Diversity of hymenopteran parasitoids in different crop ecosystems

Abstract

Surveys were carried out in different districts *viz*., Shivamogga, Davangere and Chitradurga of Karnataka to collect and document hymenopteran parasitoids parasitizing insect pests attacking different crop ecosystems. A total of 42 hymenopteran parasitoids species represented by 33 genera belonged 12 families were documented from a collection of 1379 specimens from different stages *viz*., egg, larva, pupa and adult stage of host insects from different host plants *viz*., rice, maize, cabbage, cotton, coconut, brinjal, cashew, crape jasmine, tobacco, field bean, soybean, arecanut, cocoa, bhendi and pongamia. Among them, maximum parasitoids species (20) were collected from larval stage of host insects with per cent species composition of 47.62. Among the families, Braconidae was found most dominant (comprised of 23.81%), followed by Eulophidae (16.67%), Encyrtidae and Scelionidae (each with 14.29%). Alpha and beta diversity were computed for the three zones. Species diversity in terms of richness, evenness and abundance of hymenopteran parasitoids were calculated and compared during study period using Shannon-Wiener index, Simpson diversity index, Margalef's diversity index, Menhinick's index and Evenness. Species diversity was high in Shivamogga district as evidenced by Shannon-Wiener index (2.49), Simpson diversity index (0.88), Margalef's index (4.09) and Menhinick's index (1.22) and Evenness (0.46), followed by Davanagere district with respect to Shannon-Wiener index (1.69) Simpson's diversity index (0.75), Margalef's index and Menhinick's index (2.27 and 0.90), respectively, while evenness was 0.24 and Chitradurga district with respect to Shannon-Wiener index (1.34) Simpson's diversity index (0.54), Margalef's index and Menhinick's index (2.12 and 0.59), respectively.

Keywords: Diversity, Hymenopteran parasitoids, Different crops, Ecosystems

Introduction

Hymenoptera is the largest order in the class, Insecta which is estimated to have more than 3,00,000 species (Lasalle and Gauld, 1991). Hymenoptera is a very diverse insect order, including a variety of insects such as ants, bees and wasps. Wasps are one of the largest components of terrestrial ecosystem with approximately 1,15,000 described species. They are of much economic importance as they contribute in enhancing the production of commercial products (Veena *et al*., 2018). Wasps are unique in their lifestyles relative to other hymenopterans, but they have not received as much recognition as compared to ants and bees. They inhabit all ice-free environments on earth in a wide range of ecological niches and play diverse roles such as pollinators, predators, parasitoids or parasitic wasps, plant feeders, solitary and social species. Many of these wasps are parasitoids, some are phytophagous, predators and pollinators. Predatory wasp prey on arthropods to feed their larvae, whereas parasitic wasps are wasps whose eggs and larvae grow attached to or inside a single arthropod of the host, which they eventually eat and kill (Hassell and Waage, 1984) thus controlling their host population. Most of the parasitoids are in the order, Hymenoptera which constitutes nearly 75 per cent of total species (Veena *et al*., 2018). Hymenopteran parasitoids are a speciose and diverse group of insects whose larvae feed exclusively on the bodies of other arthropods, their hosts, eventually killing them. Most insect pests are preyed upon by one or more species of hymenopteran parasitoids. Typically, they are laying their eggs onto or into the immature stages of other insects (Belshaw *et al*., 2003). Hymenopteran parasitoids are one of the most species-rich groups of animals, potentially accounting for more than 20% of the world's insects.Hymenopteran parasitoids, because of their relatively high specificity to a host species, have long been recognized as important agents in the biological control of insect pests in agriculture. Accurate documentation of the species along with its host will help in the proper identification of species and their conservation in future. Hymenopterans being an ecologically and potentially economically valuable group of insects, a clearer understanding of these parasitoids fauna in different crop ecosystems would lead to better protection of overall hymenopteran parasitoids diversity and potential biocontrol agents for agricultural applications. Thus, studying the diversity and abundance of hymenopteran parasitoids in different crop ecosystems is required as they play an important role in smooth functioning of the ecosystems and also they are considered as effective bio-control agents of insect pests in agricultural fields (Veena *et al*., 2018).

Methodology

Surveys were carried out in different districts *viz*., Shivamogga, Davangere and Chitradurga of Karnataka to collect and document hymenopteran parasitoids parasitizing insect pests attacking agricultural and horticultural crop ecosystems *viz*., rice, maize, cabbage, cotton, coconut, brinjal, cashew, crape jasmine, tobacco, field bean, soybean, arecanut, cocoa and bhendi including one tree species i.e., pongamia during 2021-2023 and nine surveys were conducted in each district during different seasons. Global Positioning System (GPS) was used to determine the latitude and longitude of the location (Fig. 1). Different stages of insect pest samples *viz*., eggs, larvae, pupae and adults were collected from different crop ecosystems along with the infested plant parts. The collected samples were reared under laboratory condition. The emerged parasitoids were collected and preserved in vials with 70% and 90% ethanol for morphological and molecular identification, respectively and were properly labeled and their numbers were counted. The tubes were stored upright in insect specimen tube box/cabinet after adding specimen numbers to vials and were used for further identification. The number of species collected and the relative abundance of the species were calculated for each district. Different diversity indices *viz*., Shannon-Weiner index, Simpson diversity index, Margalef's index, Menhinick's index and Jaccard's coefficient and Evenness were calculated to know the diversity in terms of species richness and evenness (Magurran, 1988). These indices of diversity were calculated for all the data collected across time to ascertain the temporal changes in the diversity of hymenopteran parasitoids in three districts. Relative abundance (%) = (No. of individuals of one species / no. of individuals of all species) x 100. Simpson's diversity index $D = \Sigma n (n-1)/ N(N-1)$ where n = total number of organisms of a particular species and N = total number of organisms of all species. Subtracting the value of Simpson's diversity index from 1, gives Simpson's Index of Diversity (SID). The value of the index ranges from 0 to 1, the greater the value the greater the sample diversity. Shannon-Wiener index $H' = -\Sigma Pi \ln(Pi)$, where $Pi = S / N$; S = number of individuals of one species, N = total number of all individuals in the sample, ln = logarithm to base e. Margalef index $\alpha = (S - 1) / \ln (N)$; S = total number of species, N = total number of individuals in the sample. Menhinick's index $Dmn = S/\sqrt{n}$; S = Total number of species, N = Total number of individuals in the sample. Jaccard Index (JI) (for two sites) = j / (a+b-j), where j = the number of species common to both sites A and B, a = the number of species in site A and b = the number of species in site B.

Results and Discussion

Field surveys were carried out during 2021 to 2023 in three districts viz., Shivamogga, Davanagere and Chitradurga. Hymenopteran parasitoids collected through rearing of host insects collected from different crop ecosystems *viz*., horticultural crops, field crops and tree species were processed and identified.

Species composition of hymenopteran parasitoids

A total of 42 hymenopteran parasitoids species *viz*., *Campoletis chlorideae* Uchida, *Eriborus* sp., *Charops* sp., *Ophion* sp., *Chelonus formosanus* Sonan, *Microplitis prodeniae* Rao and Kurian, *Cotesia ruficrus* (Haliday), *Cotesia vestalis* (Haliday), *Cotesia* sp., *Chelonus* sp., *Bracon* sp., *Crinibracon chromusae* Gupta and Van Achterberg, *Phanerotoma* sp., *Diaeretiella rapae* (McIntosh), *Chrysocharis* sp. 1, *Chrysocharis* sp. 2, *Chrysocharis* sp. 3, ?*Ryhonos* sp., *Aprostocetus* sp., *Oomyzus sokolowskii* (Kurdjumov), *Tetrastichus schoenobii* Ferriere, *Anagyrus pseudococci* (Girault), *Ooencyrtus* sp. 1, *Leptomastix nigrocincta* Risbec, *Prochiloneurus pulchellus* Silvestri, *Copidosoma floridanum* (Ashmead), *Ooencyrtus* sp. 2, *Trissolcus* sp. 1, *Trissolcus* sp. 2, *Telenomus* sp. 1, ?*Paratelenomus anu* Rajmohana, Sachin and Talamas, *Trissolcus* sp. 3, *Telenomus* sp. 2, *Eurytoma* sp., *Brachymeria lasus* (Walker), *Dirhinus anthracia* Walker, *Chartocerus* sp., *Coccophagus pseudococci* Compere, *Encarsia* sp., *Trichogramma chilonis* Ishii, *Nothoserphus* sp. and *Pteromalus metallicus* Sureshan representing 33 genera belonged 12 families to *viz*., Ichneumonidae, Braconidae, Eulophidae, Encyrtidae, Scelionidae, Eurytomidae, Chalcididae, Signiphoridae, Aphelinidae, Trichogrammatidae, Proctutropidae and Pteromalidae were documented from a collection of 1379 specimens from three districts *viz*., Shivamogga, Davanagere and Chitradurga during 2021-2023. Among twelve families, Ichneumonidae represented four species *viz*., *C. chlorideae* collected from larvae of *Spodoptera frugiperda* and *Plutella xylostella*, *Eriborus* sp., *Charops* sp. and *Ophion* sp. were collected from larval stage of *S. frugiperda* whereas, Braconidae represented ten species *viz*., *C. formosanus*, *M. prodeniae*, *C. ruficrus*, *C. vestalis*, *Cotesia* sp., *Chelonus* sp., *Bracon* sp., *D. rapae*, *Phanerotoma* sp. and *C. chromusae* which were collected from larval and pupal stage of *S. frugiperda*, *Spodoptera litura*, *S. frugiperda*, *Plutella xylostella*, *Exelastis atomosa*, *Acrocercops syngramma*, *Omiodes indicata*, *Haritalodes derogata* and *Hasora chromus*, respectively. Eulophidae represented seven species *viz*., *Chrysocharis* sp. 1 and

Chrysocharis sp. 2 which were collected from larvae of *A. syngramma*, *Chrysocharis* sp. 3 from larvae of S. frugiperda, ?*Ryhonos* sp. and *Aprostocetus* sp. from larvae of *H. derogata*, *O. sokolowskii* from pupa of *P. xylostella* and *T. schoenobii* from egg mass of *Scirpophaga incertulas*. Encyrtidae included six species *viz*., *A. pseudococci* was collected from adults of *Nipaecoccus nipae*, *Ooencyrtus* sp. 1 from eggs of *O. indicata*, *L. nigrocincta* and *P. pulchellus* which were collected from adults of *Coccidohystrix insolita*, *C. floridanum* from larva of *Trichoplusia ni*, and *Ooencyrtus* sp. 2 was collected from adults of *C. insolita*. Scelionidae included six species viz., *Trissolcus* sp. 1, *Trissolcus* sp. 2, *Telenomus* sp. 1, ?*P. anu* and *Trissolcus* sp. 3 which were from egg stage of *Leptoglossus phyllopus*, *Leptocorisa oratoria*, *S. incertulas*, *Megacopta cribraria* and *Erias vittela*, and *Telenomus* sp. 2 was collected from egg stage of *S. frugiperda*, *Rhynocoris marginatus* and *Leucinodes orbonalis*. Eurytomidae represented one species which was collected from larvae of *S. frugiperda* and *H. derogata*. Two species *viz*., *B. lasus* and *D. anthracia*, which were belonged to family Chalcididae, were collected from pupal stage of *S. frugiperda* and *Spilosoma obliqua*, respectively. Signiphoridae represented only one species i.e., *Chartocerus* sp. which was collected from adults of *C. insolita* and *Exallomochlus hispidus*. Aphelinidae represented two species *viz*., *C. pseudococci* which was collected from adults of *C. insolita* and *E. hispidus*, and *Encarsia* sp. was collected from Aleurocanthus arecae. Trichogrammatidae, Proctutropidae and Pteromalidae represented one species each *viz*., *T. chilonis*, *Nothoserphus* sp. and *P. metallicus*, respectively which were collected from insect hosts *viz*., *S. frugiperda* (egg mass), *H. derogata* (larvae) and *S. incertulas* (pupae), respectively (Table 1).

