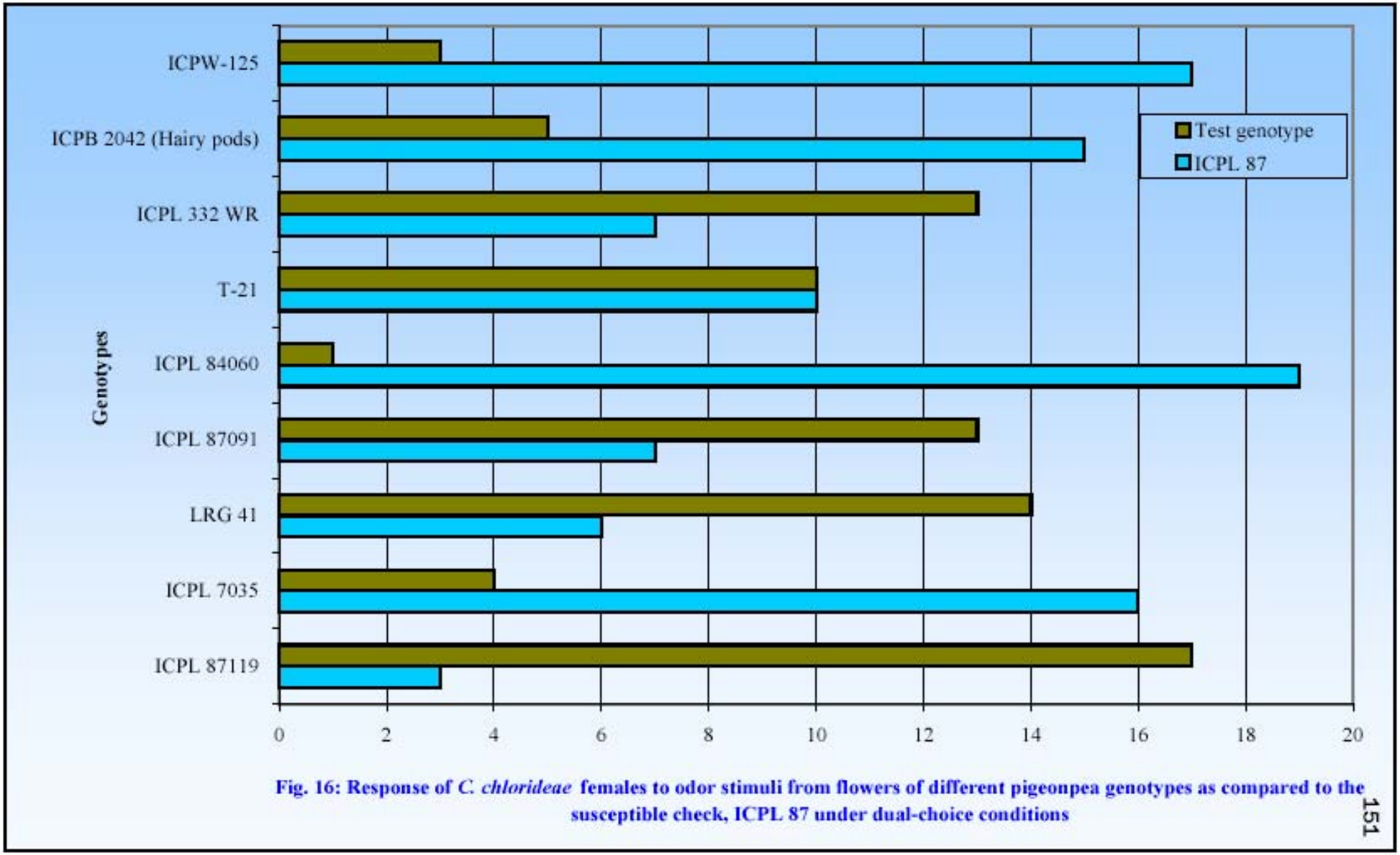


Fig. 16: Response of *C. chlorideae* females to odor stimuli from flowers of different pigeonpea genotypes as compared to the susceptible check, ICPL 87 under dual-choice conditions

artificial diet compared to the larvae reared on leaves (Fig. 17a). Simmonds and Stevenson (2001) have reported that the isoflavonoids isolated form wild relatives of chickpea, Cicer arietinum, were shown to deter larval feeding by *H. armigera*. Similarly, longer egg + larval period was recorded when the *H. armigera* larvae were reared on the wild pigeonpea genotype ICPW 125 (Fig. 17a), which may be due to higher amount of flavonoids or the antioxidant components like flavonoids, cajaninstilbene acid, pinostrobin vitexin and orientin (Wu et al., 2009) present in the plant might have deterred the feeding by the *H. armigera* and thus influenced the development and survival of the *C. chlorideae*. Sujana et al. (2008) also reported that prolonged post-embryonic development of *H. armigera* on wild pigeonpea genotypes, which may be due to high secondary metabolites (Fig. 22).

Parasitoid larvae failed to pupate in insects reared on, ICPL 87 (Fig. 17b), possibly due to lower carbohydrate content (Fig. 21) and also on ICPL 332 WR, due to high amounts of carbohydrates. Cocoon formation, adult emergence and adult longevity (Fig. 17b) was highest in LRG 41 compared to other genotypes. Cocoon formation and adult emergence of *C. chlorideae* was dependent on the carbohydrate content and was greater in the larvae reared on flowers than those reared on leaves and lyophilized pod powder incorporated into the artificial diet. There was no adult emergence from the larvae reared on leaves of ICPL 87119 and ICPL 87 (Fig. 17b). Bloem and Duffey (1990) reported that foods with excess as well as deficit in the dietary protein of *Heliothis zea* (F.) and *Spodoptera exigua* (Hubner) caused stress to the endoparasitoid, Hyposoter exiguae.

Consumption index (CI mg/mg/day), approximate digestibility (AD%) and efficiency of conversion of ingested food into body matter (ECI%) and efficiency of conversion of digested food into body matter (ECD%) of the unparasitised larvae was greater than that of the parasitized larvae (Fig. 18 - 20). These observations are similar to the findings of Murugan et al. (2000). The CI of parasitized and unparasitised larvae of *H. armigera* reared on flower (Fig. 19) was higher than on the leaves (Fig. 18) and lyophilized pod powder (Fig. 20). This may be due to lower phenol content present in the flowers of pigeonpea, compared to leaves and pods (Fig. 22). A decrease in food consumption following parasitisation has been observed in *Spodoptera litura* (Kumar and Ballal, 1992), which agrees with the present findings.

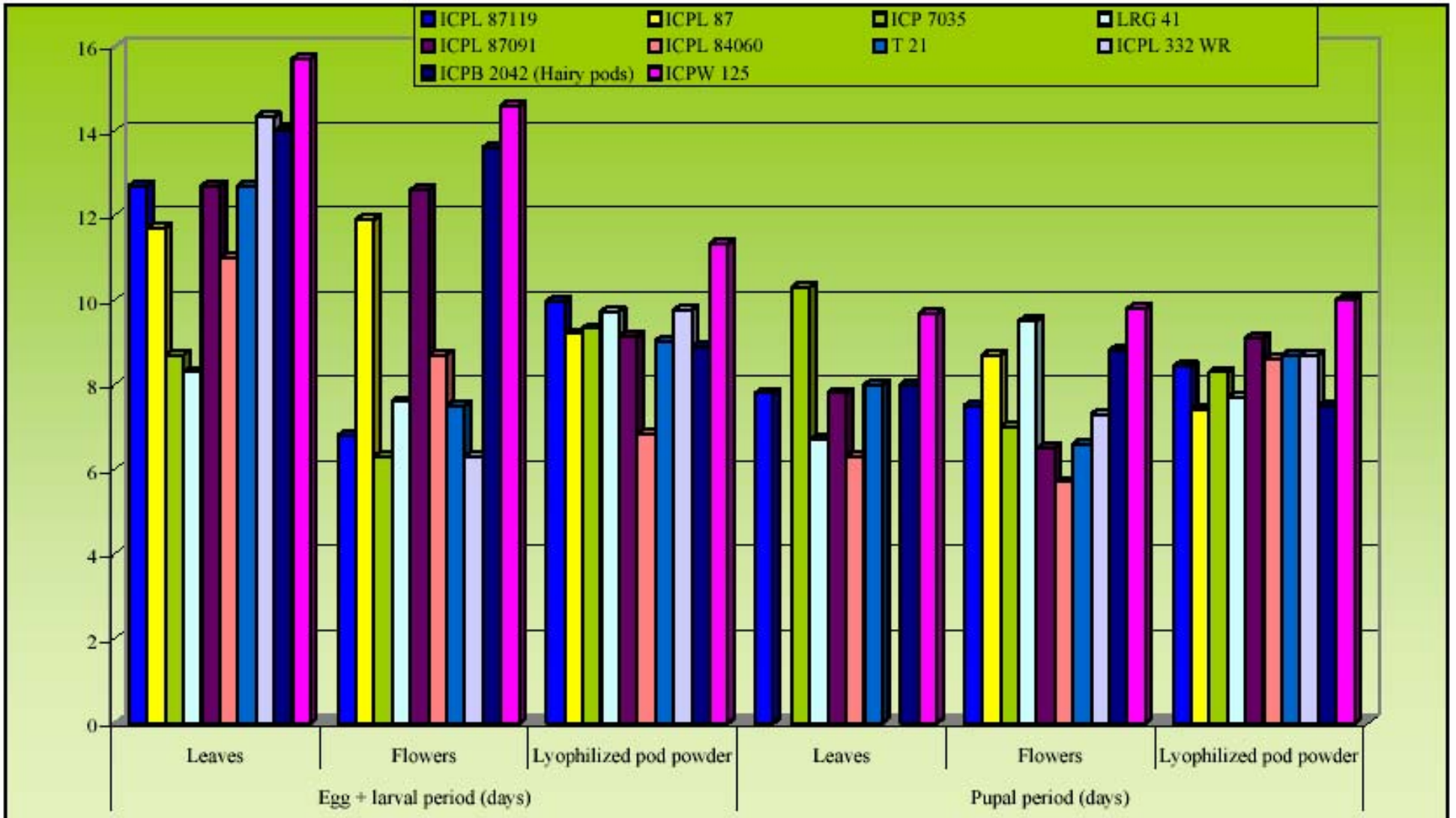


Fig. 17a: Biology of *C. chlorideae* parasitizing *H. armigera* fed on leaves, flowers and lyophilized pod powders of different pigeonpea genotypes

