# First record of *Apanteles hemara* (N.) on *Leucinodes orbonalis* Guenée and biodiversity of Hymenoptera parasitoids on Brinjal (#88540)



First submission

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# First record of *Apanteles hemara* (N.) on *Leucinodes orbonalis* Guenée and biodiversity of Hymenoptera parasitoids on Brinjal

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The brinjal fruit and shoot borer (BFSB), *Leucinodes orbonalis* Guenée (Lepidoptera: Crambidae), is a severe pest and causes economic losses for the brinjal crop worldwide. Infested brinjal fruits were collected from vegetable fields at ICAR-Indian Agricultural Research Institute (ICAR-IARI), New Delhi, India, during two consecutive seasons (2021-2022). The larvae of the pest were brought to the lab and reared for the emergence of parasitoids at 25 ± 0.5°C and relative humidity of 70 ± 5%. Further, surveying Hymenoptera parasitoids in brinjal was done using a sweep net and yellow pan trap during two seasons. Findings indicate that five parasitoid species emerged from *L. orbonalis* viz., *Apanteles hemara* Nixon, 1965, *Bracon greeni* Ashmead 1896, *Goryphus nursei* (Cameron, 1907), *Trathala flavoorbitalis* (Cameron, 1907) and *Spalangia gemina* Boucek 1963. Out of these, *A. hemara* and *S. gemina* were reported for the first time in Delhi, and *A. hemara* was recorded for the first time as a parasite on *L. orbonalis*. Among them, *T. flavoorbitalis* was observed during both seasons and showed higher parasitism of 15.55 and 18.46% during July and August 2022, respectively. However, the average parasitism (%) of *A. hemara*, *B. greeni*, *G. nursei*, *T. flavoorbitalis* and *S. gemina* was 1.20, 1.76, 1.10, 9.28 and 3.10% respectively. In addition, the results showed a significant ($p \leq 0.01$) strongly positive correlation between fruit infestation (%) by *L. orbonalis* and parasitism (%). The survey revealed the presence of a broad group (19 families and 60 species) of Hymenoptera parasitoids in the brinjal crop ecosystem in Delhi which could be valuable in biological control. In light of these results, this study revealed that *A. hemara* and other parasitoids recorded in this study alongside *T. flavoorbitalis* would be ideal biocontrol agents in the BFSB IPM program in Delhi.

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## Abstract

The brinjal fruit and shoot borer (BFSB), *Leucinodes orbonalis* Guenée (Lepidoptera: Crambidae), is a severe pest and causes economic losses for the brinjal crop worldwide. Infested brinjal fruits were collected from vegetable fields at ICAR-Indian Agricultural Research Institute (ICAR-IARI), New Delhi, India, during two consecutive seasons (2021-2022). The larvae of the pest were brought to the lab and reared for the emergence of parasitoids at 25 ± 0.5°C and relative humidity of 70 ± 5%. Further, surveying Hymenoptera parasitoids in brinjal was done using a sweep net and yellow pan trap during two seasons. Findings indicate that five parasitoid species emerged from *L. orbonalis* viz., *Apanteles hemara* Nixon, 1965, *Bracon greeni* Ashmead 1896, *Goryphus nursei* (Cameron, 1907), *Trathala flavoorbitalis* (Cameron, 1907) and *Spalangia gemina* Boucek 1963. Out of these, *A. hemara* and *S. gemina* were reported for the first time in Delhi, and *A. hemara* was recorded for the first time as a parasite on *L. orbonalis*. Among them, *T. flavoorbitalis* was observed during both seasons and showed higher parasitism of 15.55 and 18.46% during July and

August 2022, respectively. However, the average parasitism (%) of *A. hemara*, *B. greeni*, *G. nursei*, *T. flavoorbitalis* and *S. gemina* was 1.20, 1.76, 1.10, 9.28 and 3.10% respectively. In addition, the results showed a significant ($p \leq 0.01$) strongly positive correlation between fruit infestation (%) by *L. orbonalis* and parasitism (%). The survey revealed the presence of a broad group (19 families and 60 species) of Hymenoptera parasitoids in the brinjal crop ecosystem in Delhi which could be valuable in biological control. In light of these results, this study revealed that *A. hemara* and other parasitoids recorded in this study alongside *T. flavoorbitalis* would be ideal biocontrol agents in the BFSB IPM program in Delhi.

**Keywords**: Parasitoids, *Apanteles hemara*, *Trathala flavoorbitalis*, *Leucinodes orbonalis*, survey, Brinjal, Delhi.

## Introduction

Brinjal (*Solanum melongena* L.) holds a significant position as the third most widely consumed and economically valuable vegetable in Asia. India is the second largest producer of brinjal in the world, next to China. Despite the overall growth in global eggplant production, its productivity is constrained by challenges posed by insects and diseases (*Alam & Salimullah, 2021*). The primary insect pest responsible for causing damage to brinjal is the lepidopteran fruit and shoot borer, which seriously threatens its cultivation.

The Brinjal fruit and shoot borer (BFSB) *Leucinodes orbonalis* Guenée is a highly important insect pest that affects brinjal plants worldwide (*Nusra et al., 2021*). The larvae of BFSB cause damage to eggplant plants by tunneling into the leaf petioles, midribs, and tender shoots, which subsequently leads to the wilting and desiccation of the stems. Furthermore, the larvae feed on the flowers, causing them to fall prematurely or resulting in malformed fruits.

The most significant economic damage caused by BFSB occurs to the fruit itself. The fruit becomes unsuitable for human consumption and sale due to the presence of holes, feeding tunnels, and excrement from larvae. BFSB has a high ability to reproduce, quickly cycles through generations, and causes extensive damage in both wet and dry seasons, posing a significant challenge to plants (*Prodhan et al., 2018*).

Infestation levels may exceed 90%, resulting in substantial worldwide economic losses estimated at 86-90% (*Ghosh et al., 2003*). In India, brinjal is sprayed with chemicals 15 to 40 times per season (*Watkins et al., 2012*). However, this approach is environmentally hazardous, poses health risks to consumers and farmers, and incurs significant costs (*Prodhan et al., 2018*).

To adopt an environmentally friendly strategy for controlling pests, it is essential to protect and preserve the natural predators and parasitoids that naturally keep pest populations in check. Among the 21 parasitoids reported in relation to BSFB, one of the most prominent parasitoids is *T. flavoorbitalis* (*Ranjith et al., 2020*). This parasitoid has a high parasitism rate of 61.7% (*Srinivasan, 2008*). In addition to *T. flavoorbitalis*, *Goryphus nursei* was recorded in Uttar Pradesh and proved to be an active parasitoid, particularly during the winter season, exhibiting a maximum parasitism rate of 7% (*Alam et al., 2003*).

*Trathala flavoorbitalis*, a widely recognized parasitoid of *L. orbonalis*, has been observed in different regions of India, especially Bihar, Tamil Nadu, Manipur and Karnataka (*Mallik et al., 1989*; *Yasodha & Natarajan, 2009*; *Murali et al., 2017*; *Ranjith et al., 2020*; *Thokchom et al., 2022*). This parasitoid species is globally distributed and can be found in regions such as Afrotropical, Australasian, Eastern Palaearctic, Nearctic, Oceanic, and Oriental. It is particularly prevalent in the Indo-Pacific and Eastern Oriental regions (*Rousse & Villemant, 2012*).

In Tamil Nadu, (*Yasodha & Natarajan, 2009*) documented the emergence of 12 parasitoid species from BFSB, belonging to the superfamilies Ichneumonoidea and Chalcidoidea. Furthermore, (*Murali et al., 2017*) reported the presence of *Spalangia gemina* on BSFB, while *Bracon greeni* was documented by (*Venkatraman et al., 1948*).

Consequently, this research aims to evaluate the parasitism rate of parasites associated with BFSB during two seasons, which is essential for the success of its biological control. Furthermore, a survey of Hymenoptera parasitoids families in the brinjal crop ecosystem in New Delhi.