Family and species wise distribution of hymenopteran parasitoids in different localities

Among 42 hymenopteran parasitoids species collected, 25 species represented ten families viz., Ichneumonidae (*C. chlorideae*), Braconidae (*C. formosanus*, *M. prodeniae*, *C. ruficrus*, *C. vestalis*, *Cotesia* sp., *Chelonus* sp., *Bracon* sp. and *C. chromusae*), Eulophidae (*Chrysocharis* sp. 1, *Chrysocharis* sp. 2 and *Chrysocharis* sp. 3), Encyrtidae (*A. pseudococci* and *Ooencyrtus* sp. 1), Scelionidae (*Trissolcus* sp. 1, *Trissolcus* sp. 2, *Telenomus* sp. 1, ?*P. anu*, *Trissolcus* sp. 3 and *Telenomus* sp. 2), Eurytomidae (*Eurytoma* sp.), Chalcididae (*B. lasus*), Signiphoridae (*Chartocerus* sp.), Aphelinidae (*C. pseudococci*) and Trichogrammatidae (*T. chilonis*) which were collected from shivamogga district, whereas 16 species represented nine families *viz*., Ichneumonidae (*C. chlorideae* and *Ophion* sp.), Braconidae (*C. vestalis* and *D. rapae*), Eulophidae (*O. sokolowskii* and *T. schoenobii*),

Encyrtidae (*C. floridanum*, *Ooencyrtus* sp. 2, *L. nigrocincta* and *P. pulchellus*), Scelionidae (*Telenomus* sp. 2), Pteromalidae (*P. metallicus*), Signiphoridae (*Chartocerus* sp.), Aphelinidae (*C. pseudococci* and *Encarsia* sp.) and Trichogrammatidae (*T. chilonis*) which were collected from Davanagere district, while 12 species represented eight families *viz*., Ichneumonidae (*C. chlorideae*, *Eriborus* sp. and *Charops* sp.), Braconidae (*C. ruficrus* and *Phanerotoma* sp.), Eulophidae (?*Ryhonos* sp. and *Aprostocetus* sp.), Scelionidae (*Telenomus* sp. 2), Eurytomidae (*Eurytoma* sp.), Chalcididae (*D. anthracia*), Proctutropidae (*Nothoserphus* sp.) and Trichogrammatidae (*T. chilonis*) which were collected from Chitradurga district (Table 2, 3 and 4). Out of 42 species reported from three districts, three species *viz*., *C. chlorideae*, *T. chilonis* and *Telenomus* sp. 2 were common to all the three districts *viz*., Shivamogga, Davanagere and Chitradurga, three species *viz*., *C. vestalis*, *C. pseudococci* and *Chartocerus* sp. were recorded from both Shivamogga and Davanagere districts and were absent in Chitradurga district. *C. ruficrus* and *Eurytoma* sp. were recorded from both Shivamogga and Chitradurga districts and were absent in Davanagere district. However, the parasitoids species *viz*., *C. formosanus*, *M. prodeniae*, *Cotesia* sp., *Chelonus* sp., *Bracon* sp. *C. chromusae*, *Chrysocharis* sp. 1, *Chrysocharissp*. 2, *Chrysocharis* sp. 3, *A. pseudococci*, *Ooencyrtus* sp. 1, *Trissolcus* sp. 1, *Trissolcus* sp. 2, *Trissolcus* sp. 3, *Telenomus* sp. 1, ?*P. anu* and *B. lasus* were recorded only from Shivamogga district, whereas *Ophion* sp. *D. rapae*, *O. sokolowskii*, *T. schoenobii*, *L. nigrocincta*, *P. pulchellus*, *C. floridanum*, *Ooencyrtus* sp. 2, *P. metallicus* and *Encarsia* sp. were recorded only from Davanagere district, while *Eriborus* sp., *Charops* sp., *Phanerotoma* sp., ?*Ryhonos* sp., *Aprostocetus* sp., *D. anthracia* and *Nothoserphus* sp. were recorded only from Chitradurga district. Both the number of families and species of hymenopteran parasitoids found were higher (10 and 25, respectively) in Shivamogga district, followed by Davanagere district with nine families and 16 species. The lowest number of families and species of hymenopteran parasitoids (8 and 12, respectively) were recorded in Chitradurga district (Table 5). These results are in agreement with Bhat *et al*. (2010) who reported hymenopteran parasitoids *viz*., *C. chlorideae*, *C. ruficrus* and unidentified ichneumonid from different stages of *Thysanoplusia orichalcea* in laboratory rearing. Manickavasagam and Rameshkumar (2010) recorded 39 species of parasitoids comprised of 16 genera through host rearing, net sweep, yellow pan trap and malaise trap in the major districts of Tamil Nadu. Shweta and Rajmohana (2016) recorded a total of 198 individuals belonged to 38 species in 21 genera belonged to the subfamily Scelioninae in rice ecosystems of Kerala.

Hymenopteran parasitoids associated with different host plants

In the present study, a total of 42 species of hymenopteran parasitoids were recorded from different host plants *viz*., rice, maize, cabbage, cotton, coconut, brinjal, cashew, crape jasmine, tobacco, field bean, soybean, arecanut, cocoa, bhendi and pongamia. Among them, the highest number (12) of parasitoids species *viz*., *Eurytoma* sp., *C. ruficrus*, *C. chlorideae*, *T. chilonis*, *Telenomus* sp. 2, *C. formosanus*, *Chrysocharis* sp. 3, *B. lasus*, *Eriborus* sp., *Charops* sp., *Ophion* sp. and *D. anthracia* were recorded from maize, followed by 6 species *viz*., *L. nigrocincta*, *P. pulchellus*, *Ooencyrtus* sp. 2, *Telenomus* sp. 2, *C. pseudococci* and *Chartocerus* sp. were recorded in brinjal. In cabbage, 5 species viz., *O. sokolowskii*, *C. floridanum*, *C. chlorideae*, *C. vestalis* and *D. rapae* were recorded. In cotton also, 5 species viz., ?*Ryhonos* sp., *Aprostocetus* sp., *Eurytoma* sp., *Phanerotoma* sp. and *Nothoserphus* sp. were recorded. 4 species *viz*., *Telenomus* sp. 1, *T. schoenobii*, *P. metallicus* and *Trissolcus* sp. 2 were recorded from rice. In cashew also, 4 species *viz*., *Chrysocharis* sp. 1, *Chrysocharis* sp. 2, *Chelonus* sp. and *Telenomus* sp. 2 were recorded. In soybean, 3 species *viz*., ?*P. anu*, *Ooencyrtus* sp. 1 and *Bracon* sp. were recorded. 2 species *viz*., *Cotesia* sp. and ?*P. anu* were recorded in field bean. In cocoa also, 2 species *viz*., *C. pseudococci* and *Chartocerus* sp. were recorded. One species each in coconut (*A. pseudococci*), crape jasmine (*Trissolcus* sp. 1), tobacco (*M. prodeniae*), arecanut (*Encarsia* sp.), bhendi (*Trissolcus* sp. 3) and pongamia (*C. chromusae*) were recorded (Table 6).

District wise distribution of Hymenopteran parasitoids in different host plants

Among 42 species of hymenopteran parasitoids collected, 25 species were recorded from Shivamogga district in different host plants *viz*., rice, maize, cabbage, coconut, cashew, crape jasmine, tobacco, field bean, soybean, cocoa, bhendi and pongamia. Among them, highest number (8) of parasitoids species *viz*., *Eurytoma* sp., *C. ruficrus*, *C. chlorideae*, *T. chilonis*, *Telenomus* sp. 2, *C. formosanus*, *Chrysocharis* sp. 3 and *B. lasus* were recorded from maize, followed by 4 species *viz*., *Chrysocharis* sp. 1, *Chrysocharis* sp. 2, *Chelonus* sp. and *Telenomus* sp. 2 were recorded in cashew, 3 species *viz*., ?*P. anu*, *Ooencyrtus* sp. 1 and *Bracon* sp. were recorded in soybean, whereas two species each in rice (*Telenomus* sp. 1 and *Trissolcus* sp. 2), fieldbean (*Cotesia* sp. and ?*P. anu*) and cocoa (*C. pseudococci* and *Chartocerus* sp.) were recorded, while one species each in cabbage (*C. vestalis*), coconut (*A. pseudococci*), crape jasmine (*Trissolcus* sp. 1), tobacco (*M. prodeniae*), bhendi (*Trissolcus* sp. 3) and pongamia (*C. chromusae*) were recorded. However, in Davanagere district, 16 hymenopteran parasitoids species were recorded in different host plants *viz*., rice,

maize, cabbage, brinjal and arecanut. Amomg them, highest number (6) of parasitoids species *viz*., *L. nigrocincta, P. pulchellus*, *Ooencyrtus* sp. 2, *Telenomus* sp. 2, *C. pseudococci* and *Chartocerus* sp. were recorded in brinjal, followed by 5 species *viz*., *O. sokolowskii*, *C. floridanum*, *C. chlorideae*, *C. vestalis* and *D. rapae* were recorded in cabbage whereas, two species each in rice (*T. schoenobii* and *P. metallicus*) and maize (*Ophion* sp. and *T. chilonis*) were recorded while the lowest of one species was recorded in arecanut (*Encarsia* sp.). 12 hymenopteran parasitoids species were recorded from two different host plants *viz*., maize and cotton in Chitradurga district. Among them, highest number (7) of parasitoids species *viz*., *C. ruficrus*, *C. chlorideae*, *T. chilonis*, *Telenomus* sp. 2, *Eriborus* sp., *Charops* sp. and *D. anthracia* were recorded from maize, followed by 5 species *viz*., ?*Ryhonos* sp., *Aprostocetus* sp., *Eurytoma* sp., *Phanerotoma* sp. and *Nothoserphus* sp. from cotton (Table 7, 8 and 9). These results are in line with Pathummal Beevi *et al*., 2000 who reported that hymenopteran parasitoids belonged to 19 families with the most predominant species were from the genera *Telenomus*, *Tetrastichus* and *Trissolcus*, and species from other genera, such as *Aprostocetus* and *Pteromalus*, were also abundant from rice ecosystems in Kerala. Ochoa *et al*. (2001) also reported eleven species of hymenopteran parasitoids belonged to 3 families *viz*., Ichneumonidae, Braconidae and Eulophidae from larvae of fall armyworm, *S. frugiperda* on maize.