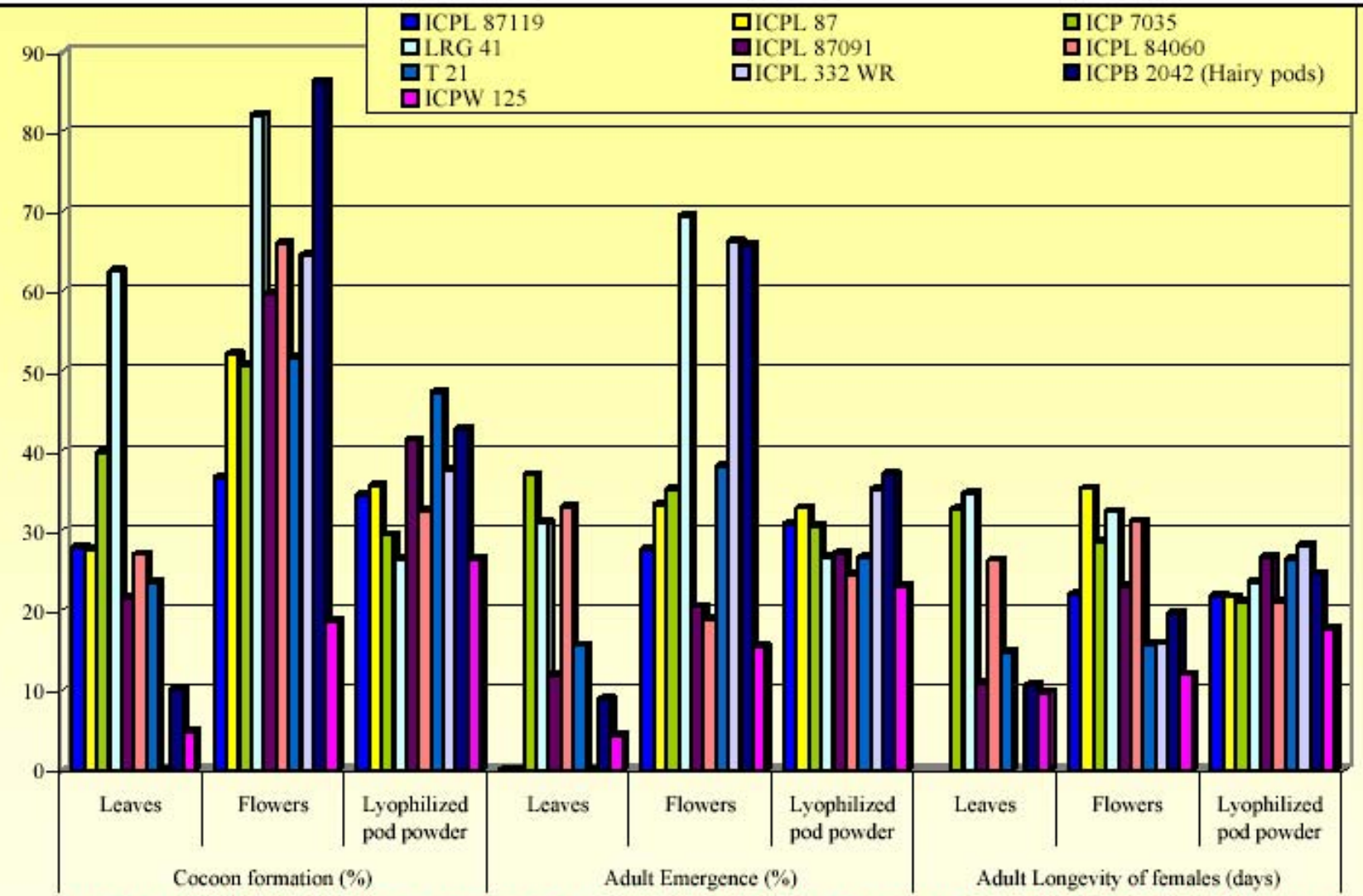


Fig. 17b: Biology of *C. chlorideae* parasitizing *H. armigera* fed on leaves, flowers and lyophilized pod powders of different pigeonpea genotypes

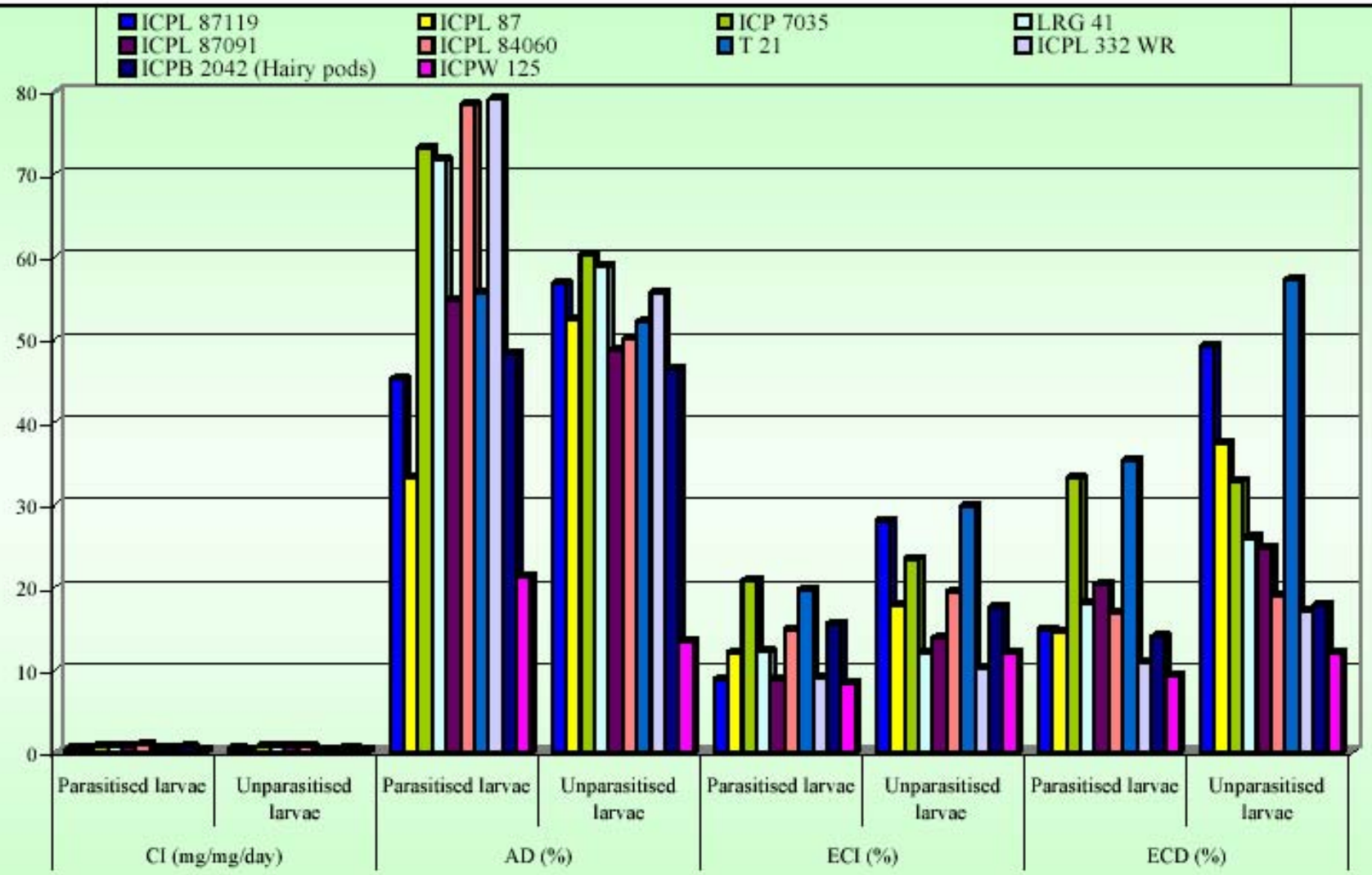


Fig. 18: Consumption and utilization of leaves of different pigeonpea genotypes by the parasitized and unparasitized 4th instar larvae of *H. armigera*

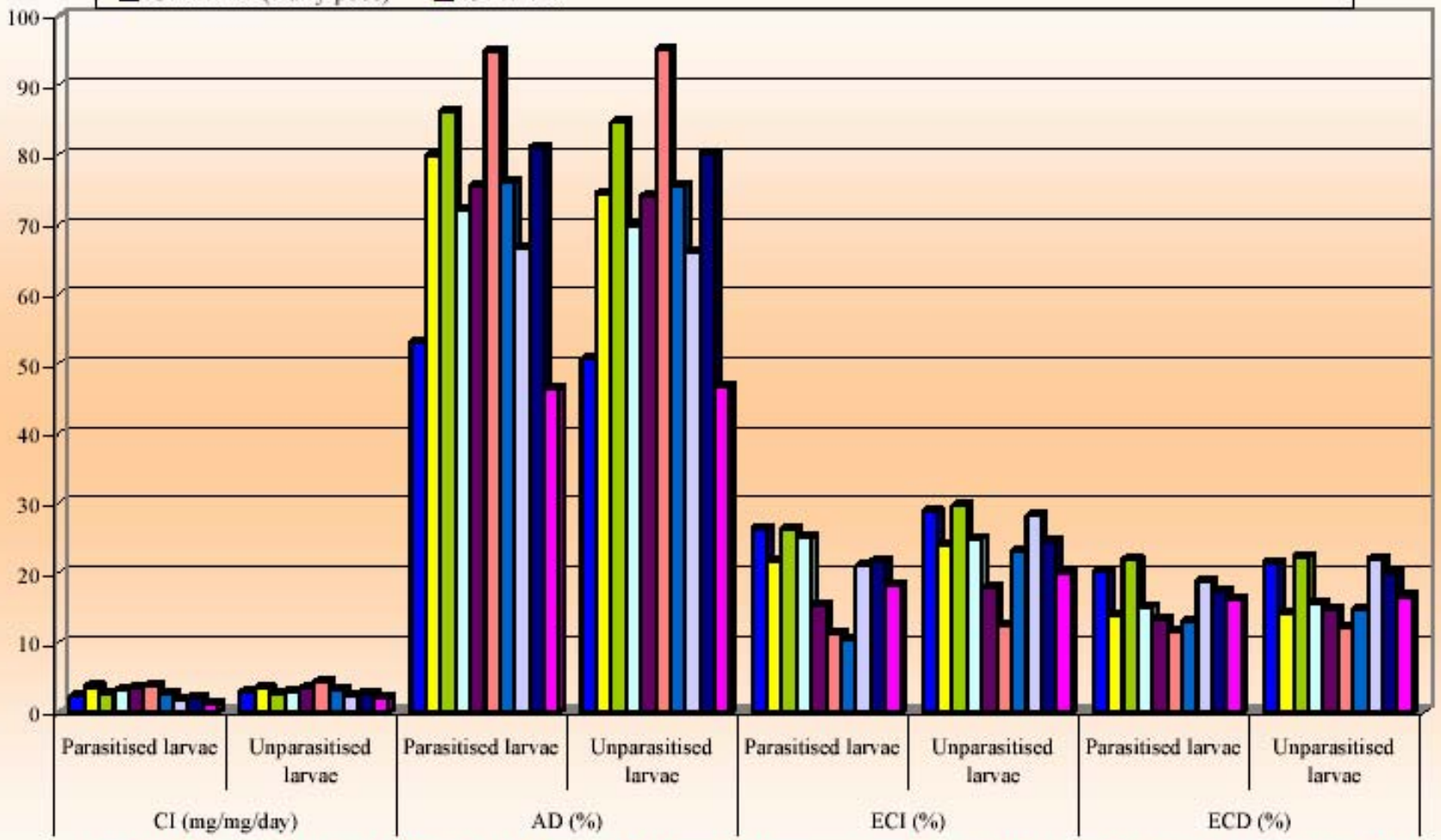


Fig. 19: Consumption and utilization of flowers of different pigeonpea genotypes by the parasitized and unparasitized 4th instar larvae of *H. armigera*