# Materials & Methods

## Insect sampling

This study was carried out to record and assess the potential of the natural enemies associated with the *L. orbonalis* Guenée during two consecutive seasons (November 2021 to October 2022) in vegetable fields at ICAR-Indian Agricultural Research Institute (ICAR-IARI), New Delhi, India.

Weather parameters during the study period such as rainfall, minimum and maximum temperature and relative humidity were recorded from an agrometeorological observatory, Division of Agricultural Physics, IARI, New Delhi and are provided in (Table S1).

To calculate the pest infestation rate (%) in brinjal, the field was divided into four quarters, and 15 plants per quarter were randomly checked. The pest incidence was observed at 7 days' intervals, and infestation (%) was calculated according to the following equation.

$$\textbf{Fruit infestation } (\%) = \frac{\text{No. of infested fruits}}{\text{Total fruits observed}} \times 100 \quad (1)$$

Infested brinjal fruits were collected, and the larvae were reared for the emergence of parasitoids under laboratory conditions of 25 ± 0.5°C, relative humidity 65 ± 5% RH and a photoperiod of 12 light: 12 Dark h. The larvae, after pupation were separated and kept in plastic containers until parasitoid emergence. The emerged parasitoids were preserved in 70% alcohol and card mounted for taxonomic studies, and the parasitism percentage during each month was calculated according to the following equation (*Van Driesche, 1983*).

$$\textbf{Parasitism } (\%) = \frac{\text{Total parasitoids emerged from larvae or pupa}}{\text{Total No. of larvae or pupa collected from field}} \times 100 \quad (2)$$

In addition, a surveying study for Hymenoptera parasitoids in brinjal was randomly done using a sweep net and yellow pan trap weekly during two seasons (2021-2022).

## Identification of parasites

From the collected parasites, big parasitoids were pinned and dry-preserved, while small ones were preserved in 70% ethanol. Parasitoids were identified with the help of (*Bouček, 1951*; *Habu, 1960*; *Stary 1975*; *Husain & Agarwal, 1982*; *Greco, 1997*; *Narendran et al., 2001*; *Belokobylskij, 2003*; *Jonathan, 2006*; *Gibson, 2009*; *Rousse et al., 2011*; *Rousse & Villemant, 2012*; *Sheeba & Narendran, 2013*; *Xu et al., 2013*; *Akhtar et al., 2014*; *Ghafouri-Moghaddam et al., 2014*; *Amer et al., 2016*; *Cao et al., 2017*; *Fernandez-Triana et al., 2017*; *Khalaim, 2018*; *Ahmed et al., 2020*; *Zerova & Fursov, 2020*; *Gull-e-Fareen et al., 2021*; *Talamas et al., 2021*). The morphological studies were carried out using a Leica S8AP0 stereo microscope and a LEICA M205 C stereozoom automountage microscope. Multi-focused montage images were taken using a LEICA MC190 HD digital camera attached to the LEICA M205 C stereozoom automountage microscope. The photographs and illustrations were processed with Adobe Photoshop CS5 and plates were prepared. The morphological terminology and wing venation are based on (*Nixon 1965*; *Jonathan, 2006*; *Gibson, 2009*; *Sheeba & Narendran, 2013*). All the specimens are deposited in the National Pusa Collection (NPC), ICAR-IARI, New Delhi, India.

## Statistical analysis

The parasitism (%) was analyzed statistically, and the extent of parasitism (%) was also subjected to correlation analysis with brinjal fruit infestation (%), also with weather factors using Minitab® Statistical Software (17.0).

# Results

The results of this study showed that five parasitoid species viz., *A. hemara*, *B. greeni* (Braconidae), *G. nursei*, *T. flavoorbitalis* (Ichneumonidae) and *S. gemina* (Pteromalidae) were recorded on *L. orbonalis*.

## I. Systematic study

The main diagnostic characteristics of five parasitic wasps that emerged from Brinjal fruit and shoot borer (*L. orbonalis* Guenée), as well as their hosts and distribution details, were highlighted as follows.

### 1. *Apanteles hemara* Nixon, 1965 (Fig. 1)

**Diagnosis**: Body black. Mandible and labrum orange testaceous, palpi pale yellow and antennae dark brown to black. Fore and mid legs yellowish orange, entire hind coxa densely punctate rugose; hind femur brown, yellow trochanter, hind tibia most often strikingly bicolor, yellow and brown on posterior with spurs white, hind tarsus infuscate. Wing hyaline, venation brown; pterostigma mostly brown. Head entirely densely setose. Clypeus ventral margin slightly concave. Face and clypeus moderately and shallowly punctate; antenna slightly shorter than body length, with 14 flagellomere. Mesosoma, mesoscutum and scutellum with relatively coarse and dense punctures (distance between punctures smaller than diameter of puncture). Propodeum with areola complete, propodeal areola strong, centrally smooth, apically pointed and basally petiolate to base of propodeum by two sub-median irregular carinas. Forewing with 2Rs more than twice shorter than r, R1 very long, pterostigma enlarged. The areolet open. Legs hind coxae entirely punctate rugose. Hind femur slightly swollen. Metasoma T1 of metasoma much longer than wide with strong, longitudinal striation, its margins sub-parallel to strongly converging apically. Tergum 2 wider than long, short, transverse and apically widened. Tergum 3 longer than tergum 2. Ovipositor sheath slightly shorter than tibia. Ovipositor large, usually slightly decurved and gradually tapered.

**Material examined**: 1♀ June; 2♀ August; 1♀ September 2022 emerged from *L. orbonalis* and 1♀ August; 2♀ September 2022 brinjal, yellow pan trap, ICAR-IARI, New Delhi.

**Host records**: *Tebenna micalis* (Choreutidae); *Cnaphalocrocis trapezalis*, *Herpetogramma stultalis*, *Hydriris ornatalis*, *Omiodes indicatae*, *Spoladea recurvalis* and *Udea ferrugalis* (Crambidae) (*Fernandez-Triana et al., 2017*) *Hymenia fascialis*, *Pachyzancla stultalis* (Pyralidae) (*Nixon 1965*).

**Distribution**: Kenya, Madagascar, Cape Verde Islands, Mauritius, Saudi Arabia, Senegal, Republic of Congo, South Africa, Yemen, Australia and India (new record established at New Delhi) (*Fernandez-Triana et al., 2017*).

### 2. *Bracon greeni* Ashmead 1896 (Fig. 2)

**Diagnosis**: Body brownish-yellow. Disc of metasoma, extreme apex of second tergite and large dorsal blotches on third and fourth tergites black; wings hyaline, stigma and veins brown. Head and thorax smooth; wings hyaline; stigma and veins brown antenna 24 segmented; vertex rugose, anteriorly smooth, shiny posteriorly and hairy; eyes glabrous, slightly emarginate; temple smooth, shiny and hairy; width of face 1.65x its height; clypeus smooth. Antenna nearly as long as the body. Mesosoma pronotum smooth and shiny; mesoscutum smooth, shiny hairy; notauli weakly impressed; posteriorly, smooth; scutellum smooth, shiny and hairy; metanotum with anterior median carina; propleuron smooth, shiny and hairy; propodeum smooth, shiny with a few hairs anteriorly and posterior median longitudinal carina extending upto its middle; propodeal spiracle round, small and medially placed; fore wing vein 3-SR about 3.0x r. Metasoma broadly oval and shagreen; second to fourth metasomal tergites subequal, remaining a little shorter. Large dorsal blotches on third and fourth tergites black; ovipositor nearly as long as metasoma.

**Material examined**: 2♀ November; 1♀ December 2021; 1♀ February 2022 emerged from *L. orbonalis* and 1♀ November; 2♀ December 2021 brinjal, yellow pan trap, ICAR-IARI, New Delhi.