Percent species composition of hymenopteran parasitoids

Per cent species composition of hymenopteran parasitoids collected during 2021-2023 is presented in Table 10 and Fig. 2. Out of the 1379 parasitoid specimens collected comprised of 42 species belonged to 12 families and 33 genera. Among the families, Braconidae was found most dominant (comprised of 23.81%), followed by Eulophidae (16.67%), Encyrtidae and Scelionidae (each with 14.29%), Ichneumonidae (9.52%), Aphelinidae and Chalcididae (each with 4.76%), Eurytomidae, Proctutropidae, Pteromalidae, Signiphoridae and Trichogrammatidae (each with 2.38%). Among all the parasitoids species recorded, the highest numbers (498) were from *C. floridanum* with per cent species composition of 36.11, followed by *Telenomus* sp. 2 (175 individuals with 12.68%). In the family Ichneumonidae, highest numbers (62) were from *C. chlorideae* with per cent species composition of 4.50, followed by *Eriborus* sp., *Charops* sp. and *Ophion* sp. (each with one individual comprised of 0.07%) whereas, in Braconidae, *C. chromusae* represented highest numbers (15) with per cent species composition of 1.09, followed by *Phanerotoma* sp. and *C. vestalis* (each with 9 individuals comprised of 0.65%), *C. ruficrus* (7 individuals with 0.51%), Bracon sp. (6

individuals with 0.44%), *Chelonus* sp. (5 individuals with 0.36%), *Cotesia* sp. (2 individuals with 0.15%), *C. formosanus*, *M. prodeniae* and *D. rapae* (each with one individual comprised of 0.07%), while in Eulophidae, highest numbers (76) were from *T. schoenobii* with per cent species composition of 5.51, followed by *Chrysocharis* sp. 1 (16 individuals with 1.16%), *Aprostocetus* sp. (11 individuals with 0.80%), *Chrysocharis* sp. 2 and *O. sokolowskii* (each with 9 individual comprised of 0.65%), *Chrysocharis* sp. 3 (5 individuals with 0.36%) and lowest of one individual was represented by *Ryhonos* sp. with per cent species composition of 0.07. However, in Encyrtidae, the highest numbers (498) were from *C. floridanum* with per cent species composition of 36.11, followed by *Ooencyrtus* sp. 2 (34 individuals with 2.47%), *P. pulchellus* (18 individuals with 1.31%), *A. Pseudococci* (9 individuals with 0.65%), *L. nigrocincta* (6 individuals with 0.44%) and lowest of 2 individuals were collected in *Ooencyrtus* sp. 1 with per cent species composition of 0.15. In the family, Scelionidae, Telenomus sp. 2 represented highest numbers (175) with per cent species composition of 12.69, followed by ?*P. anu* (86 individuals with 6.24%), *Trissolcus* sp. 3 (53 individuals with 3.84%), *Telenomus* sp. 1 (51 individuals with 3.70%), *Trissolcus* sp. 1 (14 individuals with 1.02%) and *Trissolcus* sp. 2 represented lowest number (6) of individuals with per cent species composition of 0.44. Two species *viz*., *B. lasus* and *D. anthracia* each represented one individual with per cent species composition of 0.07 from Chalcididae and two species *viz*., *C. pseudococci* and *Encarsia* sp. each represented 49 and 5 individuals with per cent species composition of 3.55 and 0.36, respectively from Aphelinidae. However, Eurytomidae, Proctutropidae, Pteromalidae, Signiphoridae and Trichogrammatidae each represented one species *viz*., *Eurytoma* sp. (18), *Nothoserphus* sp. (1), *P. metallicus* (5), *Chartocerus* sp. (13) and *T. chilonis* (86) with per cent species composition of 1.31, 0.07, 0.36, 0.94 and 6.24, respectively. In Shivamogga district, 454 hymenopteran parasitoid specimens belonged to 25 species of 10 familes were collected. Among the families, Braconidae was found dominant (comprised of 32.00%), followed by Scelionidae (24.00%), Eulophidae (12.00%), Encyrtidae (8.00%), Ichneumonidae, Aphelinidae, Chalcididae, Eurytomidae, Signiphoridae and Trichogrammatidae (each with 4.00%). Among the parasitoids species recorded, the highest numbers (89) were from *Telenomus* sp. 2 with per cent species composition of 19.60, followed by ?*P. anu* (86 individuals with 18.94%). In the family Braconidae, *C. chromusae* represented highest numbers (15) with per cent species composition of 3.30, followed by Braconsp. (6 individuals with 1.32%), *Chelonus* sp. (5 individuals with 1.10%), *C. vestalis* (3 individuals with 0.66%), *Cotesia* sp. (2 individuals with 0.44%), *C. formosanus*, *M. prodeniae* and *D. rapae* (each with

one individual comprised of 0.22%) whereas, in Scelionidae, *Telenomus* sp. 2 represented highest numbers (89) with per cent species composition of 19.60, followed by ?*P. anu* (86 individuals with 18.94%), *Trissolcus* sp. 3 (53 individuals with 11.67%), *Telenomus* sp. 1 (51 individuals with 11.23%), *Trissolcus* sp. 1 (14 individuals with 3.08%) and *Trissolcus* sp. 2 represented lowest number (6) of individuals with per cent species composition of 1.32 while in Eulophidae, highest numbers (16) were from *Chrysocharis* sp. 1 with per cent species composition of 3.52, followed by *Chrysocharis* sp. 2 (9 individuals with 1.98%) and *Chrysocharis* sp. 3 (5 individuals with 1.10%). However, in Encyrtidae, the highest numbers (9) were from A. pseudococci with per cent species composition of 1.98, followed by *Ooencyrtus* sp. 1 (2 individuals with 0.44%) whereas, Ichneumonidae, Eurytomidae, Chalcididae, Aphelinidae, Signiphoridae and Trichogrammatidae each represented one species *viz*., *C. chlorideae* (11 individuals), *Eurytoma* sp. (12 individuals), *B. lasus* (1 individuals), *C. pseudococci* (1 individuals), *Chartocerus* sp. (8 individuals) and *T. chilonis* (47 individuals) with per cent species composition of 2.42, 2.64, 0.22, 0.22, 1.76 and 10.35, respectively (Table 11 and Fig. 3). In Davanagere district, 747 hymenopteran parasitoid specimens belonging to 16 species of 9 familes were collected. Among the families, Encyrtidae was found dominant (comprising of 25.00%), followed by Ichneumonidae, Braconidae, Eulophidae and Aphelinidae (each with 12.50%), Scelionidae, Pteromalidae, Signiphoridae and Trichogrammatidae (each with 6.25%). Among the parasitoids species recorded, the highest numbers (498) were from *C. floridanum* with per cent species composition of 66.67, followed by *C. pseudococci* (48 individuals with 6.43%). In the family Ichneumonidae, there were two species *viz*., *C. chlorideae* and *Ophion* sp. each represented one individual with per cent species composition of 0.13 whereas, in Braconidae, *C. vestalis* represented highest numbers (6) with per cent species composition of 0.80, followed by *D. rapae* (one individual with 0.13%), while in Eulophidae, highest numbers (76) were from *T. schoenobii* with per cent species composition of 10.17, followed by *O. sokolowskii* (9 individuals with 1.20%). However, in Encyrtidae, the highest numbers (498) were from *C. floridanum* with per cent species composition of 66.67, followed by *Ooencyrtus* sp. 2 (34 individuals with 4.55%), *P. pulchellus* (18 individuals with 2.41%) and lowest of 6 individuals were collected from *L. nigrocincta* with per cent species composition of 0.80, whereas in Aphelinidae, two species *viz*., *C. pseudococci* and *Encarsia* sp. each represented 48 and 5 individuals with per cent species composition of 6.43 and 0.67, respectively, while Scelionidae, Pteromalidae, Signiphoridae and Trichogrammatidae each represented one species *viz*., *Telenomus* sp. 2 (18 individuals), *P. metallicus* (5 individuals),

Chartocerus sp. (5 individuals) and *T. chilonis* (16 individuals) with per cent species composition of 2.41, 0.67, 0.67 and 2.14, respectively (Table 12 and Fig. 4). In Chitradurga district, 178 hymenopteran parasitoid specimens belonging to 12 species of 8 familes were collected. Among the families, Ichneumonidae was found dominant (comprising of 25.00%), followed by Braconidae and Eulophidae (each with 16.67%), Scelionidae, Eurytomidae, Chalcididae, Proctutropidae and Trichogrammatidae (each with 8.33%). Among the parasitoids species recorded, the highest numbers (68) were from *Telenomus* sp. 2 with per cent species composition of 38.20, followed by *C. Chlorideae* (50 individuals with 28.09%). In the family Ichneumonidae, highest numbers (50) were from *C. chlorideae* with per cent species composition of 28.09, followed by *Eriborus* sp. and *Charops* sp. (each with one individual comprised of 0.56%), whereas, in Braconidae, *Phanerotoma* sp. represented highest numbers (9) with per cent species composition of 5.06, followed by *C. ruficrus* (6 individuals with 3.37%), while in Eulophidae, highest numbers (11) were from *Aprostocetus* sp. (11 individuals with 6.18%) and lowest of one individual was represented by ?*Ryhonos* sp. with per cent species composition of 0.56. However, Scelionidae, Eurytomidae, Chalcididae, Proctutropidae and Trichogrammatidae each represented one species *viz*., *Telenomus* sp. 2 (68 individuals), *Eurytoma* sp. (6 individuals), *D. anthracia* (1 individuals), *Nothoserphus* sp. (1 individuals) and *T. chilonis* (23 individuals) with per cent species composition of 38.20, 3.37, 0.56, 0.56 and 12.92, respectively (Table 13 and Fig. 5). These results are in agreement with Anbalagan *et al*. (2015) who recorded totally 4994 individuals which represented 100 species belonging to 37 families of Hymenoptera and noticed Braconidae, Encyrtidae, Eulophidae and Platygastridae were found to be the dominant in the vegetable fields of Tiruvallur District, Tamil Nadu. Kathirvelu (2019) collected and identified thirteen different agriculturally important parasitic families from rice ecosystem. Among the families collected, Ichneumonidae, Braconidae, Scelionidae and Chalcididae were found predominant. Winsou *et al*. (2022) reported that, among the parasitoids collected, the most abundant parasitoid species found was the egg parasitoid, *Telenomus remus* on fall armyworm.