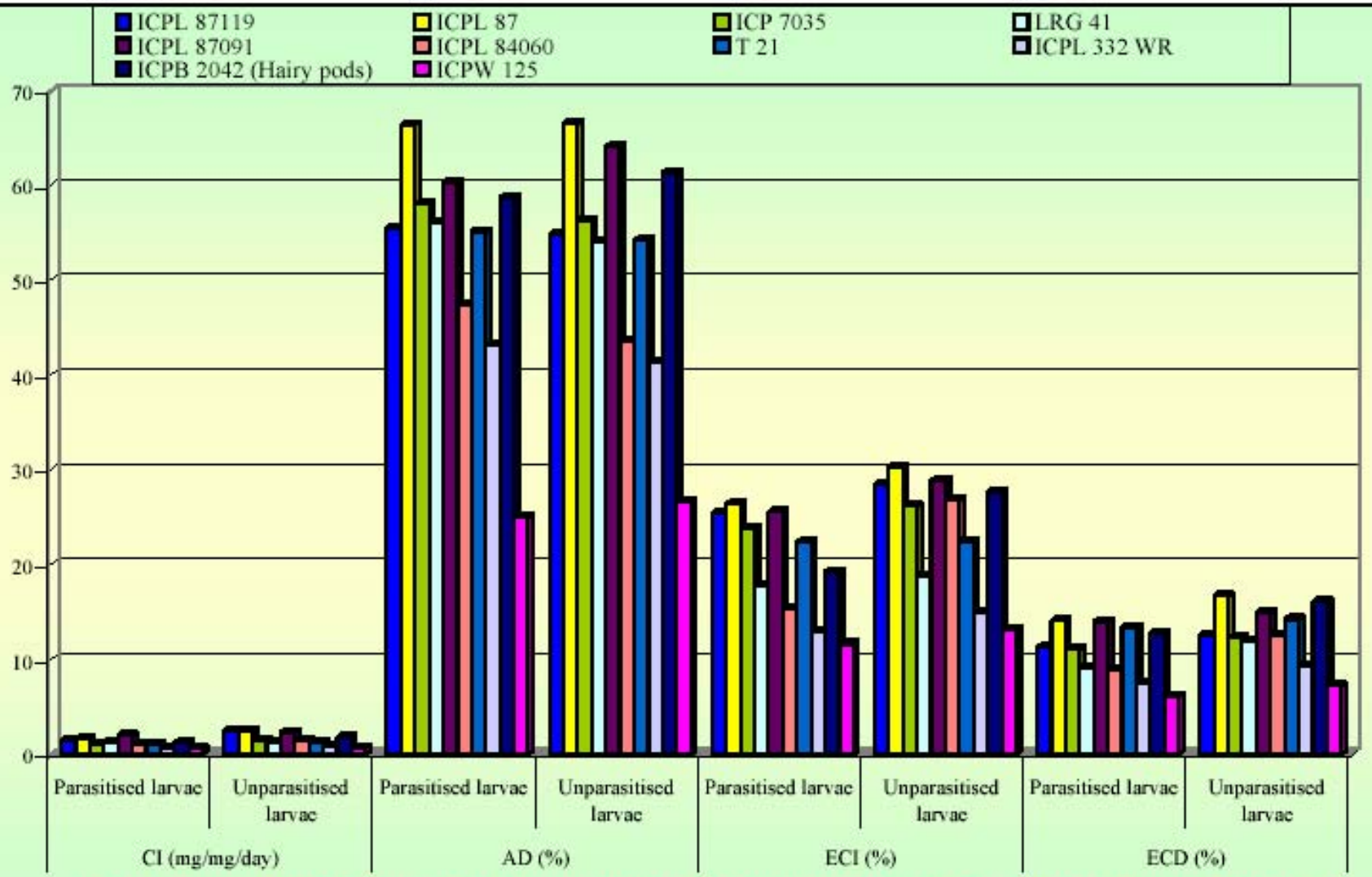


Fig. 20: Consumption and utilization of artificial diet containing lyophilized pod powders of different pigeonpea genotypes by the parasitized and unparasitized 4th instar larvae of *H. armigera*