**Host records**: *Adisura atkinsoni*, *Alcides affaber*, *Earias fabia*, *Heliothis obsolete*, *Rabila frontalis* (*Sheeba & Narendran, 2013*) and *L. orbonalis* (*Venkatraman et al., 1948*). In the present study, it emerged from *L. orbonalis*.

**Distribution**: India (Kerala, Uttar Pradesh), Bangladesh, China, and Sri Lanka.

### 3. *Goryphus nursei* (Cameron, 1907) (Fig. 3)

**Diagnosis**: Body dark orange except eighth to tenth flagellar segments white above; face and frons along the eye margin, apex of metasoma T1 and T5-T8 light yellow to white; T2-T4 entirely black. Legs in general reddish, except fore and middle tibia and tarsus tending to be brownish; hind femur broadly at apex, whole of tibia and tarsus blackish; hind tibia with a subbasal white band. Head face and clypeus strongly punctate, clypeus tending to be smooth towards the apex. Antennal scrobe shallow, smooth and shiny. Temple broadly smooth and shiny. Malar space weakly granulose, about 0.7x the basal width of mandible. Mandible teeth subequal. Mesosoma pronotum coarsely striate, Mesoscutum strongly punctate, striate along margins of each lobe. Scutellum smooth and shiny, Metascutellum smooth and shiny. Mesopleuron rugose, tending to be wrinkled above, Propodeum largely reticulate, based on basal carina transwrinkled, both transverse carinae strong and complete, basal carina more or less straight, apical carina evenly and strongly arched, bow-shaped. Areolet small, squares, about 3x as high as the width of bordering veins. Metasoma T1 short, about 1.3x as long as wide at apex, 2nd and 3rd tergite closely punctate; 4th tergite less punctate. Ovipositor tip with distinct teeth ventrally.

**Material examined**: 1♀ December 2021; 2♀ February 2022 emerged from *L. orbonalis* and 1♀ November 2021; 1♀ January 2022 brinjal, yellow pan trap, ICAR-IARI, New Delhi.

**Host records**: BFSB *L. orbonalis* (*Alam et al., 2003*).

**Distribution**: India (Bihar, Delhi, Gujarat, Haryana, Jharkhand, Maharashtra, Odisha, Punjab, Rajasthan, Tamil Nadu, Uttarakhand, and Uttar Pradesh), China and Pakistan (*Jonathan, 2006*; *Gupta 1985*).

### 4. Trathala flavoorbitalis (Cameron, 1907) (Fig. 4)

**Diagnosis**: Body brownish-yellow, Antenna scape and pedicel yellowish and flagellomere brownish, vertex (except ocelli area black) and around eye light yellow; Notauli often well marked with yellow. Tegula and scutellum yellow. Metasoma orange, tergites 1-2 and basal triangle on tergite III dark brown. Legs yellow, hind tibia slightly infuscate basally and apically; wings hyaline, pterostigma brown, its anterior half yellow. Sheath and ovipositor dark brown. Head strongly constricted behind eyes. Face densely punctate, clypeus smooth, vertex and frons granulate, center of frons smooth. Temples short and slightly rounded; malar space 0.65 times as long as basal mandible width, occipital carina complete; mandible with equal size teeth; antenna filiform longer than head and mesosoma with 33 flagellomeres; scape length 1.31x pedicel length. Mesonotum densely punctate-shagreened, scutellum and metanotum more sparsely punctate. Scutellum rounded without dorsal lateral carinae. Propodeum densely punctate-shagreened dorsally than laterally. Propodeal carination complete, area basalis small but distinct. Metasoma tergite I a little longer than tergite II and twice longer than tergite III. Tergite I almost smooth, slightly longitudinally strigose at apex. Tergite II three times longer than apically wide and longitudinally striated. Ovipositor shorter than abdomen.

**Material examined**: 3♀, 1♂ November; 2♀ December 2021; 1♀, 1♂ January; 2♀, 1♂ February; 3♀, 2♂ March; 2♀, 1♂ June; 4♀, 2♂ July; 6♀, 2♂ August; 3♀, 1♂ September; 1♀, 1♂ October 2022 emerged from *L. orbonalis* and 2♀ July; 3♀ August 2022 brinjal, sweeping net, ICAR-IARI, New Delhi.

**Host records**: Seventy-eight host records, all Lepidoptera (Gelechoidea, Noctuoidea, Pyraloidea, Tineoidea and Tortricoidea) (*Rousse et al., 2011*) brinjal shoot and fruit borer (*Alam et al., 2003*; *Ranjith et al., 2020*). In the present study, it emerged from *L. orbonalis*.

**Distribution**: Reunion, Madagascar (*Rousse et al., 2011*). Widespread through Indo-Pacific and Eastern Oriental Areas (*Rousse & Villemant, 2012*).

### 5. Spalangia gemina Boucek, 1963 (Fig. 5)

**Diagnosis**: Body dark. Legs dark except basal four tarsal segments yellow. Head with dense circular setiferous punctures; temple distinctly circular punctures. Gena with malar space distinctly shorter than eye height and malar sulcus absent. Antenna with scape about 6.8 as long as greatest width, the inner and outer surfaces uniformly setose and strongly. Mesosoma pronotal collar in lateral view convex behind neck, with coarsely reticulate-rugose, except for a nearly triangular area close to the crenulate cross-line posteriorly; axillae smooth and shiny except for a few pinprick-like setiferous punctures. Scutellum smooth and shiny except for a few pinprick-like setiferous punctures laterally; mesopleuron with longitudinal carinae extending from subalar area ventrally over almost all of upper mesepimeron, subalar scrobe extending posteroventrally along transepisternal line, and epistern. Fore wing hyaline; bare behind submarginal vein. Propodeum with postspiracular sulcus; dorsal surface punctate-rugose anteriorly and posteriorly, sculptured, sometimes almost smooth; supracoxal; propodeal sides smooth and shiny. Metasoma smooth and shiny. Petiole about 1.7-1.8x as long as medial width; almost smooth to finely, transversely carinate between longitudinal carinae.

**Material examined**: 1♀ June; 2♀ July; 2♀, 1♂ August; 1♀ September 2022 emerged from *L. orbonalis* and 2♀ July; 1♀ August 2022 brinjal, sweeping net trap, ICAR-IARI, New Delhi.

**Host records**: Micropezidae, Noctuidae and Tortricidae (Lepidoptera) as primary hosts (*Noyes, 2019*) recorded on *L. orbonalis* (*Murali et al., 2017*).

**Distribution**: Afrotropical, Australasian, Oriental, and Neotropical region (*Noyes, 2019*).

### II. Evaluation of parasitism extent by *T. flavoorbitalis* and other parasitoids on BFSB

During July and August 2022, *T. flavoorbitalis* showed higher parasitism of 15.55 and 18.46%, respectively. However, the average parasitism (%) of *T. flavoorbitalis*, *S. gemina*, *B. greeni*, *A. hemara* and *G. nursei* was 9.28, 3.10, 1.76, 1.2 and 1.1%, respectively (Fig. S1). Throughout the study period, *T. flavoorbitalis* was the dominant parasitoid. Its parasitism in 1st season peaked at 12% in November 2021, while it decreased in December 2021 and again increased during February and March 2022. In the 2nd season, its parasitism peaked at 18.5% in August 2022, and higher fruit infestation (%) was observed (Fig. S2). The parasitism (%) of *B. greeni* was 6.7 and 3.3% during November and December 2021, respectively but was not recorded during the 2nd season. The parasitism (%) of *G. nursei* was 3.3 and 2.9% during December and January, respectively but not recorded in the 2nd season (Fig. 6).

The parasitism (%) of *S. gemina* was 6.12% in August 2022. *A. hemara*, as a new parasitoid (Hymenoptera: Braconidae), was found to parasitizes on the BFSB larvae. This species was recorded in the 2nd season, and its parasitism (%) was 3.3 and 2.4% during June and September, respectively (Fig. 6). The total parasitism (%) of all parasitoids, as well as the fruit infestation (%), reach its peak during August (Fig. 7).