Hymenopteran parasitoids associated of with different host stages of insects

In the present research, 42 hymenopteran parasitoids were collected from different stages *viz*., egg, larva, pupa and adult stage of host insects. Among them, maximum parasitoids species (20) were collected from larval stage of host insects with per cent species composition of 47.62, followed by egg stage (9 species with 21.43%), adult stage (7 species with 16.67%)

and pupal stage (6 species with 14.29%) of host insects. In Shivamogga district also, more number of parasitoids species (12) were collected from larval stage of host insects with per cent species composition of 48, followed by egg stage (8 species with 32.00%), adult stage (3 species with 12.00%) and pupal stage (2 species with 8.00%) of host insects. In Davanagere district, maximum parasitoids species (6) were collected from adult stage of host insect with per cent species composition of 37.50, followed by larval stage (4) of host insects each with per cent species composition of 25.00 and egg (3) and pupal stage (3) with per cent species composition of 18.75. In Chitradurga district, more number of parasitoids species (9) were collected from larval stage of host insects with per cent species composition of 75.00, followed by egg (2) and pupal stage (1) of host insects with per cent species composition of 16.67 and 8.33, respectively and none of the parasitoids were recorded from adult stage of host insects (Table 14). This is in agreement with Taye *et al*. (2017) who observed hymenopteran parasitoids from different ecosystems of Assam Agricultural University, Jorhat campus and found that larval parasitoids represented by 6 families, and 23 species were the most dominant, followed by egg parasitoids (5 families and 13 species).

Species composition of hymenopteran parasitoids associated with crop ecosystems

During the present investigation, number of hymenopteran parasitoids species and per cent species composition in different crop ecosystems were recorded. Of which, highest per cent species composition of parasitoids species were recorded from maize crop (28.57 %), followed by brinjal (14.29 %), cabbage and cotton (each with 11.90 %), rice and cashew (each with 9.52%), soybean (7.14%), field bean (4.76%), coconut, crape jasmine, tobacco, arecanut, bhendi and pongamia (each with 2.38%) (Table 15). In Shivamogga district, maize crop recorded highest per cent species composition of parasitoids species (32.00%), followed by cashew (16.00%), soybean (12.00%), rice, fieldbean and cocoa (each with 8.00%), cabbage, coconut, crape jasmine, tobacco, bhendi and pongamia (each with 4.00%). In Davanagere district, highest per cent species composition of parasitoids species was recorded from brinjal crop (37.50 %), followed by cabbage (31.25 %), rice and maize (each with 12.50%), and the lowest per cent species composition was noticed in arecanut crop (6.25%). In Chitradurga district, the highest and lowest per cent species composition of 58.33 and 41.67 was noticed with maize and cotton crops, respectively (Table 16, 17 and 18). These results are in line with Mohapatra and Sahu (2005) who found a solitary hymenopteran parasitoid parasitizing the late instars of the cotton leaf roller, *H. derogata*. Sarfraz *et al.* (2005) observed that highest control of diamondback moth was achieved by relatively few

hymenopteran species belonged to the Braconid genus *Cotesia*, and the eulophid genus *Oomyzus*. Wold-Burkness *et al.* (2005) reported *C. floridanum* was the dominant parasitoid of cabbage looper, *T. ni.*

Species abundance, richness and diversity of hymenopteran parasitoids

Species diversity in terms of richness, evenness and abundance of hymenopteran parasitoids were calculated and compared during study period using Shannon-Wiener index, Simpson diversity index, Margalef's diversity index, Menhinick's index and Evenness. Species diversity was high in Shivamogga district as evidenced by Shannon-Wiener index (2.49), Simpson's diversity index (0.88), Margalef's index (4.09) and Menhinick's index (1.22) and Evenness (0.46), followed by Davanagere district with respect to Shannon-Wiener index (1.69) Simpson's diversity index (0.75), Margalef's index and Menhinick's index (2.27 and 0.90), respectively, while evenness was 0.24. In Chitradurga district, the diversity was low comparatively as exhibited by Shannon-Wiener index being 1.34, Simpson's diversity index 0.54, Margalef's index and Menhinick's index being 2.12 and 0.59, respectively (Table 19). These results are in agreement with Daniel and Ramaraju (2017) who reported Chacididae fauna in three rice growing zones of Tamil Nadu wherein all the indices *viz*., Simpson's Index, Shannon-Wiener Index and Margalef's index indicated that the Cauvery delta zone was the most diverse zone among the three zones surveyed, while High Rainfall Zone was found to be the least diverse zone. Daniel *et al*. (2017) studied the diversity indices (Simpson's index and Shannon-Wiener index) for Pteromalid fauna in three rice growing zones of Tamil Nadu which revealed that High rainfall zone was the most diverse zone, while Cauvery delta zone being the least diverse. Amala and Shivalingaswamy (2018) documented the diversity of hymenopteran parasitoids in different cropping systems and reported that Shannon-Weiner index, Margalef's richness index and Evenness index were higher in the inter/border/hedgerow cropped fields compared to the sole cropped ecosystems.

Conclusion

As many as 42 species of hymenopteran parasitoids were recorded which belonged to 12 families comprising of 33 genera from 20 different hosts in Shivamogga, Davanagere and Chitradurga districts. Highest number of parasitoids species were recorded from maize (12 species). A total of 9 hymenopteran parasitoids have been reported on fall armyworm which can be exploited in bio-control programmes in future. Family Braconidae was found most dominant with per cent species compostion of 23.81. The highest numbers of parasitoids

(498) were collected from the species *Copidosoma floridanum* with per cent species composition of 36.11. Maximum parasitoids species (20) were collected from larval stage of host insects with per cent species composition of 47.62. Species diversity was high in Shivamogga district as evidenced by Shannon-Wiener index (2.49), Simpson diversity index (0.88), Margalef's index (4.09) and Menhinick's index (1.22) and Evenness (0.46), followed by Davanagere district with respect to Shannon-Wiener index (1.69) Simpson's diversity index (0.75), Margalef's index and Menhinick's index (2.27 and 0.90), respectively, while evenness was 0.24 and Chitradurga district with respect to Shannon-Wiener index (1.34) Simpson's diversity index (0.54), Margalef's index and Menhinick's index (2.12 and 0.59), respectively.

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Table 1. List of hymenopteran parasitoids recorded during 2021-2023

Sl. No.	Family	Scientific name	Host insect	Host stage of insect
I	Ichneumonidae	1. *Campoletis chlorideae*	*Spodoptera frugiperda*	Larva
			Plutella xylostella	
		2. *Eriborus* sp.	*Spodoptera frugiperda*	Larva
		3. *Charops* sp.	*Spodoptera frugiperda*	Larva
		4. *Ophion* sp.	*Spodoptera frugiperda*	Larva
II	Braconidae	5. *Chelonus formosanus*	*Spodoptera frugiperda*	Larva
		6. *Microplitis prodeniae*	*Spodoptera litura*	Larva
		7. *Cotesia ruficrus*	*Spodoptera frugiperda*	Larva
		8. *Cotesia vestalis*	*Plutella xylostella*	Larva
		9. *Cotesia* sp.	*Exelastis atomosa*	Larva
		10. *Chelonus* sp.	*Acrocercops syngramma*	Larva
		11. *Bracon* sp.	*Omiodes indicata*	Larva
		12. *Crinibracon chromusae*	*Hasora chromus*	Pupa
		13. *Phanerotoma* sp.	*Haritalodes derogata*	Larva
		14. *Diaeretiella rapae*	*Brevicoryne brassicae*	Adult
III	Eulophidae	15. *Chrysocharis* sp. 1	*Acrocercops syngramma*	Larva
		16. *Chrysocharis* sp. 2	*Acrocercops syngramma*	Larva
		17. *Chrysocharis* sp. 3	*Spodoptera frugiperda*	Larva
		18. *?Ryhonos* sp.	*Haritalodes derogata*	Larva
		19. *Aprostocetus* sp.	*Haritalodes derogata*	Larva
		20. *Oomyzus sokolowskii*	*Plutella xylostella*	Pupa
		21. *Tetrastichus schoenobii*	*Scirpophaga incertulas*	Egg
IV	Encyrtidae	22. *Anagyrus pseudococci*	*Nipaecoccus nipae*	Adult
		23. *Ooencyrtus* sp. 1	*Omiodes indicata*	Egg
		24. *Leptomastix nigrocincta*	*Coccidohystrix insolita*	Adult
		25. *Prochiloneurus pulchellus*	*Coccidohystrix insolita*	Adult
		26. *Copidosoma floridanum*	*Trichoplusia ni*	Larva
		27. *Ooencyrtus* sp. 2	*Coccidohystrix insolita*	Adult
V	Scelionidae	28. *Trissolcus* sp. 1	*Leptoglossus phyllopus*	Egg
		29. *Trissolcus* sp. 2	*Leptocorisa oratoria*	Egg
		30. *Telenomus* sp. 1	*Scirpophaga incertulas*	Egg
		31. *?Paratelenomus anu*	*Megacopta cribraria*	Egg
		32. *Trissolcus* sp. 3	*Earias vittela*	Egg
		33. *Telenomus* sp. 2	*Spodoptera frugiperda*	Egg

			Rhynocoris marginatus	
			Leucinodes orbonalis	
VI	Eurytomidae	34. *Eurytoma* sp.	*Spodoptera frugiperda*	Larva
			Haritalodes derogata	
VII	Chalcididae	35. *Brachymeria lasus*	*Spodoptera frugiperda*	Pupa
		36. *Dirhinus anthracia*	*Spilosoma obliqua*	Pupa
VIII	Signiphoridae	37. *Chartocerus* sp.	*Exallomochlus hispidus*	Adult
			Coccidohystrix insolita	Adult
IX	Aphelinidae	38. *Coccophagus pseudococci*	*Exallomochlus hispidus*	Adult
			Coccidohystrix insolita	
		39. *Encarsia* sp.	*Aleurocanthus arecae*	Pupa
X	Trichogrammatidae	40. *Trichogramma chilonis*	*Spodoptera frugiperda*	Egg
XI	Proctutropidae	41. *Nothoserphus* sp.	*Haritalodes derogata*	Larva
XII	Pteromalidae	42. *Pteromalus metallicus*	*Scirpophaga incertulas*	Pupa

Table 2. List of hymenopteran parasitoids recorded in Shivamogga district during 2021-2023