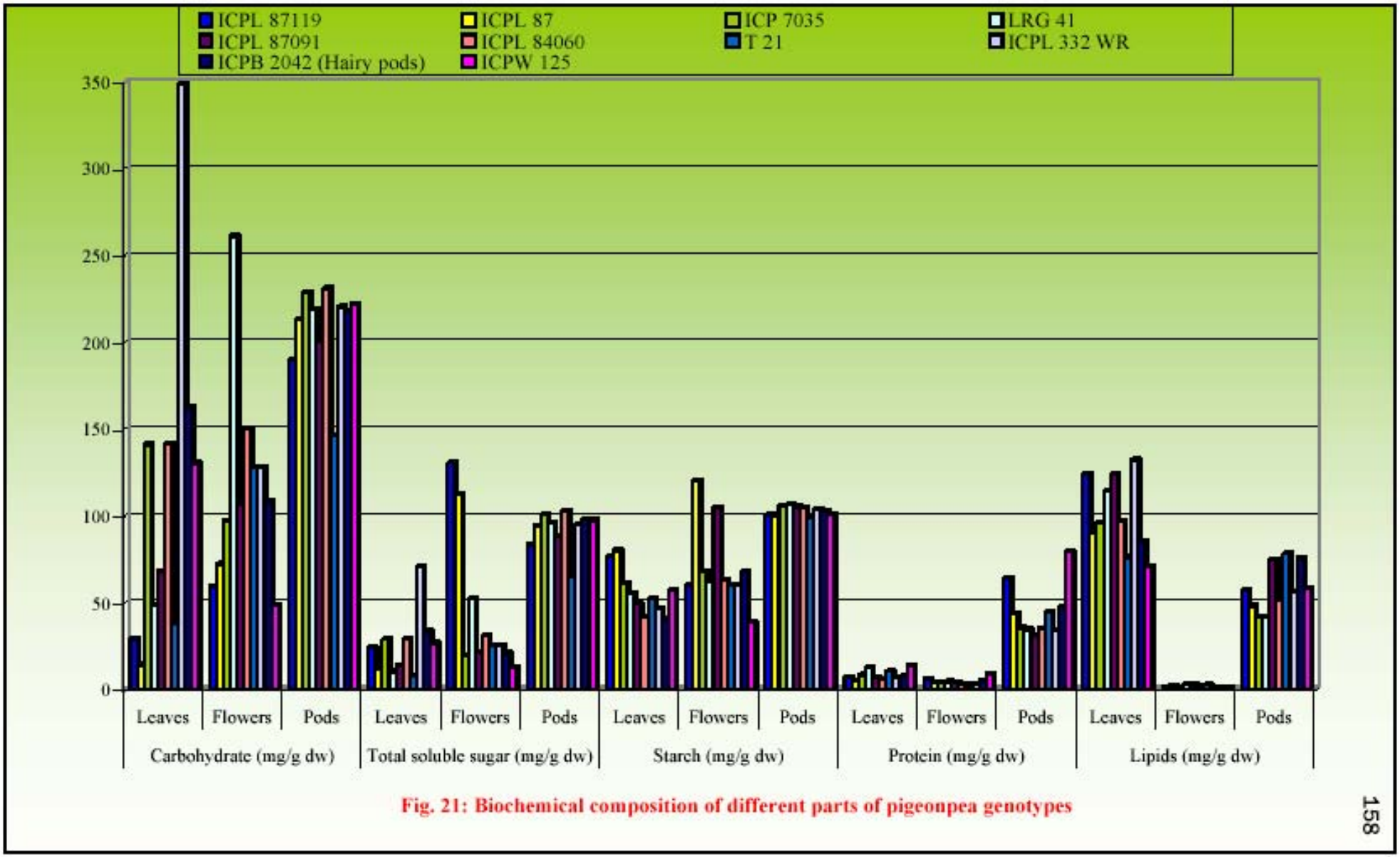


Fig. 21: Biochemical composition of different parts of pigeonpea genotypes

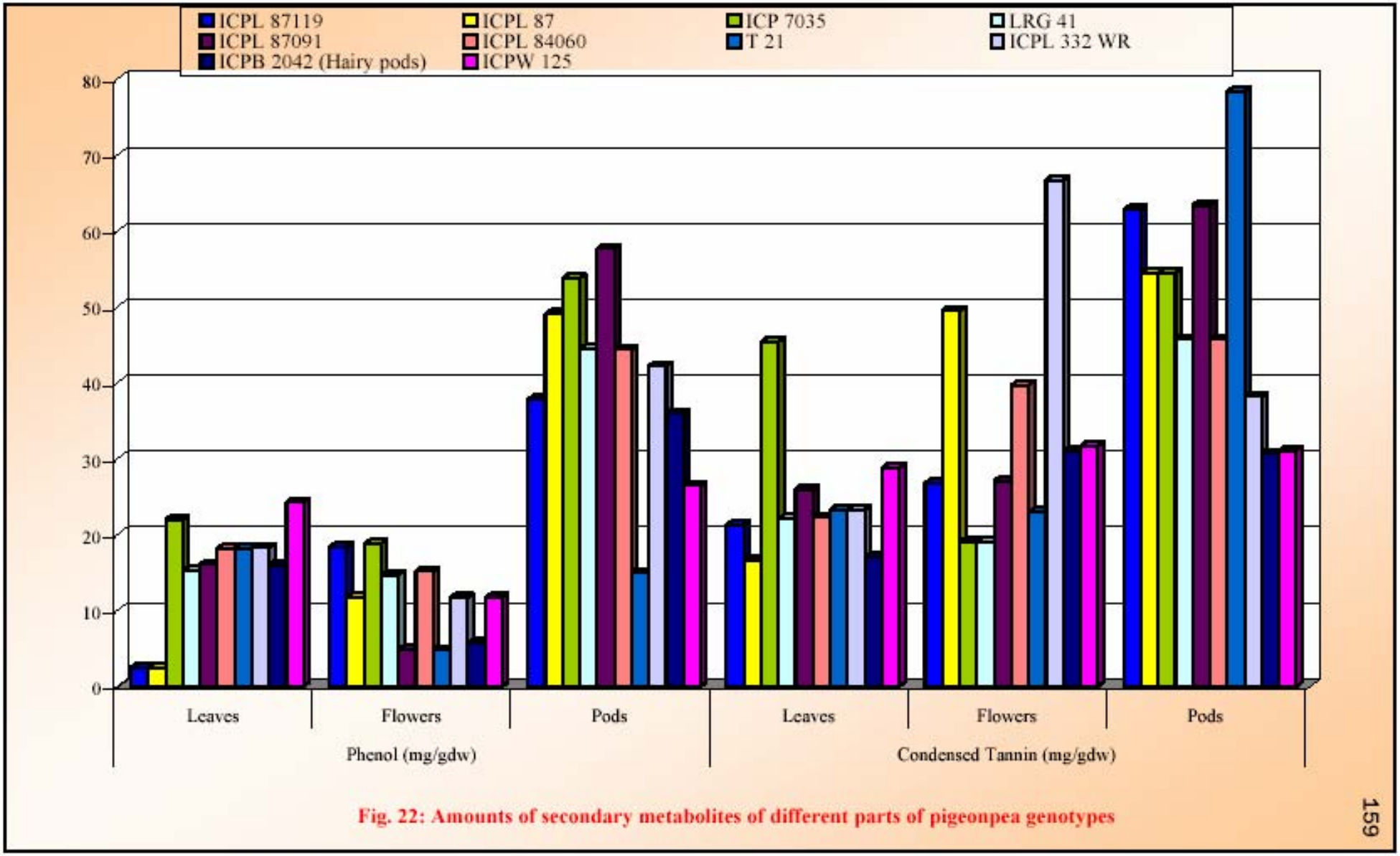


Fig. 22: Amounts of secondary metabolites of different parts of pigeonpea genotypes

The parasitoid wasp, Campoletis sonorensis (Cameron) has been reported to have obligate symbiotic ichnovirus (CsIV), which is required by the parasitic wasp for successful parasitism of the lepidopteran larval hosts (Kromer and Webb, 2003). The virions are injected along with eggs and ovarian proteins into a permissive host by the wasp during the parasitism, which interacts with the prothoracic glands to reduce ecdysone levels, and thus reduces the growth of parasitized host insect, but enables the survival of wasp progeny (Dover et al., 1988; Gunasena et al., 1989; Kroemer and Webb, 2003). Five of the seven viral genes have been reported to express in *Heliothis virescens* (Fab.) hosts within 4 h of parasitism (Kroemer and Webb, 2003). This may be one of the reasons for variation in development and survival of *C. chlorideae* on different pigeonpea genotypes.

5.3 Info-chemicals influencing parasitisation of *H. armigera* eggs and larvae in pigeonpea

There was a significant attractant or repellent effect of the host odors of different pigeonpea genotypes on response of the egg parasitoid, *T. chilonis* and the larval parasitoid, *C. chlorideae*. Odor stimuli from the hexane extract of flowers of ICPB 2042 (Hairy pods) had repellent effect on *T. chilonis* which might be due to the blend of volatile compounds emitted by the genotype (Fig. 23).

There was a significant repellent response of the *T. chilonis* females towards odors from the methanol extract of flowers of ICPB 2042 (Fig. 24) which may be due to the volatile compounds with retention time of 7 min (peak number 2 and peak area 10942), 8 min (peak number 3 and peak area 1318895), 9.5 min (peak number 4 and peak area 385327), 10 min (peak number 5 and peak area 781656) and 10.5 min (peak number 7 and peak area 280755). The repellent effect of flowers of ICPL 87119, may be due to the volatile compound having retention time (min) of 13.5 (peak number 12 and peak area 225988) (Fig. 24). Similarly by the flowers of LRG 41 had repellent effect which may be due to the blend of volatile compounds (Fig. 24). Odors from the methanol extract of flowers of ICPL 84060 attracted significantly more numbers of *T. chilonis* females (Fig. 24), but exhibited a repellent effect towards *C. chlorideae* as compared to the natural air (Fig. 28), which may be due to the blend of volatile compounds emitted by that genotype.

Fig. 23: Response of *T. chilonis* females to the odor stimuli from the hexane extract of flowers of different pigeonpea genotypes in comparison to natural air

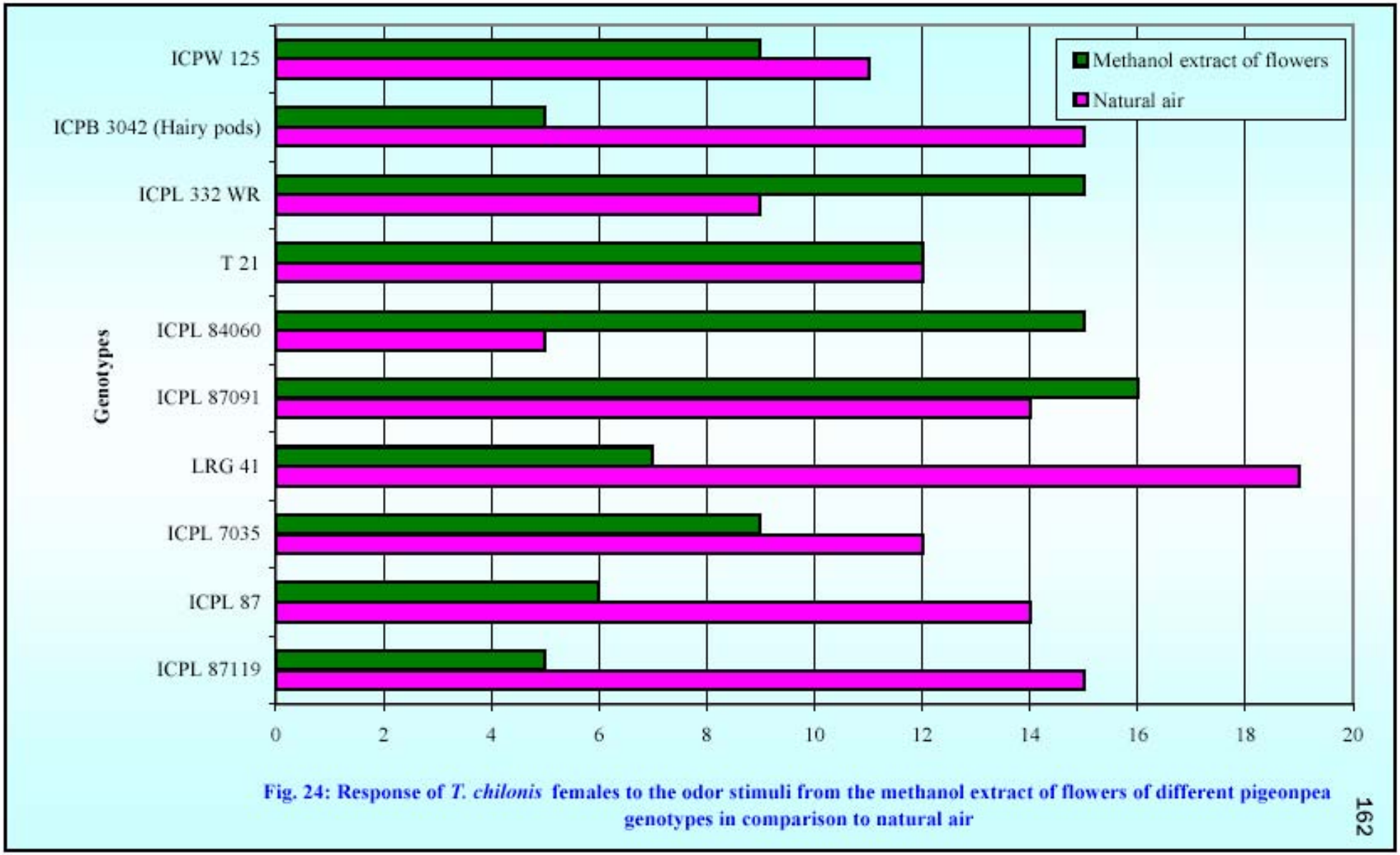


Fig. 24: Response of *T. chilonis* females to the odor stimuli from the methanol extract of flowers of different pigeonpea genotypes in comparison to natural air

Odor stimuli from the hexane extract of ICPB 2042 and ICPL 87119 pods had the attraction effect on the females of *T. chilonis* (Fig. 25). It may be due to the volatile compounds with retention time of 13 min (peak number 13 and peak area 21680) and 14 min (peak number 14 and peak area 262171) from the hexane extract of ICPB 2042, and the blend of compounds from the ICPL 87119. Hexane extract of pods of ICPL 84060 had the repellent effect on the females of *T. chilonis* (Fig. 25).

There was more attraction of *T. chilonis* towards the methanol extract of flowers of genotypes viz.,T 21, ICPL 84060, ICPL 87119 and ICPL 87091. This may be due to the presence or absence of certain blend of volatiles with certain amount. Volatile compounds of methanol extract of pods of ICPW 125 having repellent effect had retention time of 4-5 min (peak number 2 and peak area 30604).

Odour stimuli from the hexane extract of flowers of ICPB 2042 had repellent effect on *C. chlorideae* compared to natural air (Fig. 27), whereas in methanol extract of flowers, ICPL 87, ICPW 125 and ICPL 87119 attracted more number of *C. chlorideae* females compared to natural air (Fig. 28). Hexane extract of ICPL 87 and ICPL 84060 pods had repellent effect towards *C. chlorideae* (Fig. 29).

Larval parasitoid, *Campoletis chlorideae* females attracted towards odour stimuli from the methanol extract of pods of ICPL 87, ICPL 87119 and ICPL 87091, which may be due to the blend of volatile compounds (Fig. 30).

ICPL 87091 having retention time of 13 min (peak number 10 and peak area 215006), may be attributed for the attraction of both species of parasitoids towards methanol extract of pods of different genotypes (Fig. 26 and 30).