### III. Correlation analysis of fruit infestation (%) and parasitism (%) under study conditions

Correlation analysis was performed on the data obtained under this study to explore the interrelationship among the infestation (%) and parasitism (%) with the environmental parameters during the study period. A significant ($p \leq 0.01$) strongly positive correlation (r= 0.7) was shown between fruit infestation (%) and total parasitism (%) of parasitoid species. Also, a significant (p ≤0.01) strongly positive correlation (r= 0.7) was recorded between infestation (%) and parasitism (%) of *T. flavoorbitalis*. Parasitism (%) of *T. flavoorbitalis* showed a significant ($p \leq 0.5$) moderately negative correlation with rainfall (r= -0.4), moderately positive correlation with *Tmin* (r= 0.3), RH (r= 0.4) and not correlated with *Tmax* (r= -0.02). Fruit infestation (%) showed a significantly ($p \leq 0.1$-0.5) moderately positive correlation with *Tmax*, (r= 0.3), *Tmin* (r= 0.5), RH (r= 0.4), and a moderate negative correlation with rainfall (r= -0.5). Total parasitism (%) showed a significant ($p \leq 0.5$) moderately negative correlation with rainfall (r= -0.3), weakly positive correlation with *Tmin* (r= 0.2), moderately positive correlation with RH (r= 0.4) and not correlated with *Tmax* (r= -0.05).

### IV. Survey for study of associated Hymenoptera parasitoids

Parasitoids were collected weekly from brinjal during two seasons (November 2021 to October 2022), using a sweep net and yellow pan trap. The monthly distribution of different Hymenoptera parasitoid families (19 families) collected from brinjal is shown in (Fig. S3). About 60 species were recorded, from which 46 were identified up to the species level, and 14 were identified up to the genus level. Superfamily Chalcidoidea was the most dominant, followed by Ichneumonoidea, Platygastroidae and Ceraphronoidea. Among 60 species recorded, eleven species (Braconidae), ten species (Ichneumonidae), eight species (Chalcididae), eight species (Scelionidae), three species (Eulophidae), four species (Pteromalidae), three species (Dryinidae), three species (Diapriidae), two species (Mymaridae), two species (Figitidae) and one species were recorded in (Platygastridae, Agonidae, Bethylidae, Ceraphronidae, Eurytomidae and Aphelinidae) (Table 1 and Fig. 8) families.

## Discussion

Several studies carried out in different time-lines suggest the occurrence of different parasitoids on *L. orbonalis*. Along with *T. flavoorbitalis*, a few other Ichneumonids recorded were *Pristomerus testaceous* (*Ayyar, 1927*), *Eriborus argentiopilosus* (*Tewari & Sardana, 1987*), *Xanthopimpla punctata* (*Navasero, 1983*; *Navasero & Calilung, 1990*), *E. sinicus* (*Talekar, 1995*) and *Diadegma apostate* (*Krishnamoorthy & Mani, 1998*). Previous studies suggest the occurrence of braconids *viz*., *Chelonus* sp. (*Sandanayake & Edirisinghe, 1992*), *Bracon* sp. (*Tewari & Sardana, 1987*), *B. greeni* (*Venkatraman et al., 1948*), and *Phanerotoma* sp. (*Tewari & Moorthy, 1984*; *Sandanayake & Edirisinghe, 1992*) *Apanteles* sp. (*Navasero, 1983*). Among various larval parasitoids, *T. flavoorbitalis* was recorded as the most critical species constituting about 60% of larval parasitoids. It has been recorded as a major parasitoid of *L. orbonalis* in Sri Lanka, Gujarat (India) and Bangladesh, with maximum parasitism of 61.7% (*Alam et al., 2003*). The superfamily

Chalcidoidea species identified in relation to *L. orbonalis viz*., *Brachymeria* sp., *B. lasus*, *B. obscurata*, *Antrocephalus mitys* (Chalcididae), *S. irregularis*, *S. gemina*, *S. endius* (Pteromalidae) and *Trichogramma* sp. (Trichogrammatidae) (Navasero & Calilung, 1990).

In the present study, five species belong to five genera under three families (Braconidae, Ichneumonidae, and Pteromalidae). *T. flavoorbitalis* had the highest parasitism rate compared to other parasitoids, with an average parasitism rate of 9.28%, while the parasitism rate of *B. greeni*, *A. hemara*, *S. gemina* and *G. nursei* was 1.76, 1.21, 3.11, and 1.06%, respectively. These findings align with the other reports (Alam et al., 2003; Nagalingam, 2006; Ranjith et al., 2020). *T. flavororbitalis* has also been recorded as an important parasitoid in different countries, such as Hawaii and several places in the USA (Swezey, 1926), Bangladesh (Alam & Sana, 1962), Sri Lanka (Sandanayake & Edirisinghe, 1992), India (Bihar (Mallik et al. 1989), Karnataka (Ranjith et al., 2020); Manipur (Thokchom et al., 2022); Gujarat, Uttar Pradesh (Alam et al., 2003) and Nepal (Kafle, 1970). The current study revealed a higher maximum parasitism of 18.45% on larvae of *L. orbonalis* in August during 2$^{nd}$ season, and our findings agree with (Srinivasan, 2008; Ranjith et al., 2020) indicating that the parasitoid potentially reduced the population of *L. orbonalis* (Srinivasan, 2008; Kumar & Raghuraman, 2014). In this study, during the summer season *A. hemara* was recorded as a parasitoid on *L. orbonalis*, for the first time. This finding agrees with (Navasero, 1983), who recorded *Apanteles* sp. on BFSB in Philippines. *G. nursei* and *B. greeni* were active during the winter but did not appear in the summer, indicating that their activity decreased under high temperatures, according to (Alam et al., 2003).

The brinjal fruit and shoot borer (BFSB) damage varied considerably, and highest damage was observed during summer, while there was very little fruit infestation during the winter season (Fig. 7). This could be due to high summer temperatures and cooling temperatures from December to January (Fig. 7). At the peak period, the pest damage exceeded 70% of total fruits, whereas in January, barely 27% damage was seen. Generally, the level of parasitism concisely concurs with the population of the pest. However, there was a significant correlation between fruit infestation (%) and parasitism (%), and these findings are in line with (Alam et al., 2003; Ranjith et al., 2020).

## Conclusion

In summary, the fruit and shoot borer (BFSB) *L. orbonalis*, is a major pest of brinjal worldwide, causing extensive damage to the fruit and making it unsuitable for human consumption. We have recorded five species of parasitoids on *L. orbonalis*, including the first-ever recorded instance of *Apanteles hemara* acting as a parasite on this pest in New Delhi. The survey revealed the presence of various Hymenoptera parasitoids within the brinjal crop ecosystem. However, the parasitism rate varied significantly depending on the environmental conditions during the survey. We found a significant strongly positive correlation between parasitism (%) of parasitoids with fruit infestation (%) by *L. orbonalis*. This research emphasizes the importance of preserving and protecting the natural enemies as they serve as effective biocontrol agents for *L. orbonalis*, thereby reducing the need for pesticides.

## Acknowledgements

The authors express their gratitude to ICAR-Indian Agricultural Research Institute, Division of Entomology, for providing necessary research facilities. The authors also would like to thank Princess Nourah bint Abdulrahman University, Riyadh, Saudi Arabia for the support through University Researchers Supporting Project number PNURSP2023R37.