Sl. No.	Family	Scientific name	Host insect	Host stage of insect
I	Ichneumonidae	1. *Campoletis chlorideae*	*Spodoptera frugiperda*	Larva
II	Braconidae	2. *Chelonus formosanus*	*Spodoptera frugiperda*	Larva
		3. *Microplitis prodeniae*	*Spodoptera litura*	Larva
		4. *Cotesia ruficrus*	*Spodoptera frugiperda*	Larva
		5. *Cotesia vestalis*	*Plutella xylostella*	Larva
		6. *Cotesia* sp.	*Exelastis atomosa*	Larva
		7. *Chelonus* sp.	*Acrocercops syngramma*	Larva
		8. *Bracon* sp.	*Omiodes indicata*	Larva
		9. *Crinibracon chromusae*	*Hasora chromus*	Pupa
III	Eulophidae	10. *Chrysocharis* sp. 1	*Acrocercops syngramma*	Larva
		11. *Chrysocharis* sp. 2	*Acrocercops syngramma*	Larva
		12. *Chrysocharis* sp. 3	*Spodoptera frugiperda*	Larva
IV	Encyrtidae	13. *Anagyrus pseudococci*	*Nipaecoccus nipae*	Adult
		14. *Ooencyrtus* sp. 1	*Omiodes indicata*	Egg
V	Scelionidae	15. *Trissolcus* sp. 1	*Leptoglossus phyllopus*	Egg
		16. *Trissolcus* sp. 2	*Leptocorisa oratoria*	Egg
		17. *Telenomus* sp. 1	*Scirpophaga incertulas*	Egg
		18. *?Paratelenomus anu*	*Megacopta cribraria*	Egg
		19. *Trissolcus* sp. 3	*Earias vittela*	Egg
		20. *Telenomus* sp. 2	*Spodoptera frugiperda*	Egg
			Rhynocoris marginatus	
VI	Eurytomidae	21. *Eurytoma* sp.	*Spodoptera frugiperda*	Larva
VII	Chalcididae	22. *Brachymeria lasus*	*Spodoptera frugiperda*	Pupa
VIII	Signiphoridae	23. *Chartocerus* sp.	*Exallomochlus hispidus*	Adult
IX	Aphelinidae	24. *Coccophagus pseudococci*	*Exallomochlus hispidus*	Adult
X	Trichogrammatidae	25. *Trichogramma chilonis*	*Spodoptera frugiperda*	Egg

Table 3. List of hymenopteran parasitoids recorded in Davanagere district during 2021-2023

Sl. No.	Family	Scientific name	Host insect	Host stage

				of insect
I	Ichneumonidae	1. *Campoletis chlorideae*	*Plutella xylostella*	Larva
		2. *Ophion* sp.	*Spodoptera frugiperda*	Larva
II	Braconidae	3. *Cotesia vestalis*	*Plutella xylostella*	Larva
		4. *Diaeretiella rapae*	*Brevicoryne brassicae*	Adult
III	Eulophidae	5. *Oomyzus sokolowskii*	*Plutella xylostella*	Pupa
		6. *Tetrastichus schoenobii*	*Scirpophaga incertulas*	Egg
IV	Encyrtidae	7. *Leptomastix nigrocincta*	*Coccidohystrix insolita*	Adult
		8. *Prochiloneurus pulchellus*	*Coccidohystrix insolita*	Adult
		9. *Copidosoma floridanum*	*Trichoplusia ni*	Larva
		10. *Ooencyrtus* sp. 2	*Coccidohystrix insolita*	Adult
V	Scelionidae	11. *Telenomus* sp. 2	*Leucinodes orbonalis*	Egg
VI	Pteromalidae	12. *Pteromalus metallicus*	*Scirpophaga incertulas*	Pupa
VII	Signiphoridae	13. *Chartocerus* sp.	*Coccidohystrix insolita*	Adult
VIII	Aphelinidae	14. *Coccophagus pseudococci*	*Coccidohystrix insolita*	Adult
		15. *Encarsia* sp.	*Aleurocanthus arecae*	Pupa
IX	Trichogrammatidae	16. *Trichogramma chilonis*	*Spodoptera frugiperda*	Egg

Table 4. List of hymenopteran parasitoids recorded in Chitradurga district during 2021-2023

Sl. No.	Family	Scientific name	Host insect	Host stage of insect
I	Ichneumonidae	1. *Campoletis chlorideae*	*Spodoptera frugiperda*	Larva
		2. *Eriborus* sp.	*Spodoptera frugiperda*	Larva
		3. *Charops* sp.	*Spodoptera frugiperda*	Larva
II	Braconidae	4. *Phanerotoma* sp.	*Haritalodes derogata*	Larva
		5. *Cotesia ruficrus*	*Spodoptera frugiperda*	Larva
III	Eulophidae	6. *?Ryhonos* sp.	*Haritalodes derogata*	Larva
		7. *Aprostocetus* sp.	*Haritalodes derogata*	Larva
IV	Scelionidae	8. *Telenomus* sp. 2	*Spodoptera frugiperda*	Egg
V	Eurytomidae	9. *Eurytoma* sp.	*Haritalodes derogata*	Larva
VI	Chalcididae	10. *Dirhinus anthracia*	*Spilosoma obliqua*	Pupa
VII	Proctutropidae	11. *Nothoserphus* sp.	*Haritalodes derogata*	Larva
VIII	Trichogrammatidae	12. *Trichogramma chilonis*	*Spodoptera frugiperda*	Egg

Table 5. Distribution of hymenopteran parasitoids recorded in three districts during 2021-2023

Sl. No.	Name of the species	Shivamogga	Davanagere	Chitradurga
1	*?Ryhonos* sp.	-	-	+
2	*Eurytoma* sp.	+	-	+
3	*Oomyzus sokolowskii*	-	+	-
4	*Chrysocharis* sp. 1	+	-	-
5	*Chrysocharis* sp. 2	+	-	-
6	*Anagyrus pseudococci*	+	-	-
7	*Leptomastix nigrocincta*	-	+	-
8	*Prochiloneurus pulchellus*	-	+	-
9	*Copidosoma floridanum*	-	+	-
10	*Campoletis chlorideae*	+	+	+
11	*Chelonus formosanus*	+	-	-
12	*Trissolcus* sp. 1	+	-	-

13	*Trissolcus* sp. 2	+	-	-
14	*Microplitis prodeniae*	+	-	-
15	*Cotesia ruficrus*	+	-	+
16	*Cotesia vestalis*	+	+	-
17	*Cotesia* sp.	+	-	-
18	*Telenomus* sp. 1	+	-	-
19	*Telenomus* sp. 2	+	+	+
20	*?Paratelenomus anu*	+	-	-
21	*Chelonus* sp.	+	-	-
22	*Bracon* sp.	+	-	-
23	*Phanerotoma* sp.	-	-	+
24	*Diaeretiella rapae*	-	+	-
25	*Brachymeria lasus*	+	-	-
26	*Chrysocharis* sp. 3	+	-	-
27	*Ooencyrtus* sp. 1	+	-	-
28	*Encarsia* sp.	-	+	-
29	*Coccophagus pseudococci*	+	+	-
30	*Ooencyrtus* sp. 2	-	+	-
31	*Chartocerus* sp.	+	+	-
32	*Pteromalus metallicus*	-	+	-
33	*Tetrastichus schoenobii*	-	+	-
34	*Aprostocetus* sp.	-	-	+
35	*Eriborus* sp.	-	-	+
36	*Charops* sp.	-	-	+
37	*Nothoserphus* sp.	-	-	+
38	*Ophion* sp.	-	+	-
39	*Dirhinus anthracia*	-	-	+
40	*Trissolcus* sp. 3	+	-	-
41	*Crinibracon chromusae*	+	-	-
42	*Trichogramma chilonis*	+	+	+

Table 6. Crop wise distribution of hymenopteran parasitoids recorded during 2021-2023

Sl. No.	Host plant	Name of species	Parasitoid family
I	Rice (*Oryza sativa*)	1. *Telenomus* sp. 1	Scelionidae
		2. *Tetrastichus schoenobii*	Eulophidae
		3. *Pteromalus metallicus*	Pteromalidae
		4. *Trissolcus* sp. 2	Scelionidae
II	Maize (*Zea mays*)	1. *Eurytoma* sp.	Eurytomidae
		2. *Chelonus formosanus*	Braconidae
		3. *Campoletis chlorideae*	Ichneumonidae
		4. *Cotesia ruficrus*	Braconidae
		5. *Telenomus* sp. 2	Scelionidae
		6. *Brachymeria lasus*	Chalcididae
		7. *Chrysocharis* sp. 3	Eulophidae
		8. *Eriborus* sp.	Ichneumonidae
		9. *Charops* sp.	Ichneumonidae
		10. *Ophion* sp.	Ichneumonidae

		11. *Trichogramma chilonis*	Trichogrammatidae
		12. *Dirhinus anthracia*	Chalcididae
III	Cabbage (*Brassica oleracea*)	1. *Oomyzus sokolowskii*	Eulophidae
		2. *Copidosoma floridanum*	Encyrtidae
		3. *Campoletis chlorideae*	Ichneumonidae
		4. *Cotesia vestalis*	Braconidae
		5. *Diaeretiella rapae*	Braconidae
IV	Cotton (*Gossypium hirsutum*)	1. *?Ryhonos* sp.	Eulophidae
		2. *Eurytoma* sp.	Eurytomidae
		3. *Aprostocetus* sp.	Eulophidae
		4. *Phanerotoma* sp.	Braconidae
		5. *Nothoserphus* sp.	Proctutropidae
V	Coconut (*Cocos nucifera*)	1. *Anagyrus pseudococci*	Encyrtidae
VI	Brinjal (*Solanum melongena*)	1. *Leptomastix nigrocincta*	Encyrtidae
		2. *Prochiloneurus pulchellus*	Encyrtidae
		3. *Telenomus* sp. 2	Scelionidae
		4. *Ooencyrtus* sp. 2	Encyrtidae
		5. *Coccophagus pseudococci*	Aphelinidae
		6. *Chartocerus* sp.	Signiphoridae
VII	Cashew (*Anacardium occidentale*)	1. *Chrysocharis* sp. 1	Eulophidae
		2. *Chrysocharis* sp. 2	Eulophidae
		3. *Telenomus* sp. 2	Scelionidae
		4. *Chelonus* sp.	Braconidae
VIII	Crape jasmine (*Tabernaemontana divaricata*)	1. *Trissolcus* sp. 1	Scelionidae
IX	Tobacco (*Nicotiana tabacum*)	1. *Microplitis prodeniae*	Braconidae
X	Field bean (*Vicia faba*)	1. *Cotesia* sp.	Braconidae
		2. *?Paratelenomus anu*	Scelionidae
XI	Soybean (*Glycine max*)	1. *?Paratelenomus anu*	Scelionidae
		2. *Bracon* sp.	Braconidae
		3. *Ooencyrtus* sp. 1	Encyrtidae
XII	Arecanut (*Areca catechu*)	1. *Encarsia* sp.	Aphelinidae
XIII	Cocoa (*Theobroma cacao*)	1. *Coccophagus pseudococci*	Aphelinidae
		2. *Chartocerus* sp.	Signiphoridae
X1V	Bhendi (*Abelmoschus esculentus*)	1. *Trissolcus* sp. 3	Scelionidae
XV	Pongamia (*Pongamia pinnata*)	1. *Crinibracon chromusae*	Braconidae