The egg parasitoid, *T. chilonis* and the larval parasitoid, *C. chlorideae* responded positively towards volatile compounds, (E)-Alpha faenesene, methylbenzoate, (Z)-3-hexene-1-ol and linalool. Benzaldehyde and acetaldehyde were not attractive to these parasitoids (Fig. 31 and 32). These results are similar to the findings of Yan and Wang (2006), who reported that (Z)-3-hexene-1-ol, (Z)-3-hexenyl acetate, (E)-2-hexenal, linalool and phenylethyl acetate elicited electroantenogram responses in *C. chlorideae*. They also suggested that (Z)-3-hexenyl acetate and linalool may be the key infochemical in the host foraging behavior of *C. chlorideae*, and may act as a food-

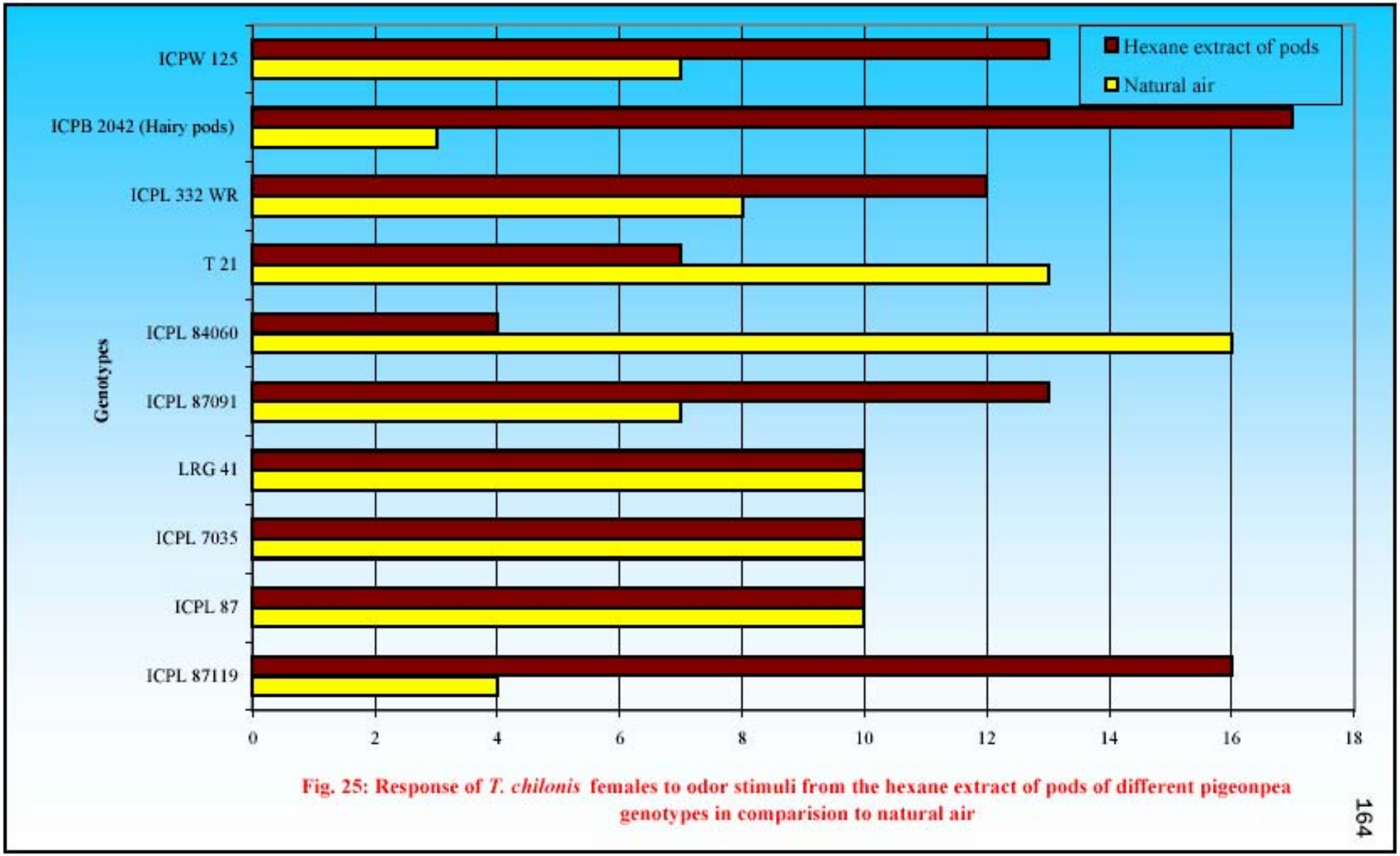


Fig. 25: Response of *T. chilonis* females to odor stimuli from the hexane extract of pods of different pigeonpea genotypes in comparision to natural air

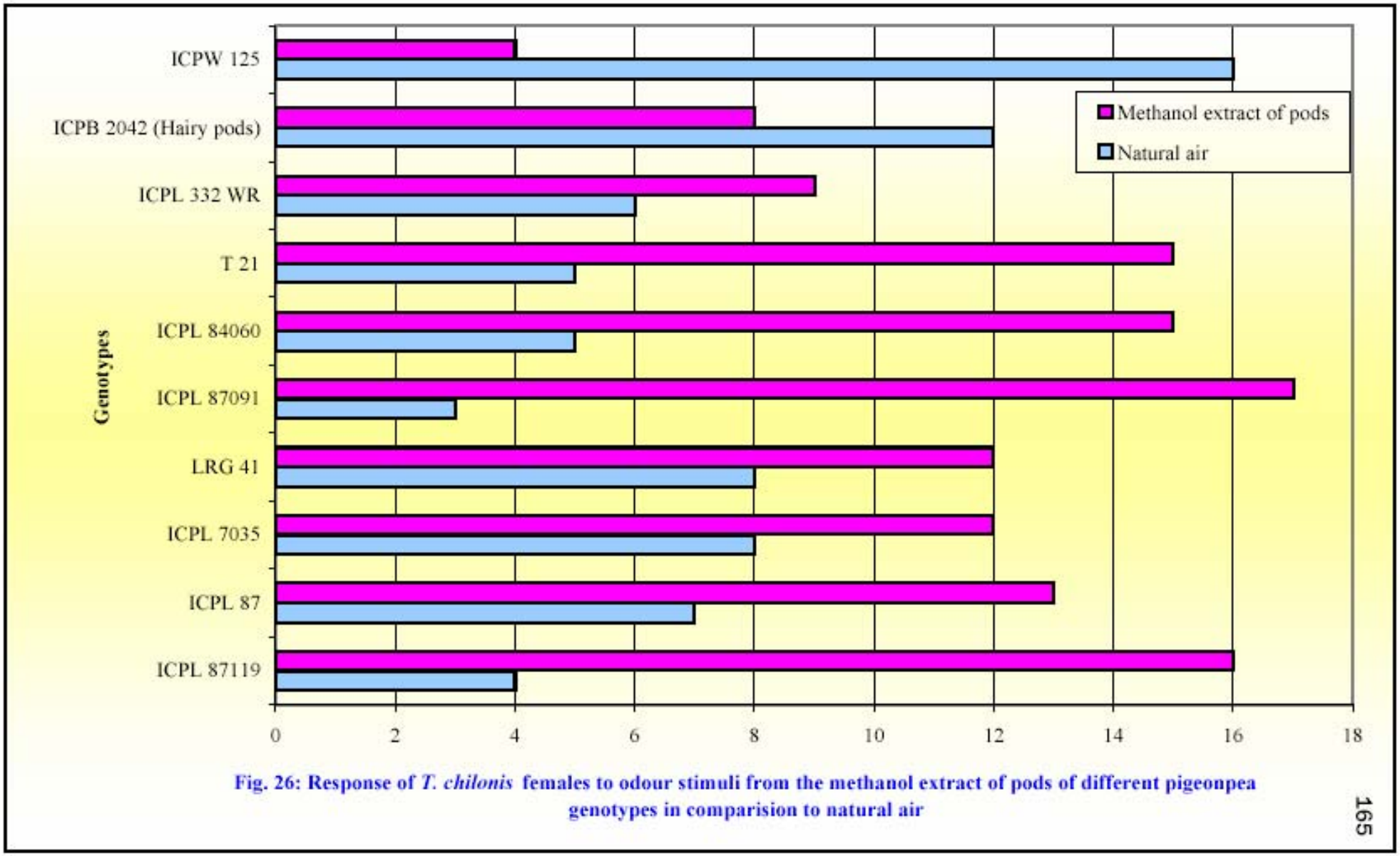


Fig. 26: Response of *T. chilonis* females to odour stimuli from the methanol extract of pods of different pigeonpea genotypes in comparision to natural air

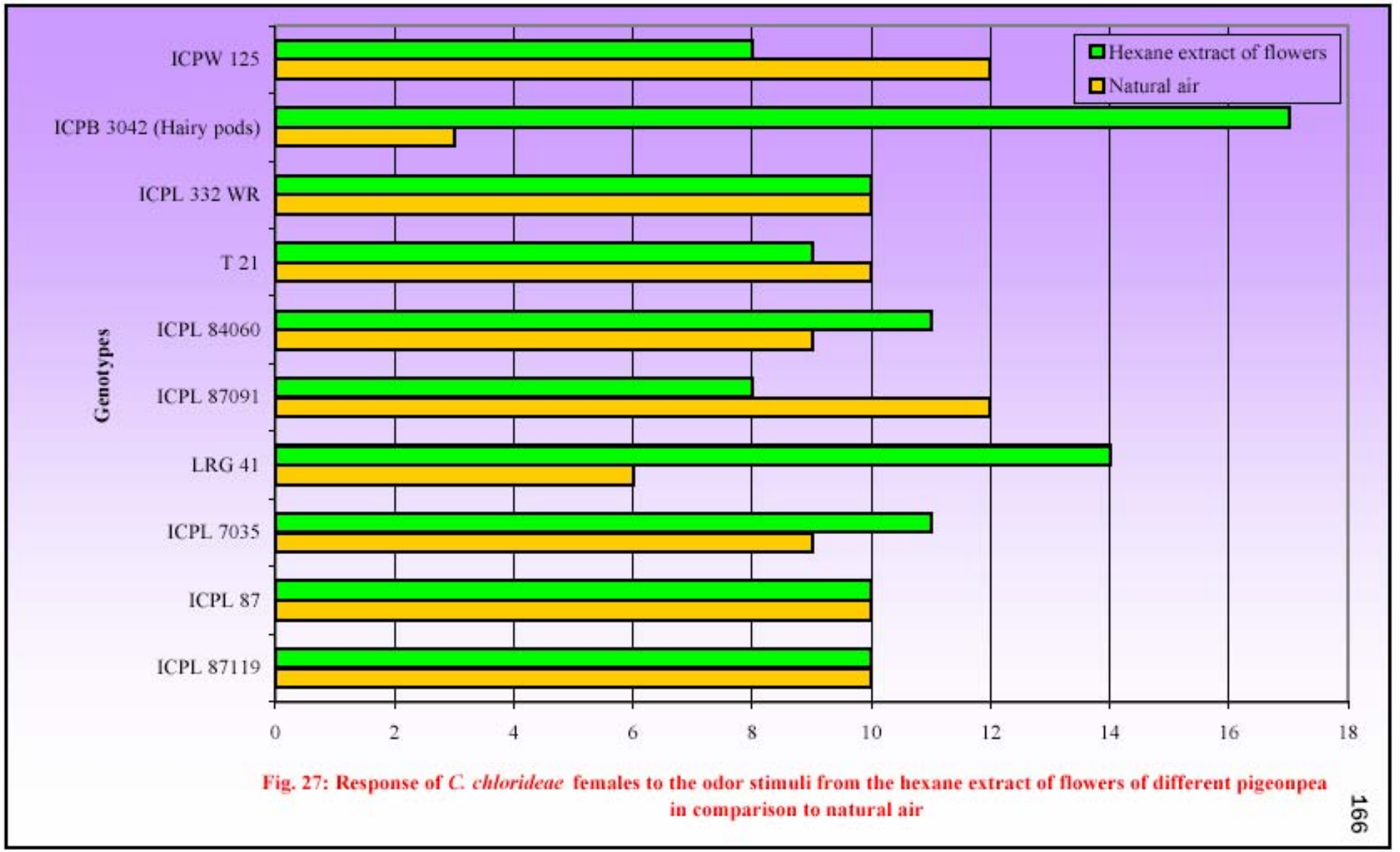


Fig. 27: Response of *C. chlorideae* females to the odor stimuli from the hexane extract of flowers of different pigeonpea in comparison to natural air