## Author Contributions

Conceptualization, H.M.M.S., A.A.A-K., M.A.A. and D.D.; methodology, H.M.M.S. and D.D.; software, H.M.M.S., A.A.A-K., M.A.A. and D.D.; validation, H.M.M.S., A.A.A-K., M.A.A. and D.D.; formal analysis, H.M.M.S., A.A.A-K., M.A.A. and D.D.; investigation, H.M.M.S., A.A.A-K., M.A.A. and D.D.; resources, H.M.M.S., A.A.A-K., M.A.A. and D.D.; data curation, H.M.M.S., A.A.A-K., M.A.A., A.E. and D.D.; writing-original draft preparation, H.M.M.S., A.A.A-K., M.A.A. and D.D.; writing-review and editing, H.M.M.S., A.A.A-K., M.A.A. and D.D.; visualization, H.M.M.S., A.A.A-K., M.A.A. and D.D.; supervision, H.M.M.S. and D.D.; project administration, H.M.M.S. and D.D.; funding acquisition, H.M.M.S., A.A.A-K., M.A.A. and D.D. All authors have read and agreed to the published version of the manuscript

## Data Availability Statement

The data presented in this study are available on request from the corresponding author.

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## Table 1(on next page)

Table 1 Surveying of the Hymenoptera parasitoids in brinjal during two seasons (November 2021 to October 2022).

* 1st, first season; 2nd, second season; **+**, Presence; **–**, Absence

**Table 1 Surveying of the Hymenoptera parasitoids in brinjal during two seasons (November 2021 to October 2022).**

| S.No. | Families/Parasitoids * | $1^{st}$ | $2^{nd}$ |
|---|---|---|---|
| **Family Ichneumonidae** | | | |
| 1 | *Trathala flavoorbitalis* | + | + |
| 2 | *Xanthopimpla punctate* | - | + |
| 3 | *Xanthopimpla flavolineata* | + | + |
| 4 | *Ichneumon* sp. | + | - |
| 5 | *Diplazon laetatorius* | + | + |
| 6 | *Goryphus nursei* | + | + |
| 7 | *Goryphus apollonis* | - | + |
| 8 | *Aneuclis* sp. | + | - |
| 9 | *Temelucha* sp. | - | + |
| 10 | *Amyosoma chinese* | - | + |
| **Family Braconidae** | | | |
| 11 | *Macrocentrus delhiensis* | + | - |
| 12 | *Cotesia* sp. | | |
| 13 | *Aphidius colemani* | + | + |
| 14 | *Microplates* sp. | + | + |
| 15 | *Chelonus blackburni* | - | + |
| 16 | *Bracon carpomyiae* | + | + |
| 17 | *Apanteles hemara* | - | + |
| 18 | *Bracon greeni* | + | - |
| 19 | *Phaenocarpa* sp. | + | - |
| 20 | *Spathius helle Nixon* | + | - |
| 21 | *Phanerotoma* sp. | | |
| **Family Chalcididae** | | | |
| 22 | *Brachymeria bengalensis* | + | + |
| 23 | *Brachymeria lasus* | + | - |
| 24 | *Brachymeria hime* | + | + |
| 25 | *Brachymeria podagrica* | + | - |
| 26 | *Dirhinus auratus* | + | - |
| 27 | *Antrocephalus sepyra* | + | + |
| 28 | *Kriechbaumerella kraussi* | + | + |
| 29 | *Kriechbaumerella pulvinatus* | + | + |
| **Family Eurytomidae** | | | |
| 30 | *Eurytoma* sp. | + | - |
| **Family Scelionidae** | | | |
| 31 | *Trissolcus basalis* | - | + |
| 32 | *Baryconus europaeus* | + | + |
| 33 | *Scelio* sp. | - | + |
| 34 | *Hadronotus fulviventris* | + | + |
| 35 | *Hadronotus hogenakalense* | + | + |
| 36 | *Gryonoides pulcherllus* | - | + |
| 37 | *Protelenomus* sp. | - | + |
| 38 | *Telenomus dignus* | - | + |
| **Family Platygastridae** | | | |
| 39 | *Macroteleia livingstoni* | - | + |
| **Family Eulophidae** | | | |
| 40 | *Tetrastichus schoenobii* | + | - |
| 41 | *Pediobius foveolatus* | + | + |
| 42 | *Quadrastichus* sp. | + | + |
| **Family Agonidae** | | | |
| 43 | *Eupristina saundersi* | + | + |
| **Family Aphelinidae** | | | |
| 44 | *Aphelinus asychis* | + | + |
| **Family Mymaridae** | | | |
| 45 | *Anagrus atomus* | + | - |
| 46 | *Mymar taprobanicum* | + | + |
| **Family Dryinidae** | | | |
| 47 | *Aphelopus* sp. | + | + |
| 48 | *Anteon achterbergi* | - | + |
| 49 | *Anteon yasumatsui* | - | + |
| **Family Diapriidae** | | | |
| 50 | *Trichopria* sp. | + | + |
| 51 | *Trichopria keralensis* | + | - |
| 52 | *Psillus* sp. | + | + |
| **Family Bethylidae** | | | |
| 53 | *Goniozus indicus* | + | + |
| ***Family Ceraphronidae*** | | | |
| 54 | *Aphanogmus fijiensis* | + | - |
| **Family Pteromalidae** | | | |
| 55 | *Pachyneuron Solitarium* | + | - |
| 56 | *Spalangia gemina* | + | + |
| 57 | *Pteromalus puparum* | + | + |
| 58 | *Sphegigaster brunneicornis* | + | + |
| **Family Figitidae** | | | |
| 59 | *Alloxysta rubidus* | + | - |
| 60 | *Callaspidia notate* | + | - |

* $1^{st}$, first season; $2^{nd}$, second season; +, Presence; –, Absence

# Figure 1

Figure 1 *Apanteles hemara* Nixon, 1965 (female)

**A**. Dorsal habitus, **B**. Fore and hind wings, **C**. Dorsal view of mesosoma, **D**. Dorsal view of metasoma and **E**. Emerged parasite from host.

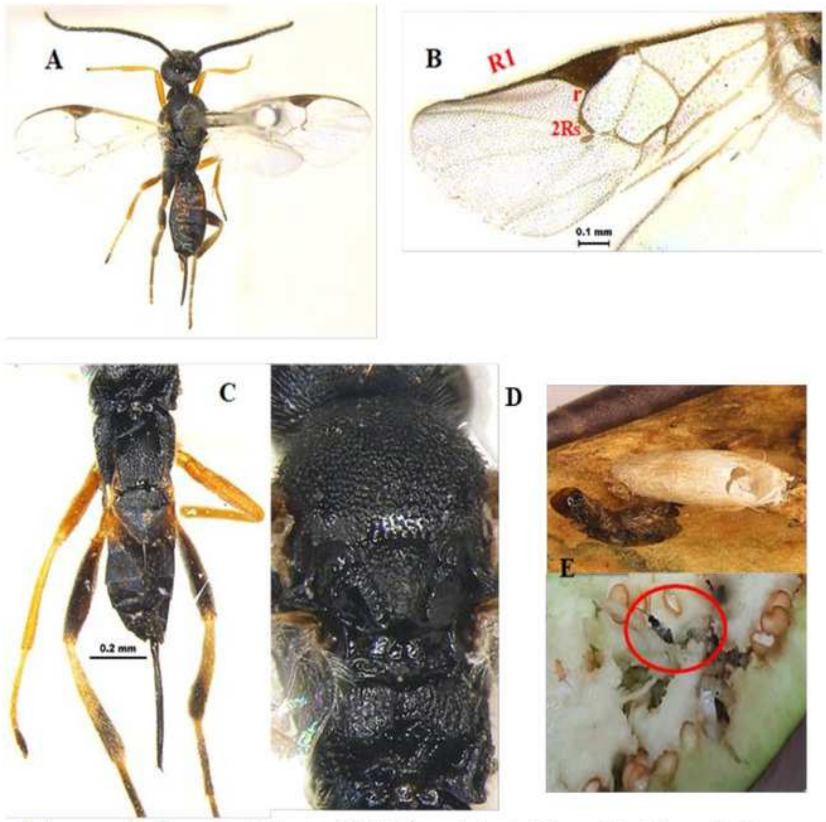


**Figure 1** ***Apanteles hemara*** **Nixon, 1965** (female); **A**. Dorsal habitus, **B**. Fore and hind wings, **C**. Dorsal view of mesosoma, **D**. Dorsal view of metasoma and **E**. Emerged parasite from host.