Table 7. Crop wise distribution of hymenopteran parasitoids recorded in Shivamogga district during 2021-2023

Sl. No.	Host plant	Name of species	Parasitoid family
I	Rice (*Oryza sativa*)	1. *Telenomus* sp. 1	Scelionidae
		2. *Trissolcus* sp. 2	Scelionidae
II	Maize	1. *Eurytoma* sp.	Eurytomidae

	(*Zea mays*)	2. *Chelonus formosanus*	Braconidae
		3. *Campoletis chlorideae*	Ichneumonidae
		4. *Cotesia ruficrus*	Braconidae
		5. *Telenomus* sp. 2	Scelionidae
		6. *Brachymeria lasus*	Chalcididae
		7. *Chrysocharis* sp. 3	Eulophidae
		8. *Trichogramma chilonis*	Trichogrammatidae
III	Cabbage (*Brassica oleracea*)	1. *Cotesia vestalis*	Braconidae
IV	Coconut (*Cocos nucifera*)	1. *Anagyrus pseudococci*	Encyrtidae
V	Cashew (*Anacardium occidentale*)	1. *Chrysocharis* sp. 1	Eulophidae
		2. *Chrysocharis* sp. 2	Eulophidae
		3. *Telenomus* sp. 2	Scelionidae
		4. *Chelonus* sp.	Braconidae
VI	Crape jasmine (*Tabernaemontana divaricata*)	1. *Trissolcus* sp. 1	Scelionidae
VII	Tobacco (*Nicotiana tabacum*)	1. *Microplitis prodeniae*	Braconidae
VIII	Field bean (*Vicia faba*)	1. *Cotesia* sp.	Braconidae
		2. *?Paratelenomus anu*	Scelionidae
IX	Soybean (*Glycine max*)	1. *?Paratelenomus anu*	Scelionidae
		2. *Bracon* sp.	Braconidae
		3. *Ooencyrtus* sp. 1	Encyrtidae
X	Cocoa (*Theobroma cacao*)	1. *Coccophagus pseudococci*	Aphelinidae
		2. *Chartocerus* sp.	Signiphoridae
XI	Bhendi (*Abelmoschus esculentus*)	1. *Trissolcus* sp. 3	Scelionidae
XII	Pongamia (*Pongamia pinnata*)	1. *Crinibracon chromusae*	Braconidae

Table 8. Crop wise distribution of hymenopteran parasitoids recorded in Davanagere district during 2021-2023

Sl. No.	Host plant	Name of species	Parasitoid family
I	Rice (*Oryza sativa*)	1. *Tetrastichus schoenobii*	Eulophidae
		2. *Pteromalus metallicus*	Pteromalidae
II	Maize (*Zea mays*)	1. *Trichogramma chilonis*	Trichogrammatidae
		2. *Ophion* sp.	Ichneumonidae
III	Cabbage (*Brassica oleracea*)	1. *Oomyzus sokolowskii*	Eulophidae
		2. *Copidosoma floridanum*	Encyrtidae
		3. *Campoletis chlorideae*	Ichneumonidae
		4. *Cotesia vestalis*	Braconidae
		5. *Diaeretiella rapae*	Braconidae
IV	Brinjal (*Solanum melongena*)	1. *Leptomastix nigrocincta*	Encyrtidae
		2. *Prochiloneurus pulchellus*	Encyrtidae
		3. *Telenomus* sp. 2	Scelionidae
		4. *Ooencyrtus* sp. 2	Encyrtidae

		5. *Coccophagus pseudococci*	Aphelinidae
		6. *Chartocerus* sp.	Signiphoridae
V	Arecanut (*Areca catechu*)	1. *Encarsia* sp.	Aphelinidae

Table 9. Crop wise distribution of hymenopteran parasitoids recorded in Chitradurga district during 2021-2023

Sl. No.	Host plant	Name of species	Parasitoid family
I	Maize (*Zea mays*)	1. *Campoletis chlorideae*	Ichneumonidae
		2. *Trichogramma chilonis*	Trichogrammatidae
		3. *Cotesia ruficrus*	Braconidae
		4. *Telenomus* sp. 2	Scelionidae
		5. *Eriborus* sp.	Ichneumonidae
		6. *Charops* sp.	Ichneumonidae
		7. *Dirhinus anthracia*	Chalcididae
II	Cotton (*Gossypium hirsutum*)	1. *?Ryhonos* sp.	Eulophidae
		2. *Eurytoma* sp.	Eurytomidae
		3. *Aprostocetus* sp.	Eulophidae
		4. *Phanerotoma* sp.	Braconidae
		5. *Nothoserphus* sp.	Proctutropidae

Table 10. Per cent species composition of hymenopteran parasitoids recorded during 2021-2023

Sl. No.	Species	No. of parasitoids	Percentage
I	**Ichneumonidae**		
1	*Campoletis chlorideae*	62	4.50
2	*Eriborus* sp.	1	0.07
3	*Charops* sp.	1	0.07
4	*Ophion* sp.	1	0.07
II	**Braconidae**		
5	*Chelonus formosanus*	1	0.07
6	*Microplitis prodeniae*	1	0.07
7	*Cotesia ruficrus*	7	0.51
8	*Cotesia vestalis*	9	0.65
9	*Cotesia* sp.	2	0.15
10	*Chelonus* sp.	5	0.36
11	*Bracon* sp.	6	0.44
12	*Crinibracon chromusae*	15	1.09
13	*Phanerotoma* sp.	9	0.65
14	*Diaeretiella rapae*	1	0.07
III	**Eulophidae**		
15	*Chrysocharis* sp. 1	16	1.16
16	*Chrysocharis* sp. 2	9	0.65
17	*Chrysocharis* sp. 3	5	0.36
18	*?Ryhonos* sp.	1	0.07
19	*Aprostocetus* sp.	11	0.80
20	*Oomyzus sokolowskii*	9	0.65

21	*Tetrastichus schoenobii*	76	5.51
IV	**Encyrtidae**		
22	*Anagyrus pseudococci*	9	0.65
23	*Ooencyrtus* sp. 1	2	0.15
24	*Leptomastix nigrocincta*	6	0.44
25	*Prochiloneurus pulchellus*	18	1.31
26	*Copidosoma floridanum*	498	36.11
27	*Ooencyrtus* sp. 2	34	2.47
V	**Scelionidae**		
28	*Trissolcus* sp. 1	14	1.02
29	*Trissolcus* sp. 2	6	0.44
30	*Telenomus* sp. 1	51	3.70
31	*?Paratelenomus anu*	86	6.24
32	*Trissolcus* sp. 3	53	3.84
33	*Telenomus* sp. 2	175	12.69
VI	**Eurytomidae**		
34	*Eurytoma* sp.	18	1.31
VII	**Chalcididae**		
35	*Brachymeria lasus*	1	0.07
36	*Dirhinus anthracia*	1	0.07
VIII	**Aphelinidae**		
37	*Coccophagus pseudococci*	49	3.55
38	*Encarsia* sp.	5	0.36
IX	**Signiphoridae**		
39	*Chartocerus* sp.	13	0.94
X	**Trichogrammatidae**		
40	*Trichogramma chilonis*	86	6.24
XI	**Proctutropidae**		
41	*Nothoserphus* sp.	1	0.07
XII	**Ptromalidae**		
42	*Pteromalus metallicus*	5	0.36
Total		**1379**	**100**

Table 11. Per cent species composition of hymenopteran parasitoids recorded in Shivamogga district during 2021-2023

Sl. No.	Species	No. of parasitoids	Percentage
I	**Ichneumonidae**		
1	*Campoletis chlorideae*	11	2.42
II	**Braconidae**		
2	*Chelonus formosanus*	1	0.22
3	*Microplitis prodeniae*	1	0.22
4	*Cotesia ruficrus*	1	0.22
5	*Cotesia vestalis*	3	0.66
6	*Cotesia* sp.	2	0.44
7	*Chelonus* sp.	5	1.10
8	*Bracon* sp.	6	1.32
9	*Crinibracon chromusae*	15	3.30

III	**Eulophidae**		
10	*Chrysocharis* sp. 1	16	3.52
11	*Chrysocharis* sp. 2	9	1.98
12	*Chrysocharis* sp. 3	5	1.10
IV	**Encyrtidae**		
13	*Anagyrus pseudococci*	9	1.98
14	*Ooencyrtus* sp. 1	2	0.44
V	**Scelionidae**		
15	*Trissolcus* sp. 1	14	3.08
16	*Trissolcus* sp. 2	6	1.32
17	*Telenomus* sp. 1	51	11.23
18	*?Paratelenomus anu*	86	18.94
19	*Trissolcus* sp. 3	53	11.67
20	*Telenomus* sp. 2	89	19.60
VI	**Eurytomidae**		
21	*Eurytoma* sp.	12	2.64
VII	**Chalcididae**		
22	*Brachymeria lasus*	1	0.22
VIII	**Aphelinidae**		
23	*Coccophagus pseudococci*	1	0.22
IX	**Signiphoridae**		
24	*Chartocerus* sp.	8	1.76
X	**Trichogrammatidae**		
25	*Trichogramma chilonis*	47	10.35
Total		**454**	**100**

Table 12. Per cent species composition of hymenopteran parasitoids recorded in Davanagere district during 2021-2023

Sl. No.	Species	No. of parasitoids	Percentage
I	**Ichneumonidae**		
1	*Campoletis chlorideae*	1	0.13
2	*Ophion* sp.	1	0.13
II	**Braconidae**		
3	*Cotesia vestalis*	6	0.80
4	*Diaeretiella rapae*	1	0.13
III	**Eulophidae**		
5	*Oomyzus sokolowskii*	9	1.20
6	*Tetrastichus schoenobii*	76	10.17
IV	**Encyrtidae**		
7	*Leptomastix nigrocincta*	6	0.80
8	*Prochiloneurus pulchellus*	18	2.41
9	*Copidosoma floridanum*	498	66.67
10	*Ooencyrtus* sp. 2	34	4.55
V	**Scelionidae**		
11	*Telenomus* sp. 2	18	2.41
VI	**Ptromalidae**		
12	*Pteromalus metallicus*	5	0.67

VII	**Signiphoridae**		
13	*Chartocerus* sp.	5	0.67
VIII	**Aphelinidae**		
14	*Coccophagus pseudococci*	48	6.43
15	*Encarsia* sp.	5	0.67
IX	**Trichogrammatidae**		
16	*Trichogramma chilonis*	16	2.14
Total		**747**	**100**

Table 13. Per cent species composition of hymenopteran parasitoids recorded in Chitradurga district during 2021-2023