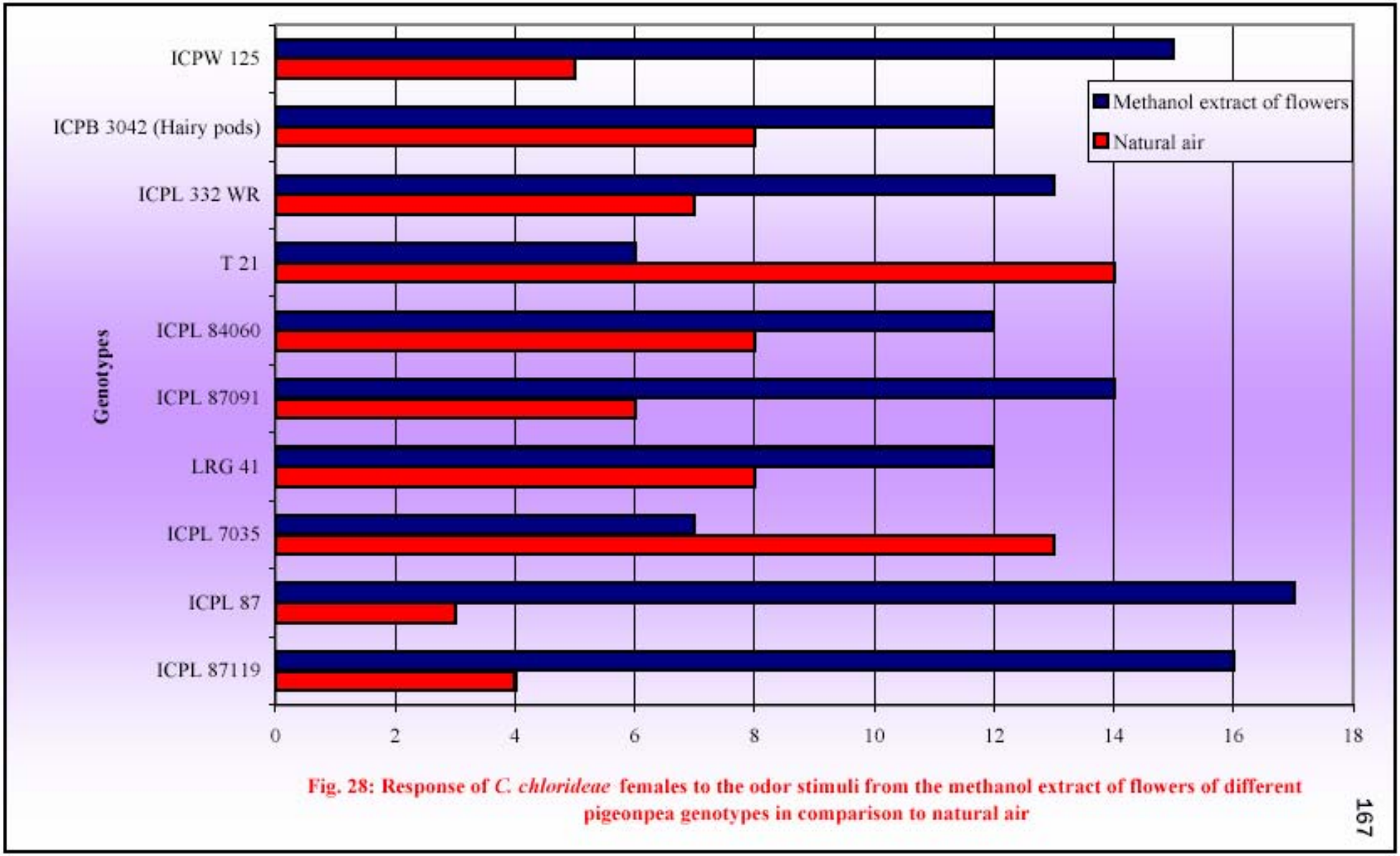


Fig. 28: Response of *C. chlorideae* females to the odor stimuli from the methanol extract of flowers of different pigeonpea genotypes in comparison to natural air

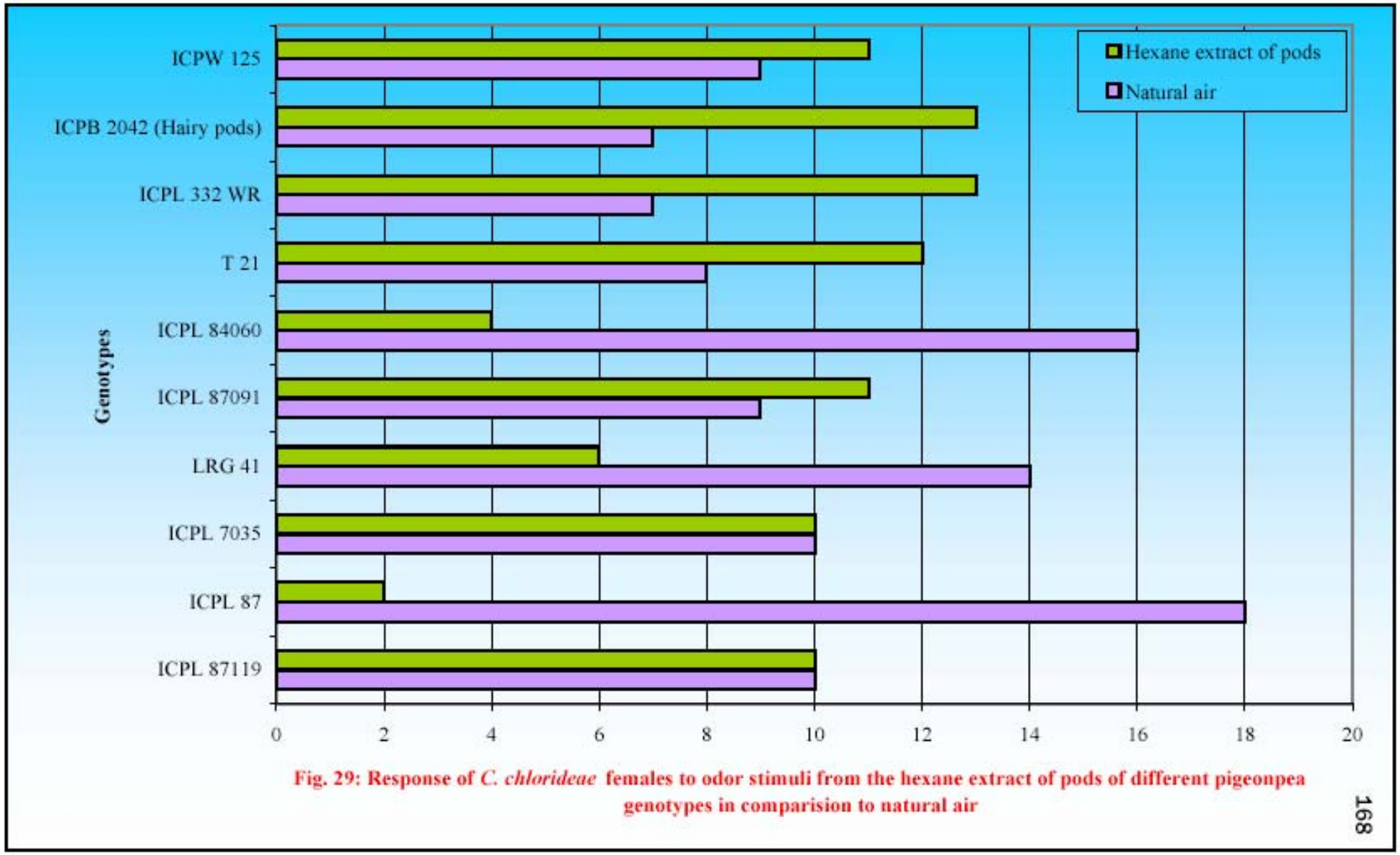


Fig. 29: Response of *C. chlorideae* females to odor stimuli from the hexane extract of pods of different pigeonpea genotypes in comparision to natural air

