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Insect pollinator fauna of coriander (*Coriandrum sativum* L.) ecosystem

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Abstract
Insect pollinator fauna, their diversity and abundance was studied in coriander during *rabi* 2018-19 at S.V. Agricultural College, ANGRAU, Tirupati. Coriander flowers were visited by ten species of insects belonging to four orders. The family, Apidae constituted the major pollinators among the total pollinator guild. Within Apidae, Indian bee (*Apis cerana indica* F.) was most abundant followed by little bee (*A. florea* F) and Stingless bee (*Tetragonula iridipennis* Smith). Foraging activity of major floral visitors began from 07.00 h, Indian bee exhibited a bimodal peak within a day between 09.30-11.05 h and 15.30-17.05 h, whereas, *A. florea* and *T. iridipennis* showed single peak during 12.30-14.05 h and 09.30-13.30 h, respectively. Shannon-Wiener diversity index (H) remained less in the early hours following an increase later in the day and then, remained same throughout the day with two small peaks in the morning and noon hours. Berger-Parker dominance (d) and "H" index increased with increasing per cent floral abundance.

Keywords: Coriander, diversity, dominance, abundance, pollination and pollinators

1. Introduction
Pollination is one of the important service to increase crop productivity, environment conservation and ecosystem balance. Gates (1917) [13] warned the crop growers that, "without pollinating agents, chief among which are the honey bees, to transfer the pollen from the stamens to the pistil of the blooms, the crop may fail." This statement marked the importance of pollination that, in the absence of pollinators, it not only results in reduced yields but also in a high percentage of culls or inferior fruits (McGregor, 1976) [18]. About three-fourths of angiosperms (more than 115 leading crops) rely on animal vectors to move pollen among flowers, a form of indirect control mediated through pollinators, mainly insects (Campbell and Dooley, 1992) [6], whereas, only 28 crop species are self-pollinated (Klein *et al*., 2007) [16]. The hindrance in cross pollinated crops to set fruit or seed can be conquered by introducing external agents called pollinators. Bees act as cost free external agents in agriculture and forest system holding lion's share among other agents rendering pollination service to crop plants (Melinichenko, 1977) [20] in sustainable manner.

Coriander (*Coriandrum sativum* L.) is an annual herbaceous plant being popularly called with 'Dhania' in north India, 'Dhaniyalu' in Andhra Pradesh, 'Dhana' in Bengal, and 'Kothambari' in Karnataka (Evans *et al.*, 2002) [12]. Its origin is thought to be eastern Mediterranean and it is cultivated more in India, Morocco, Russian, European countries and USA (Coskuner and Karababa, 2007) [9]. Coriander flowers are hermaphrodite, protandrous and this nature made the crop to depend on cross pollination as protandry precedes stigma receptivity making flowers to depend pollen from other flowers (Blade, 2008 [5]; Wierdak, 2013 [28]). A number of insects were reported to be responsible for coriander pollination majorly including few honeybee species (Khaled, 2008) [15]; *i.e.*, Indian bee, little bee, European bee and stingless bees (Deodikar and Suryanarayana, 1977 [10]; Shelar and Suryanarayana, 1981 [26]; Shivashankara *et al.* 2015) [27] and other few flower visiting species though not contributing for higher fruit set like syrphids and dipteran flies, moths and butterflies, Coleopterans like Coccinellids (Chaudhary and Singh, 2006) [7].

Ever increasing demand for coriander green leaves and seeds for culinary, medicinal, essential oils, antibacterial, antifungal and antioxidant activities (Mandal and Mandal, 2015) [17] are creating huge demand for this crop. Since, it is highly cross pollinated crop, floral visitors plays vital role in seed set and in getting higher yields.

Information on flower visitors, pollinators including their diversity and abundance from Andhra Pradesh is not exists, hence, there is more scope to explore and identify the native flower visiting species of coriander in India and in particular from this state being more popular for delicious spice recipes. Hence, this study emphasize on identification of local pollinator diversity, their abundance and foraging behavior of insect species visiting coriander flowers which may help to encourage the native pollinators.