# Figure 2

Figure 2 *Bracon greeni* Ashmead 1896 (female)

**A**. Lateral habitus, **B**. Frontal view of head, **C**. Dorsal view of head, **D**. Dorsal view of metasoma, **E**. Fore wing and **F**. Emerged parasite from host.

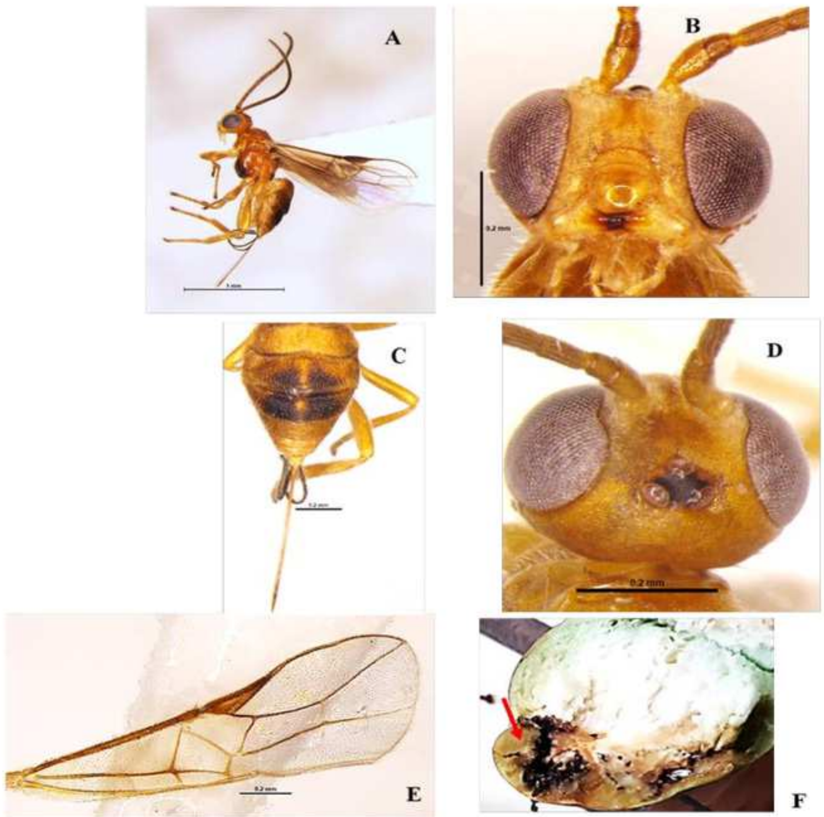


**Figure 2** ***Bracon greeni*** **Ashmead 1896** (female); **A**. Lateral habitus, **B**. Frontal view of head, **C**. Dorsal view of head, **D**. Dorsal view of metasoma, **E**. Fore wing and **F**. Emerged parasite from host.

# Figure 3

Figure 3 *Goryphus nursei* (Cameron, 1907) (female)

**A**. Dorsal habitus, **B**. Frontal view of head, **C**. Dorsal view of mesosoma, **D**. Fore and hind wings and **E**. Dorso-lateral view of metasoma.

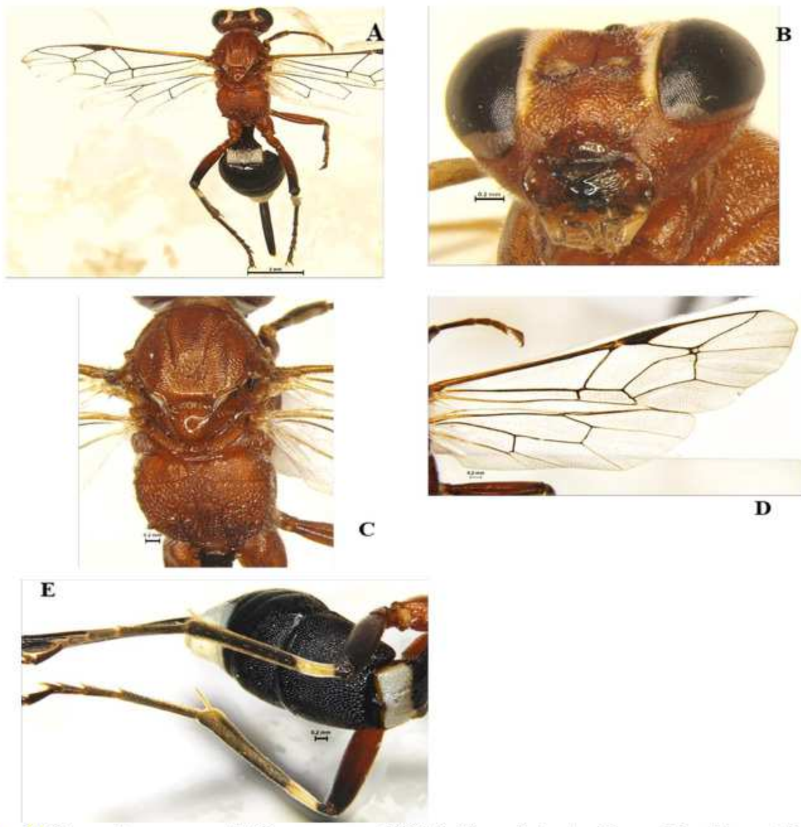


**Figure 3** ***Goryphus nursei*** **(Cameron, 1907)** (female); **A**. Dorsal habitus, **B**. Frontal view of head, **C**. Dorsal view of mesosoma, **D**. Fore and hind wings and **E**. Dorso-lateral view of metasoma.

# Figure 4

Figure 4 *Trathala flavoorbitalis* (Cameron, 1907) (female)

**A**. Dorso-lateral habitus, **B**. Dorsal view of head, **C**. Frontal view of head, **D**. Dorsal view of mesosoma, **E**. Fore and hind wings and **F**. Lateral view of metasoma.

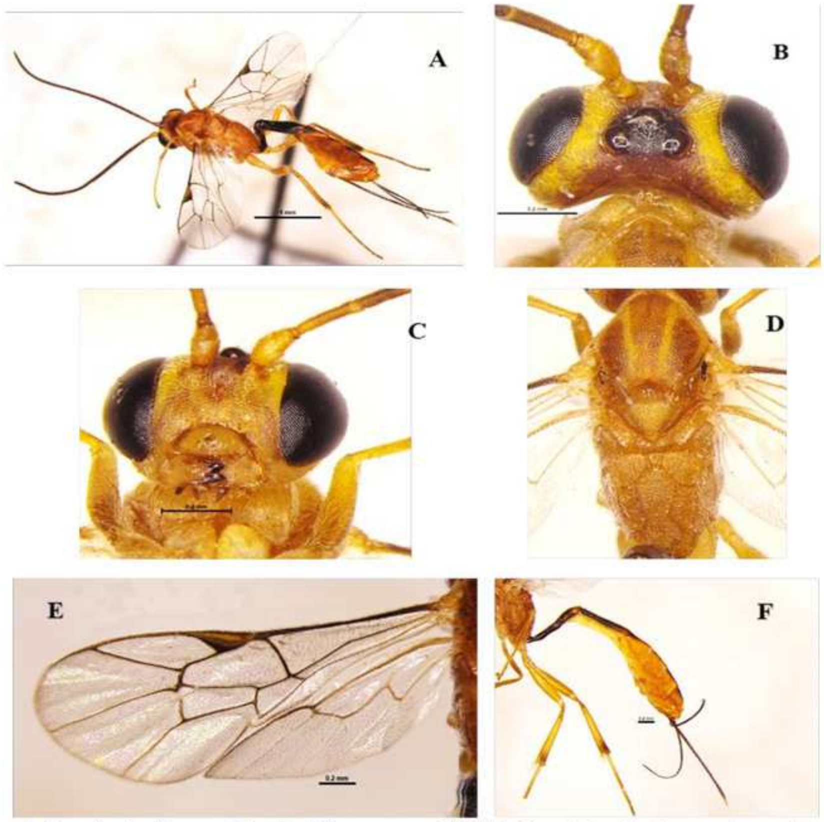


**Figure 4** ***Trathala flavoorbitalis*** **(Cameron, 1907)** (female); **A**. Dorso-lateral habitus, **B**. Dorsal view of head, **C**. Frontal view of head, **D**. Dorsal view of mesosoma, **E**. Fore and hind wings and **F**. Lateral view of metasoma.