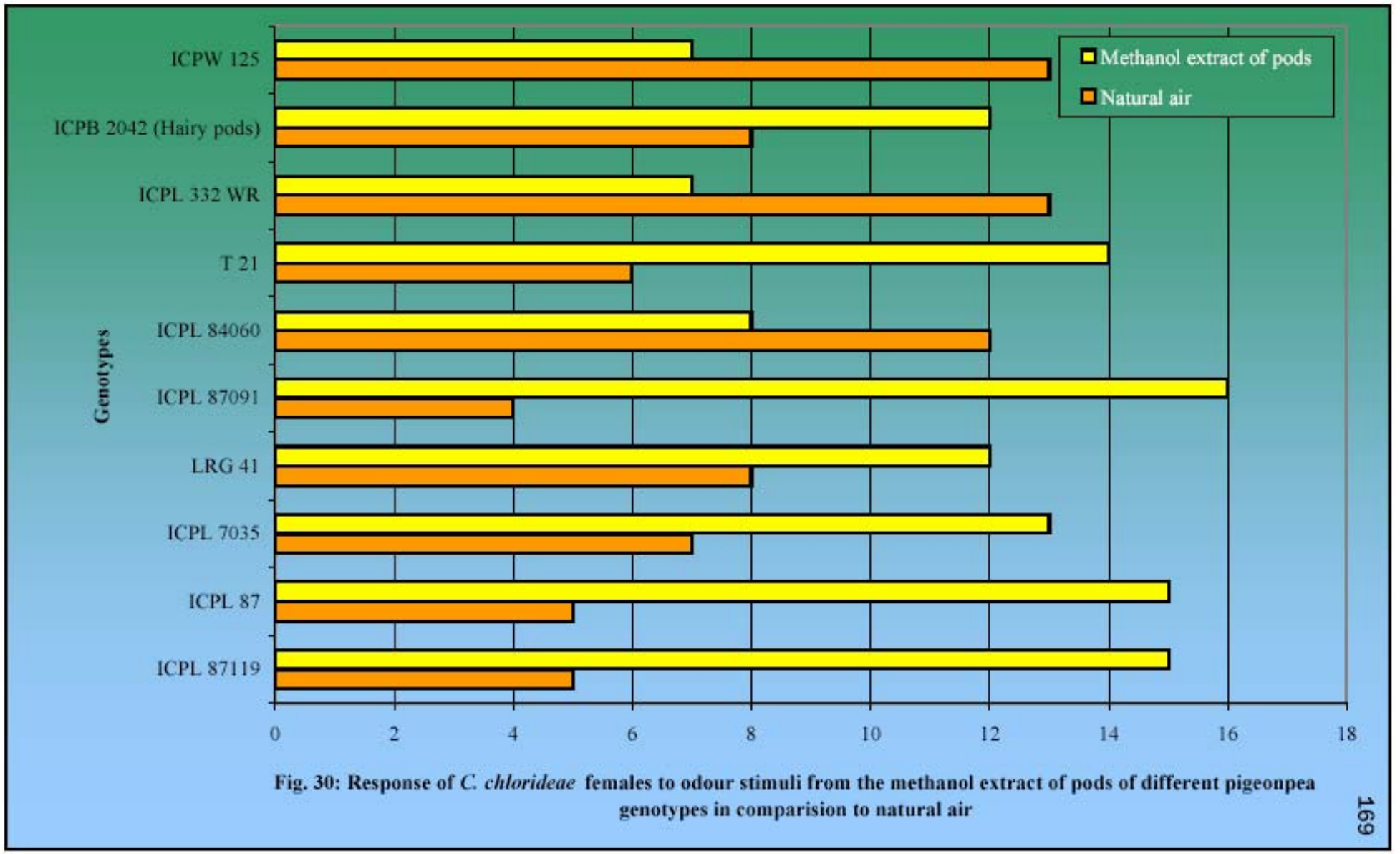


Fig. 30: Response of *C. chlorideae* females to odour stimuli from the methanol extract of pods of different pigeonpea genotypes in comparision to natural air

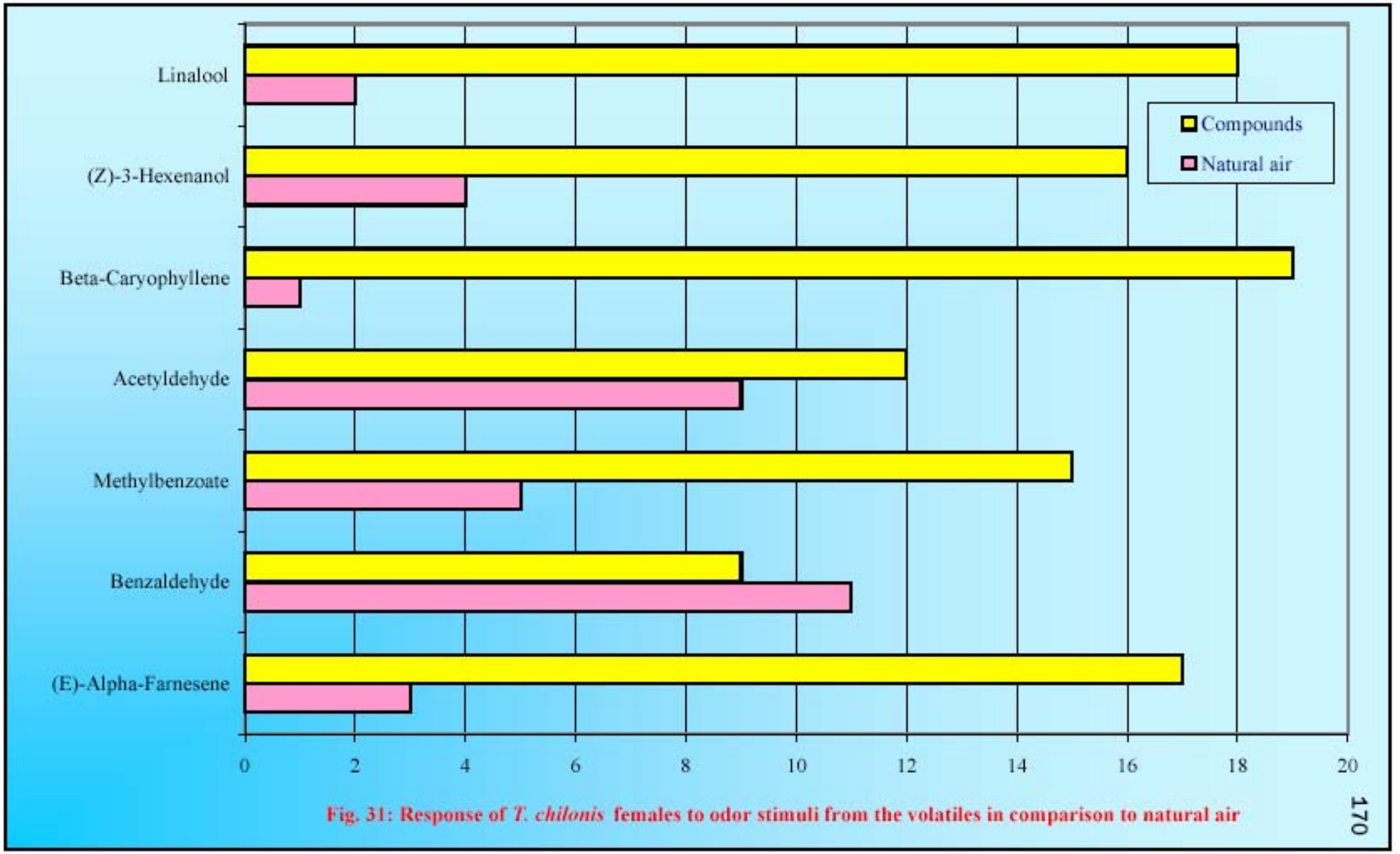


Fig. 31: Response of *T. chilonis* females to odor stimuli from the volatiles in comparison to natural air

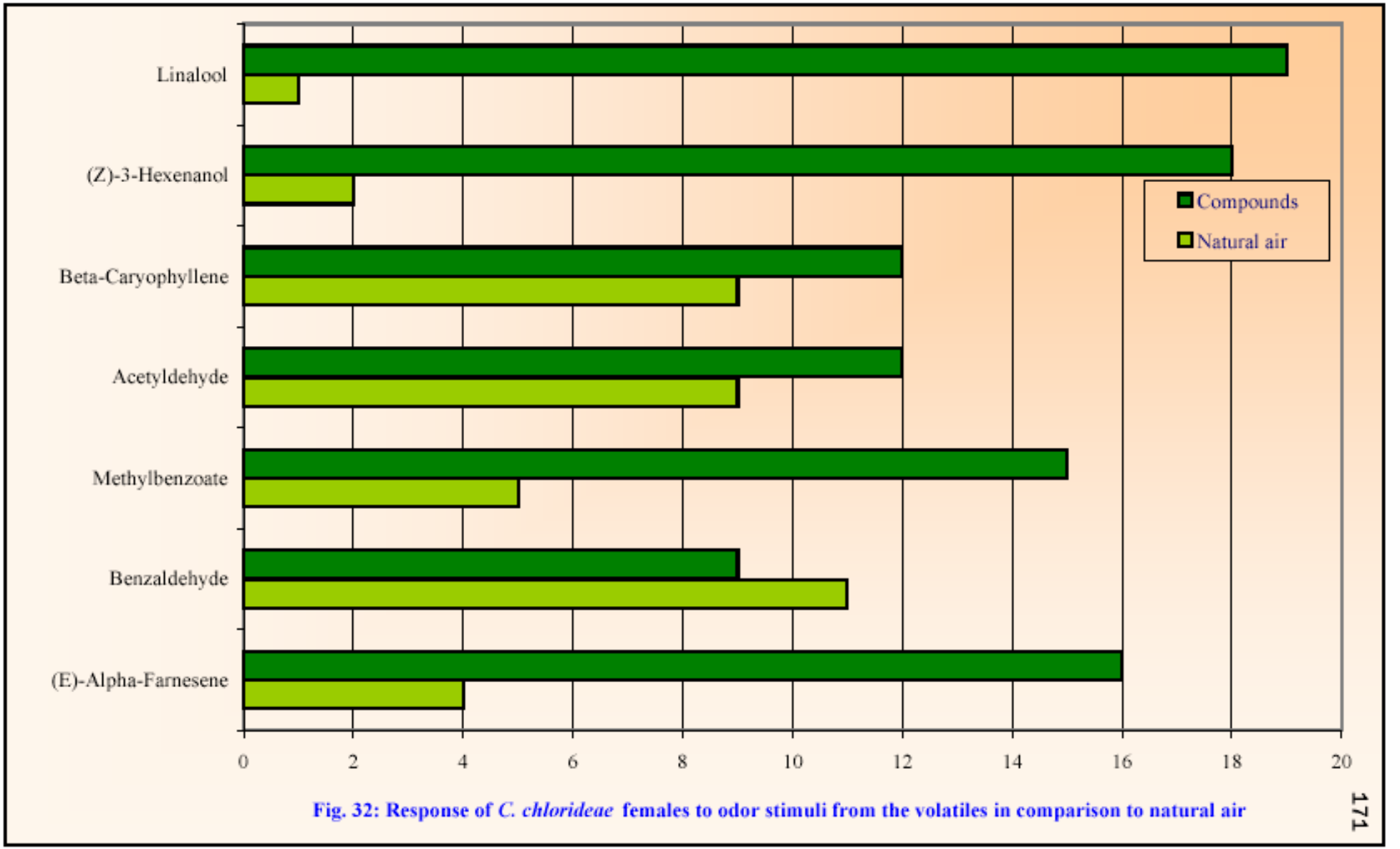


Fig. 32: Response of *C. chlorideae* females to odor stimuli from the volatiles in comparison to natural air

source signal for the parasitoid. ß-caryophyllene attracted the egg parasitoid, *T. chilonis* but not the larval parasitoid, *C. chlorideae*. Similarly Sen et al. (2005) obtained EAG response of largest peak amplitudes in females of *T. chilonis* with caryophyllene.