Sl. No.	Species	No. of parasitoids	Percentage
I	**Ichneumonidae**		
1	*Campoletis chlorideae*	50	28.09
2	*Eriborus* sp.	1	0.56
3	*Charops* sp.	1	0.56
II	**Braconidae**		
4	*Phanerotoma* sp.	9	5.06
5	*Cotesia ruficrus*	6	3.37
III	**Eulophidae**		
6	*?Ryhonos* sp.	1	0.56
7	*Aprostocetus* sp.	11	6.18
IV	**Scelionidae**		
8	*Telenomus* sp. 2	68	38.20
V	**Eurytomidae**		
9	*Eurytoma* sp.	6	3.37
VI	**Chalcididae**		
10	*Dirhinus anthracia*	1	0.56
VII	**Proctutropidae**		
11	*Nothoserphus* sp.	1	0.56
VIII	**Trichogrammatidae**		
12	*Trichogramma chilonis*	23	12.92
Total		**178**	**100**

Table 15. Per cent species composition of hymenopteran parasitoids recorded from different crop ecosystems during 2021-2023

Sl. No.	Name of crop	No. of species	Percentage
1	Rice (*Oryza sativa*)	4	9.52
2	Maize (*Zea mays*)	12	28.57

3	Cabbage (*Brassica oleracea*)	5	11.90
4	Cotton (*Gossypium hirsutum*)	5	11.90
5	Coconut (*Cocos nucifera*)	1	2.38
6	Brinjal (*Solanum melongena*)	6	14.29
7	Cashew (*Anacardium occidentale*)	4	9.52
8	Crape jasmine (*Tabernaemontana divaricata*)	1	2.38
9	Tobacco (*Nicotiana tabacum*)	1	2.38
10	Field bean (*Vicia faba*)	2	4.76
11	Soybean (*Glycine max*)	3	7.14
12	Arecanut (*Areca catechu*)	1	2.38
13	Cocoa (*Theobroma cacao*)	2	4.76
14	Bhendi (*Abelmoschus esculentus*)	1	2.38
15	Pongamia (*Pongamia pinnata*)	1	2.38
Total			**100**

Table 16. Per cent species composition of hymenopteran parasitoids recorded from different crop ecosystems in Shivamogga district during 2021-2023

Sl. No.	Name of crop	No. of species	Percentage
1	Rice (*Oryza sativa*)	2	8.00
2	Maize (*Zea mays*)	8	32.00
3	Cabbage (*Brassica oleracea*)	1	4.00
4	Coconut (*Cocos nucifera*)	1	4.00
5	Cashew (*Anacardium occidentale*)	4	16.00
6	Crape jasmine (*Tabernaemontana divaricata*)	1	4.00
7	Tobacco (*Nicotiana tabacum*)	1	4.00
8	Field bean (*Vicia faba*)	2	8.00
9	Soybean (*Glycine max*)	3	12.00

10	Cocoa (*Theobroma cacao*)	2	8.00
11	Bhendi (*Abelmoschus esculentus*)	1	4.00
12	Pongamia (*Pongamia pinnata*)	1	4.00
Total			**100**

Table 17. Per cent species composition of hymenopteran parasitoids recorded from different crop ecosystems in Davanagere district during 2021-2023

Sl. No.	Name of crop	No. of species	Percentage
1	Rice (*Oryza sativa*)	2	12.50
2	Maize (*Zea mays*)	2	12.50
3	Cabbage (*Brassica oleracea*)	5	31.25
4	Brinjal (*Solanum melongena*)	6	37.50
5	Arecanut (*Areca catechu*)	1	6.25
Total			**100**

Table 18. Per cent species composition of hymenopteran parasitoids recorded from different crop ecosystems in Chitradurga district during 2021-2023

Sl. No.	Name of crop	No. of species	Percentage
1	Maize (*Zea mays*)	7	58.33
2	Cotton (*Gossypium hirsutum*)	5	41.67
Total			**100**

Table 19. Diversity indices for hymenopteran parasitoids recorded during 2021-2023

Diversity indices	Shivamogga	Davanagere	Chitradurga
Total number of individuals (N)	455	747	178
Number of species (S)	26	16	12
Shannon-Weiner index (H)	2.49	1.69	1.34
Simpson diversity index (D)	0.88	0.75	0.54

Evenness (J)	0.46	0.24	0.45
Margalef’ s index	4.09	2.27	2.12
Menhinick’s index	1.22	0.90	0.59

Table 14. Per cent species composition of hymenopteran parasitoids collected from different host stages of insects during 2021-2023

Sl. No.	Host stage of insect	Overall		Shivamogga		Davanagere		Chitradurga	
		No. of species	Percentage	No. of species	Percentage	No. of species	Percentage	No. of species	Percentage
1	Egg	9	21.43	8	32.00	3	18.75	2	16.67
2	Larva	20	47.62	12	48.00	4	25.00	9	75.00
3	Pupa	6	14.29	2	8.00	3	18.75	1	8.33
4	Adult	7	16.67	3	12.00	6	37.50	0	0.00
Total		**42**	**100**	**25**	**100**	**16**	**100**	**12**	**100**

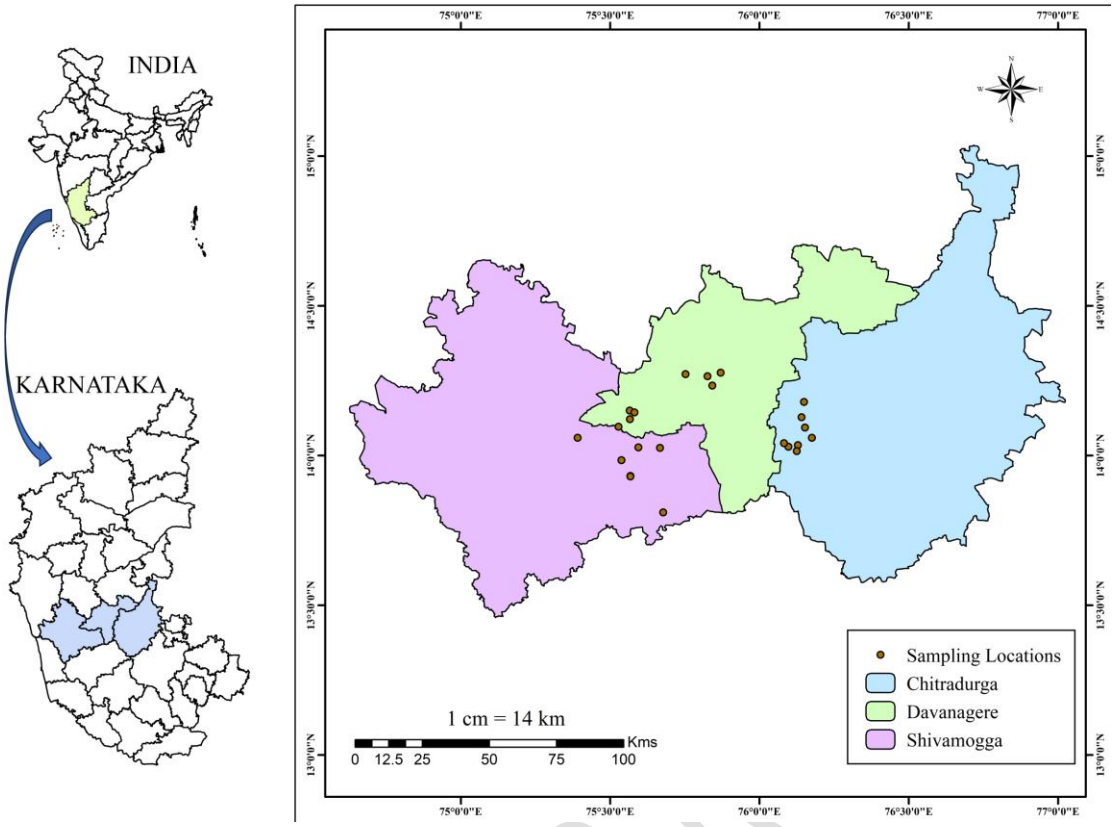

Figure 1. Locations of survey of hymenopteran parasitoids in the study

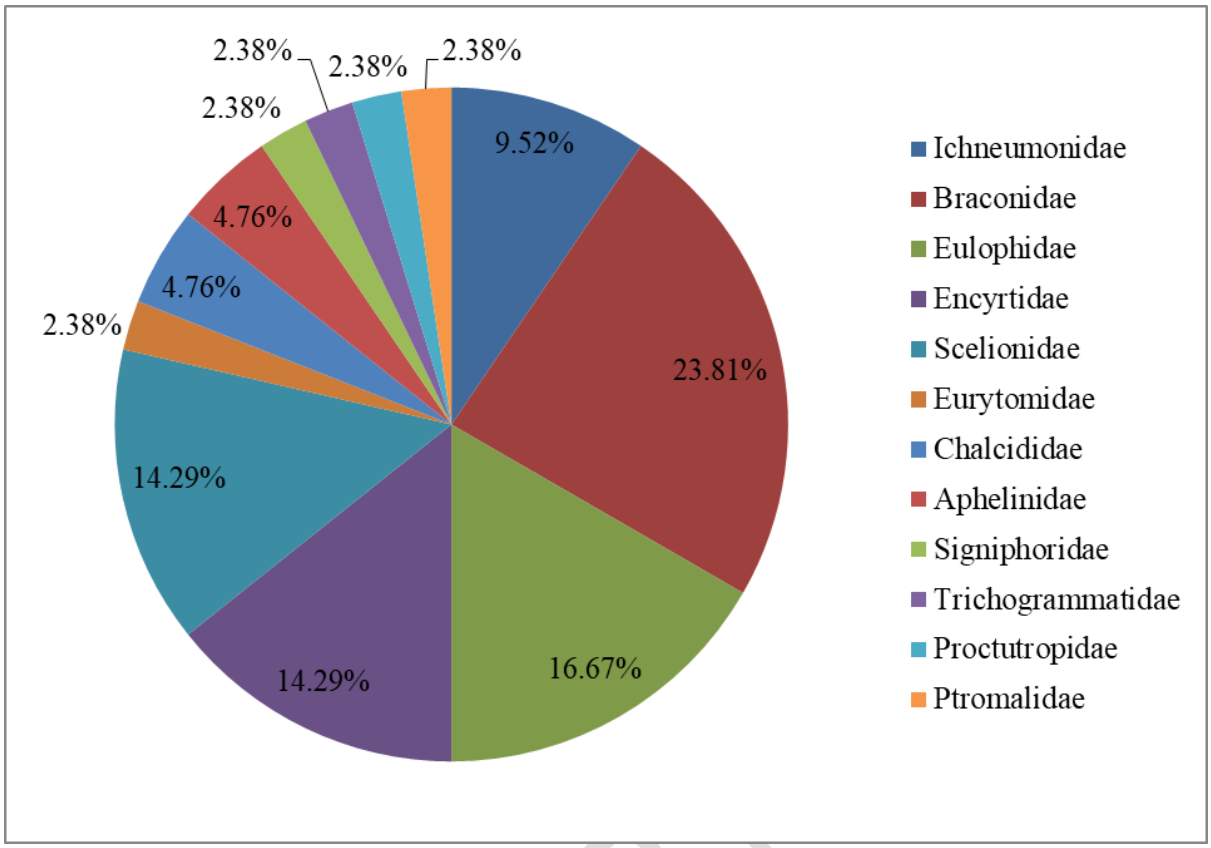

Figure 2. Per cent species composition of parasitic hymenopteran families recorded during 2021-2023