# Figure 5

Figure 5 *Spalangia gemina* Boucek, 1963 (female)

**A.** Lateral habitus, **B.** Frontal view of head, **C.** Mesopleuron, **D.** Dorsal view of mesosoma and **E.** Fore wing.

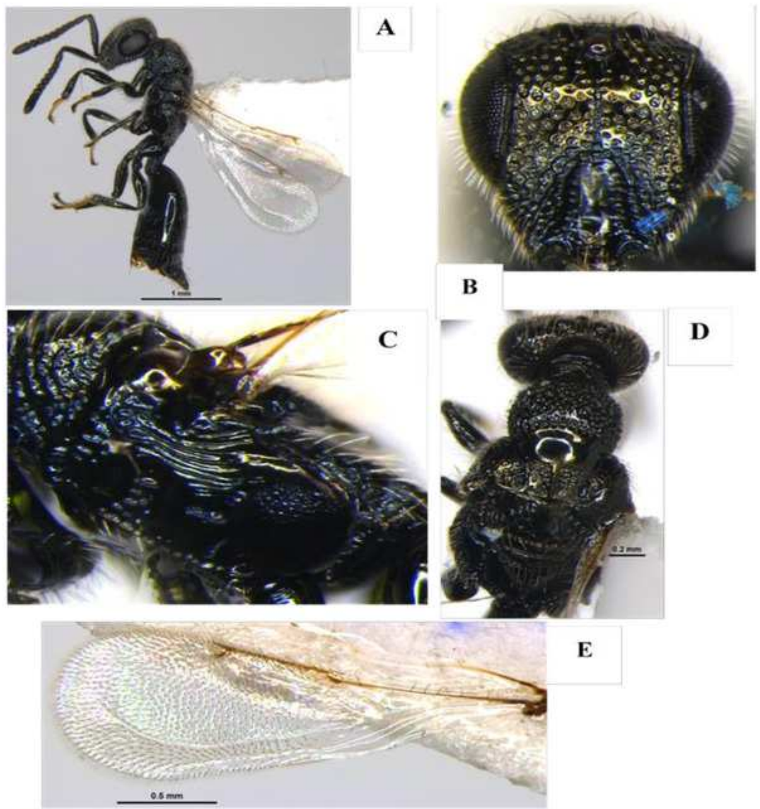


**Figure 5** ***Spalangia gemina*** **Boucek, 1963** (female); **A.** Lateral habitus, **B.** Frontal view of head, **C.** Mesopleuron, **D.** Dorsal view of mesosoma and **E.** Fore wing.

# Figure 6

Figure 6 Parasitism (%) of all parasitoid species on L. orbonalis during two seasons (November 2021 to October 2022)

No Legend

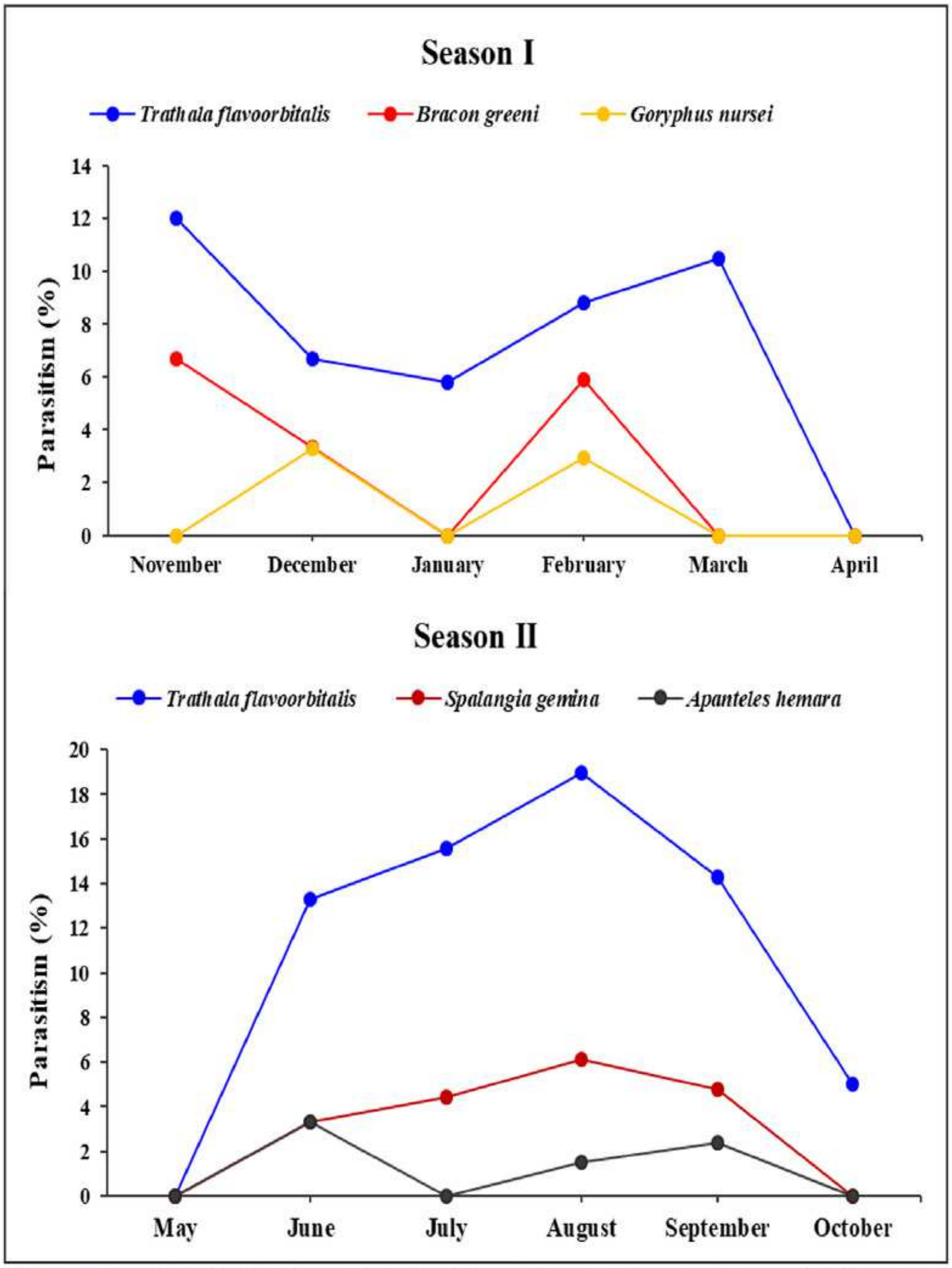


**Figure 6** Parasitism (%) of all parasitoid species on L. orbonalis during two seasons (November 2021 to October 2022)

# Figure 7

Figure 7 Monthly fruit infestation (%) by *L. orbonalis* and parasitism (%) of parasitoids during the study period (November 2021 to October 2022)