Future line of work

1. Identification of actual or blend of volatile compounds of pigeonpea for the mass trapping and killing of *H. armigera* moths.

2. Identification of the gene involved in the production of type B trichomes and silencing the gene to avoid preference of *H. armigera* for egg laying.

3. Identification of the gene involved in increasing the pod wall thickness to avoid entry of the larvae in to the pods and making it prone to the parasitoid.

4. Identification of actual or blend of volatile compounds (GCMS) for attraction or repulsion of *T. chilonis* and *C. chlorideae* from all the popular cultivars of pigeonpea.

5. Identification of the gene involved in the production of different types of trichomes and incorporation of the gene involved in production of type D trichome into the cultivatable pigeonpea genotypes i.e. development of cisgenic pigeonpea.

6. Identification of actual biochemical compounds which enhance the survival and development of *C. chlorideae* on the pigeonpea.

7. Identification of the gene involved in the production of particular volatile compound attracting the parasitoids.

6. SUMMARY AND CONCLUSIONS

Studies of the experiments carried out on the identification of pigeonpea genotypes hospitable to *Tricogramma chilonis* Ishii and *Campoletis chloridae* Uchida, attractant/ repellent properties of host genotypes on the *T. chilonis*, attractant/ repellent and antibiotic effects of host genotypes on the *C. chloridae*, and info-chemicals influencing parasitization of *Helicoverpa armigera* (Hübner) eggs and larvae in pigeonpea are summarized hereunder.

Under no-choice and multi-choice cage conditions, egg laying by *H. armigera* on lower surface of ICPW 125 was minimum, followed by ICPL 87, ICPL 87091, ICPL 87119, ICPL 84060 and LRG 41. There were some differences in relative preference for egg laying by *H. armigera* on ICPB 2042, ICPL 332 WR and ICP 7035 under no-choice and multi-choice conditions. Similar trends were observed for relative preference for egg laying on the upper leaf surface, calyxes, flower buds, and pods. The relative preference for egg laying on petals of ICPW 125 under no-choice and multi-choice conditions was least.

Parasitisation of *H. armigera* eggs by *T. chilonis* on different pigeonpea genotypes differed under no-choice, dual-choice and multi-choice conditions. Low egg parasitisation was recorded under no-choice conditions as compared to multi-choice conditions. Egg parasitisation was higher on LRG 41, T 21 and ICPL 332 WR under no-choice conditions and these genotypes are compatible with natural enemies of *H. armigera*. Parasitisation of eggs on ICPW 125 was lower under no-, dual- and multi-choice conditions due to the high trichome density, and longer length of trichome D. Under multi choice conditions, eggs on calyxes of ICPL 84060 and ICPL 87119 had the highest and lowest percentage of parasitisation, respectively. Under no-choice conditions eggs laid on ICPB 2042 and T 21 had higher percentage of parasitisation. Under no-choice and multiple-choice conditions, percentage parasitisation was greater on ICPL 87, ICPL 87091 and ICPL 87119.

Odors from the flowers of ICPL 84060 and ICP 7035 were attractive to the egg parasitoid, *T. chilonis*, and larval parasitoid, *C. chlorideae* as compared to the natural air. The flowers of ICP 7035 were highly attractive, while that of ICPL 84060 were

repellent to the females of *C. chlorideae* when compared to the susceptible check, ICPL 87. Odors from the flowers of all the pigeonpea genotypes were attractive to the larval parasitoid, *C. chlorideae*. Odors from the flowers of ICPL 87119 were also attractive, while that of ICP 7035, ICPB 2042 and ICPL 84060 were repellent to the females of *C. chlorideae* as compared to the susceptible check, ICPL 87.

Helicoverpa armigera exhibited better life history performance on flowers than on lyophilized pods and leaves. Egg + larval period was shorter when the insects were reared on flowers except for ICPW 125. Similarly, shorter Egg + larval period was observed when the insects were reared on lyophilized pod powder incorporated into the artificial diet, except on ICPL 84060, ICPB 2042 and ICPW 125 as compared to the larvae reared on flowers. Longer egg + larval period was recorded when *H. armigera* larvae were fed on leaves of LRG 41 and ICP 7035. Larvae failed to pupate in insects reared on ICPL 87, due to lower protein content and also on ICPL 332 WR, due to high amounts of carbohydrates and lipids. Cocoon formation and adult emergence of *C. chlorideae* were positively correlated with the carbohydrate content and was greater in the larvae reared on flowers than those recorded on leaves and lyophilized pod powder incorporated into the artificial diet. There was no adult emergence from the larvae reared on leaves of ICPL 87119 and ICPL 87.

Consumption index (CI mg/mg/day), approximate digestibility (AD%) and efficiency of conversion of ingested food into body matter (ECI%) of the unparasitised larvae was greater than that of the parasitized larvae. Efficiency of conversion of digested food into body matter (ECD%) of the unparasitized larvae was also greater than that of the parasitized larvae, except on ICP 7035.

Consumption index of the parasitized larvae reared on flowers was positively correlated with the starch content and negatively correlated with the protein content of the flowers. Similarly, approximate digestibility of parasitized and unparasitised larvae reared on flowers was negatively correlated with the protein content, and the Efficiency of conversion of digested food into body matter of parasitized larvae was positively correlated with the phenol content.

There was a significant repellent or attractive effect of the host odors on response of the egg parasitoid, *T. chilonis* females, and the larval parasitoid, *C. chlorideae*, respectively to odor stimuli from the hexane extract of flowers of ICPB 2042 (Hairy pods). There was a significant repellent response of the *T. chilonis* females towards odors from the methanol extract of flowers of ICPB 2042. Odors from the methanol extract of flowers of ICPL 84060 attracted significantly more numbers of *T. chilonis* females, but exhibited a repellent effect towards *C. chlorideae* as compared to the natural air.

Odor stimuli from the hexane extract of ICPB 2042 and ICPL 87119 pods had the attraction effect on the females of *T. chilonis*. Hexane extract of pods of ICPL 84060 had the repellence effect on the females of *T. chilonis* and *C. chlorideae*, and Females of *C. chlorideae* were repelled by the odor stimuli from the hexane extract of pods of ICPL 87.

There was more attraction of *T. chilonis* towards the genotypes T 21, ICPW 125, ICPL 84060 and ICPL 87091 and of *Campoletis chlorideae* females attracted towards odour stimuli from the methanol extract of pods of ICPL 87, ICPL 87119 and ICPL 87091.

The egg parasitoid, *T. chilonis* and the larval parasitoid, *C. chlorideae* responded positively towards volatile compounds, (E)-Alpha faenesene, methylbenzoate, (Z)-3-hexene-1-ol and linalool. Benzaldehyde and acetaldehyde were not attractive to these parasitoids. ß-caryophyllene attracted the egg parasitoid, *T. chilonis* but not the larval parasitoid, *C. chlorideae*.

Conclusions

- ICPW 125 was least preferred and ICPL 87 and ICPL 87091 were highly preferred for egg laying by the *H. armigera*.
- Lower numbers of eggs were laid on the leaf surfaces than the calyxes and pods in all the pigeonpea genotypes.
- Higher numbers of eggs were laid on the genotypes having higher density of type B trichomes.

- Parasitisation of eggs by *T. chilonis* laid on the upper and lower leaf surface was higher on all the pigeonpea genotypes when compared with the reproductive parts.
- Density and length of the type D trichome played a major role in hindering the parasitization of *H. armigera* eggs by *T. chilonis*.
- Larval parasitisation by the *C. chlorideae* was highest on the susceptible genotypes ICPL 87 and ICPL 87091 which had clustering type of flowering and lowest on the wild genotype ICPW 125 having creeping habit.
- Leaves of pigeonpea genotypes had the antibiotic effect on the *C. chlorideae* via *H. armigera* and flowers were more congenial for the successful completion of the *C. chlorideae* biology.
- Higher the pod length, pod wall thickness and pod width more will be the H. larvae prone to the larval parasitoid.
- Parasitised larvae had the lowest consumption index, approximate digestibility and efficiency of conversion of ingested food than the unparasitised larvae.
- ICPW 125 and ICPL 332 WR had the antibiotic effect on the larval parasitoid
- Up to certain extent higher the carbohydrate content higher is the cocoon formation and adult emergence and higher the protein content shorter the egg + larval period.
- Blend of volatile compounds of pigeonpea influenced the behavior of *T. chilonis* and *C. chlorideae*.
- Linalool and hexane-1-ol were attractive to the parasitoids.

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** - Originals not seen*

TRITROPHIC INTERACTIONS BETWEEN PIGEONPEA GENOTYPES, *Helicoverpa armigera* (Hübner) AND NATURAL ENEMIES

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ABSTRACT

The present investigation on "Tritrophic interaction between pigeonpea genotypes, *Helicoverpa armigera* (Hübner) and natural enemies" was carried out during 2008-12 at ICRISAT (Patancheru, Hyderabad). Under no, dual and multi-choice conditions, egg laying by *H. armigera* on ICPW 125 was minimum due to high density of type D trichomes, while it was maximum on ICPL 87. The per cent Parasitisation by *Trichogramma chilonis* Ishii was higher on ICPB 2042 and by *Campoletis chlorideae* Uchida it was greater on ICPL 87 and ICPL 87091 due to longer pods and clustering type of habitat and ICPL 87119 due to higher pod wall thickness.

Odors from the flowers of ICPL 84060 and ICP 7035 attracted *T. chilonis* and *C. chlorideae*. *C. chlorideae* performed better on LRG 41, ICP 7035 and ICPL 84060. Larvae failed to pupate in insects reared on leaves of ICPL 87 and ICPL 332 WR, due to lower protein content and high amounts of carbohydrates and lipids, respectively. There was no adult emergence from the larvae reared on leaves of ICPL 87119. Consumption index, approximate digestibility and efficiency of conversion of ingested food into body matter of the unparasitised larvae was greater than that of the parasitized larvae.

Odor stimuli from the hexane extract of flowers of ICPB 2042 attracted *C. chlorideae*, while the methanol extract of flowers of ICPL 84060 attracted *T. chilonis* females. Odor stimuli from the hexane extract of ICPB 2042 and ICPL 87119 pods attracted the females of *T. chilonis,* while the methanol extract of pods of ICPL 87, ICPL 87119 and ICPL 87091 attracted *C. chlorideae* females.

T. chilonis and *C. chlorideae* responded positively towards volatile compounds *viz.,* (E)-Alpha faenesene, methylbenzoate (Z)-3-hexene-1-ol and linalool, while benzaldehyde and acetaldehyde were not attractive to these parasitoids. β-caryophyllene attracted *T. chilonis* but not the *C. chlorideae.*