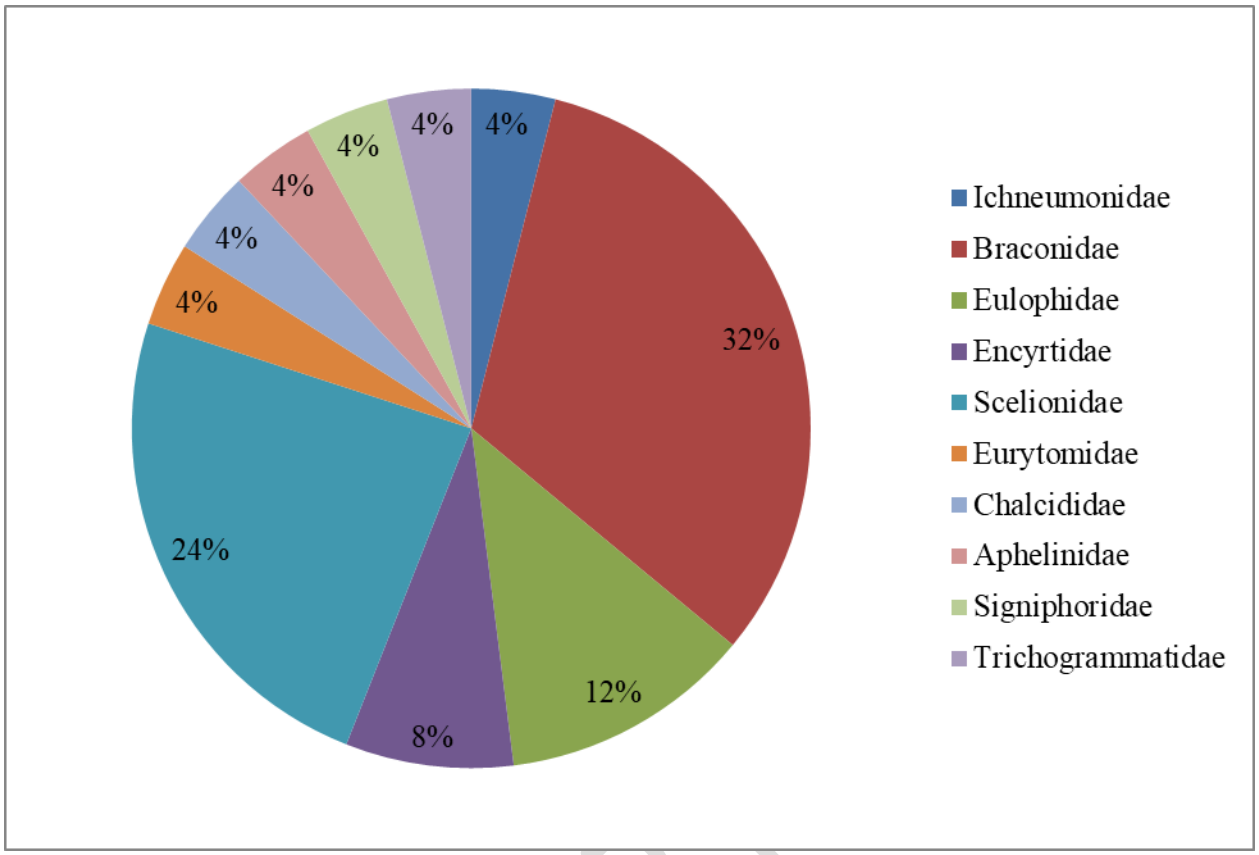

Figure 3. Per cent species composition of parasitic hymenopteran families recorded in Shivamogga district during 2021-2023

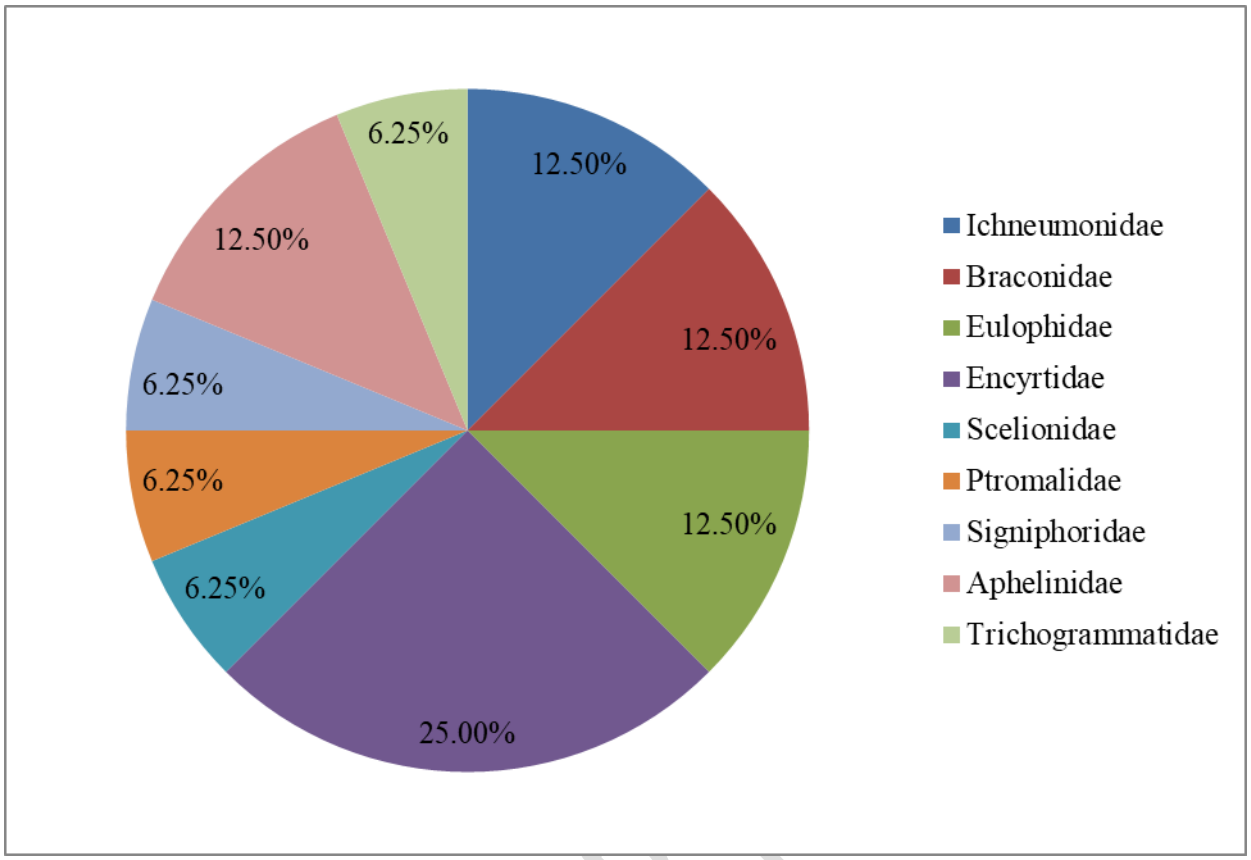

Figure 4. Per cent species composition of parasitic hymenopteran families recorded in Davanagere district during 2021-2023

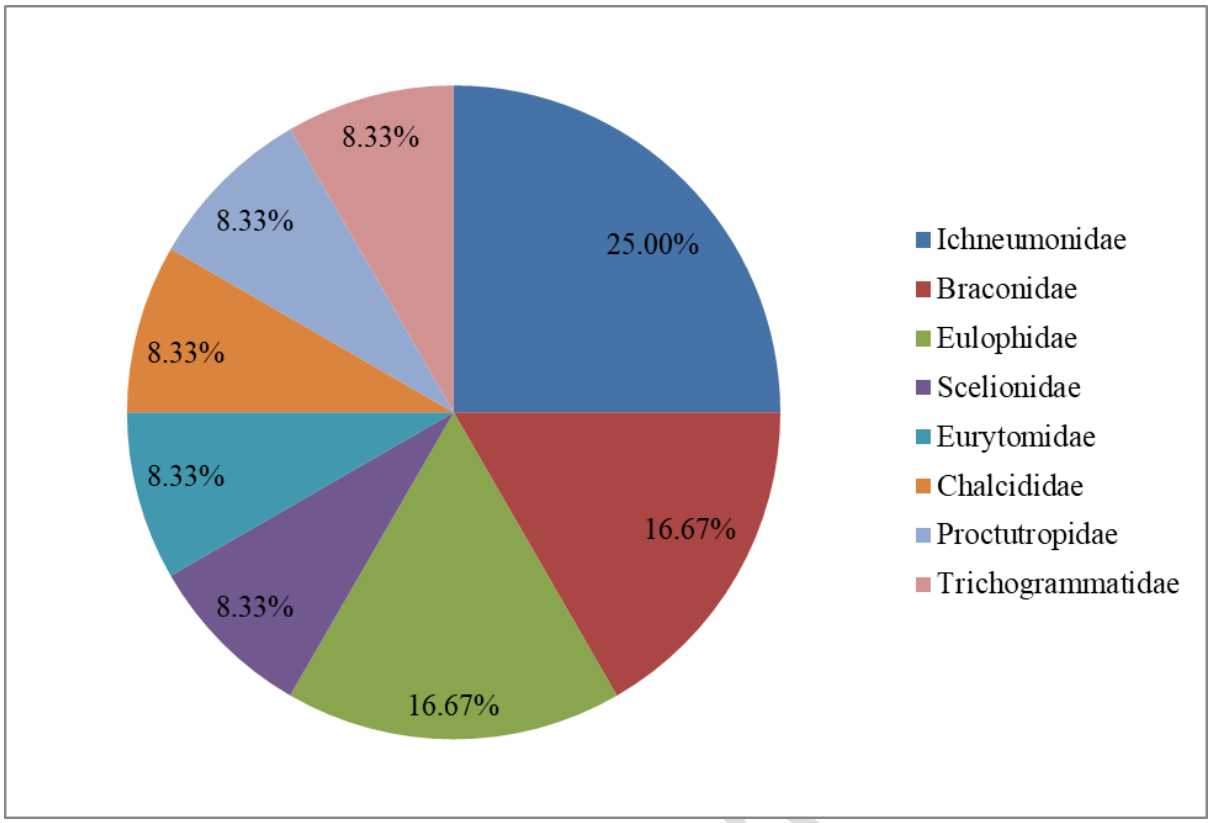

Figure 5. Per cent species composition of parasitic hymenopteran families recorded in Chitradurga district during 2021-2023