No Legend

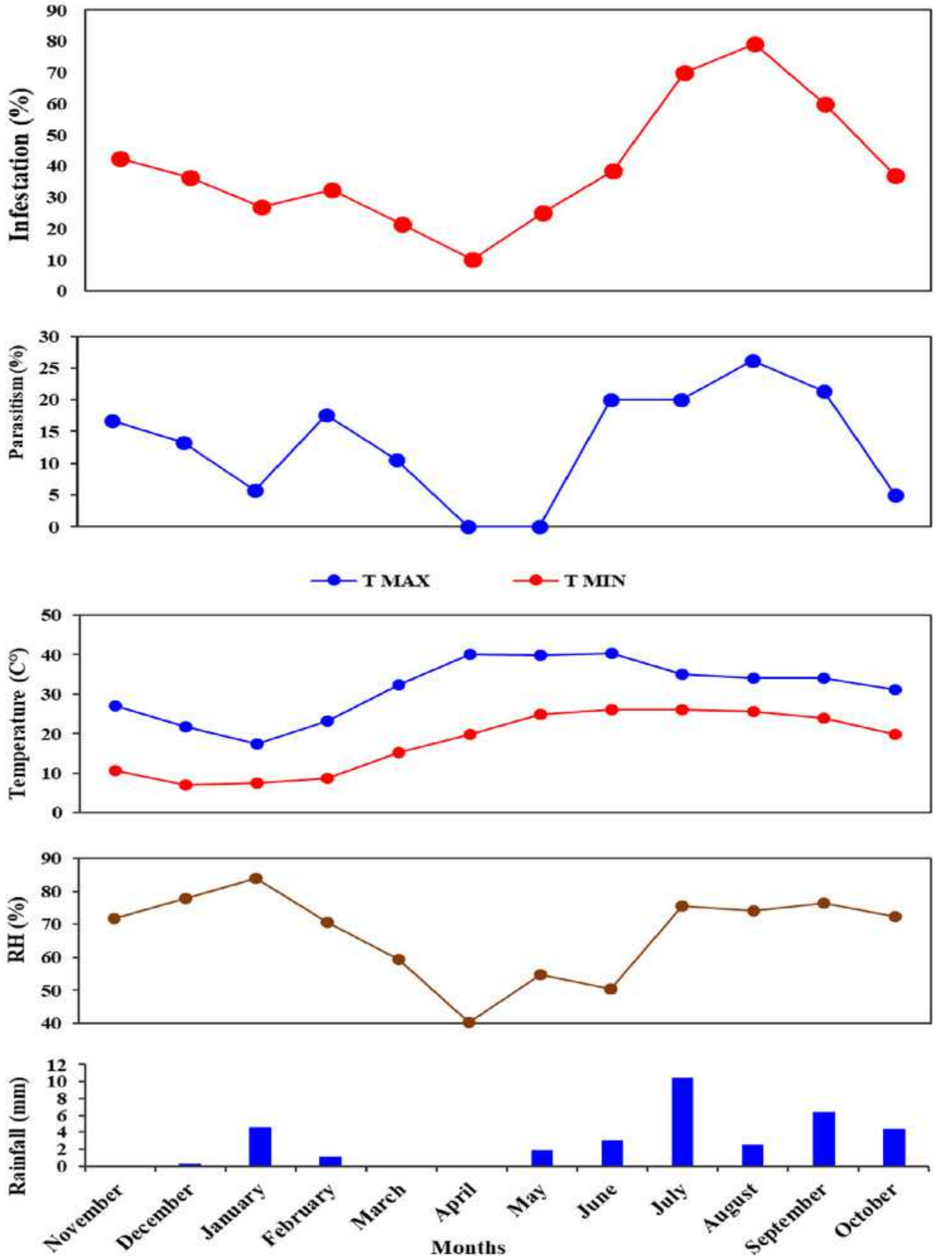


**Figure 7** Monthly fruit infestation (%) by *L. orbonalis* and parasitism (%) of parasitoids during the study period (November 2021 to October 2022)

# Figure 8 (on next page)

Figure 8 Some Hymenoptera parasitoid species collected during the study period (November 2021 to October 2022)

No Legend

***Hadronotus hogenakalense***

***Telenomus dignus***

***Hadronotus fulviventris***

*Macroteleia livingstoni*

***Baryconus europaeus***

***Gryonoides pulcherllus***

***Pediobius foveolatus*♂**

***Aphanogmus fijiensis***

***Eurytoma sp***

***Sphegigaster brunneicornis***

***Aphelopus* sp**

***Callaspidia notate***

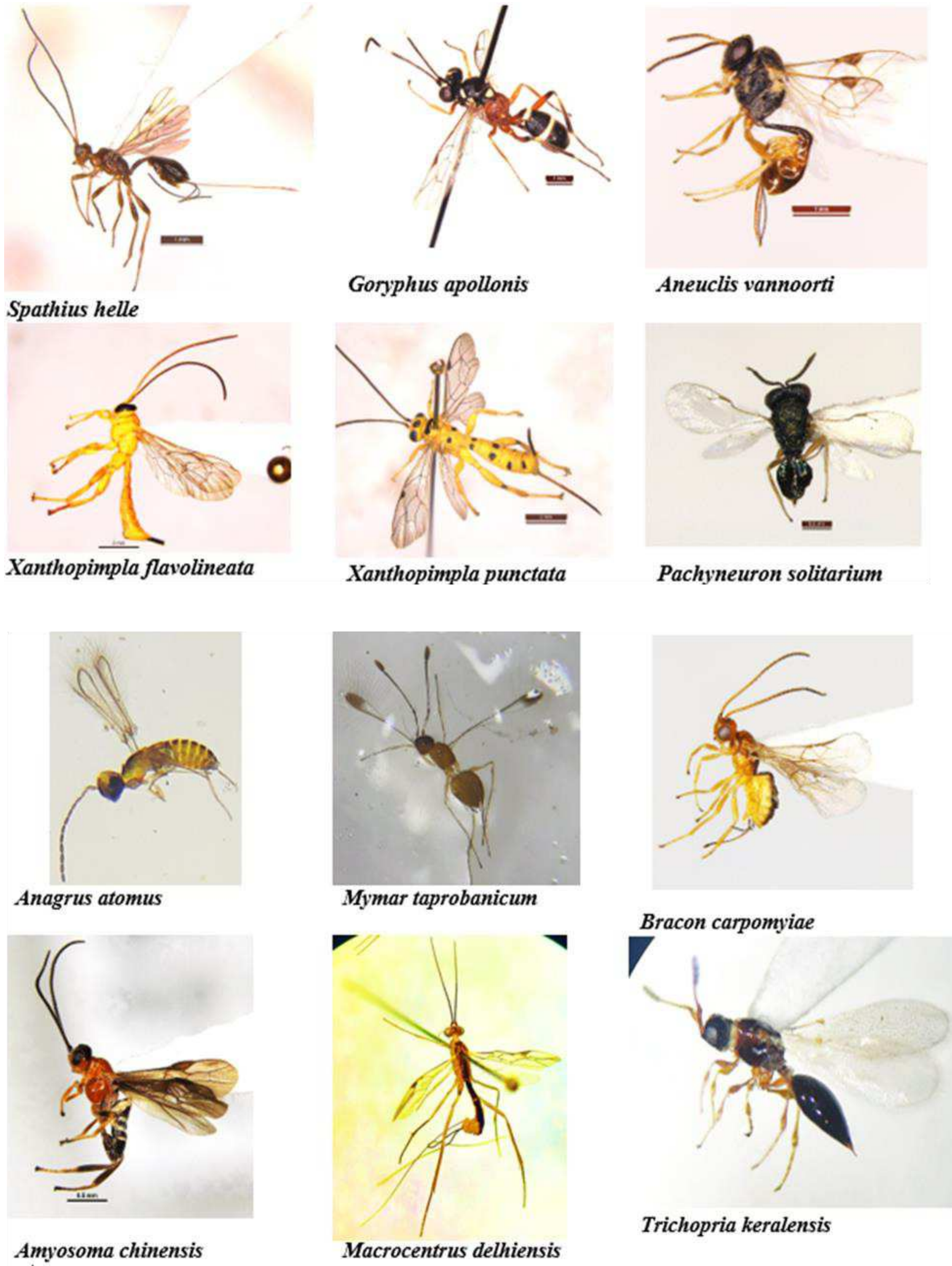


**Figure 8 Some Hymenoptera parasitoid species collected during the study period (November 2021 to October 2022)**