2. Materials and Methods

2.1 Experimental site and crop

Investigation was carried out during *rabi* 2018-19 at Insectary, Department of Entomology, Sri Venkateswara Agricultural College, Tirupati a campus under ANGRAU, Guntur (AP, India). The experimental site is situated at an altitude of 189.2 m above MSL, 13^0N latitude and 79^0E longitude, geographically receiving 905 mm rainfall annually. The coriander variety Suguma (LCC-236) was sown with a spacing of 30×10 cm. Before sowing, the seeds were crushed into halves by gently rubbing between palms, presoaked overnight and were shade dried and further they were treated with combi-product of Carbendazim and Mancozeb (Companion) @ 2 g/ kg seed. Sowing was done manually with a seed rate of 10 kg/ ha. Thinning was done 30 days after sowing to ensure plant to plant distance at 10 cm. Other recommended agronomical practices except plant protection measures were taken periodically to raise the crop.

2.2 Flower visitors and pollinators fauna of coriander

Two methods namely, sweep net sampling and visual counting of insect species visiting coriander flowers in open pollination treatment plots was done by randomly selecting sampling spots of one meter square each. Five such spots were considered for each observation interval (Belavadi and Ganeshaiah, 2013) [2]. Visual count on insect pollinators was recorded for five minutes in each sampling spots and was repeated at 0630 h, 0930 h, 1230 h and 1530 h. The same observations were repeated at four days interval which represented 25, 50, 75 and 90 per cent of flowering, commencing from three days after commencement of flowering to till 90 per cent flowering (Revanasidda and Belavadi, 2019) [22]. During the period of observations, pollinators visiting the crop were collected, preserved and identified with the help of available taxonomic keys and Insect Taxonomists. Observations were recorded in pollinator data sheet using stopwatch.

2.3 Diversity of flower visitors

Data collected on species using visual count method was used to work out Shannon-Weiner diversity (1963) [24] 'H' index which is a measure of diversity that combines species richness (the number of species in a given area) and their relative abundances. In general, it depicts the existing species diversity in an ecosystem/community normally calculated through following formula.

Shannon-Weiner [11] (1963) [24] Diversity Index (H) = Σ (ln pi × pi)

Where, pi is the proportion of the i^{th} species of pollinator ln is the natural log with base e.

2.4 Dominance of flower visitors

The dominant species on any given sampling day was determined by the Berger-Parker dominance index 'd', which gives the proportion of the total numbers of individuals in a sample that is due to the dominant species and was calculated by.

Berger-parker (1970) [3] Dominance Index (d) = n_i / NT

Where n_i is the number of individuals of the i^{th} species on sampling date and NT is the total number of individuals in the sample.

2.5 Relative abundance of insect pollinators

The relative abundance of the flower visiting insect species on umbels of coriander were recorded from 0630 to 1530 h at three hourly intervals during peak flowering period. Each spots with one square meter area were demarcated in the crop area (methods followed with slight modifications from Revanasidda and Belavadi, 2013) [22] and all the insect visitors landing on coriander flowers were recorded in each spot and the collected data was used to work out the mean and expressed as mean number of pollinators visited per square meter per five minutes and the pooled data for four different time intervals were grouped (0630 h, 0930 h, 1230 h and 1530 h) and converted to hourly data to work out relative abundance.

3. Results and Discussion

3.1 Flower visitors and pollinators fauna of coriander

Coriander flowers were visited by ten species of insects belonging to four Orders, five families. Among these insects, five species belong to Hymenoptera, one species belong to Diptera, two species belongs to Coleoptera and two species belongs to Lepidoptera. Among the Hymenopterans, five species *viz., Apis cerana indica, A. florea, A. mellifera, Tetragonula iridipennis* and *Braunsapis sp.* belongs to Apidae family. In case of Order Diptera, *Stomorhina sp.* (Calliphoridae). Whereas, the order Coleoptera consisted of two species (*Coccinella transversalis* and *Micraspis discolor*) of insect pollinators belonging to Coccinelidae family. Lepidopterans consisted of two species of flower visitors, one species each belongs to family Lycaenidae (*Polyommatus icarus*) and the other to Pieridae (*Catopsilia pomona*) (Table 1, Plates 1). Overall, *Apis* species observed more to forage on coriander ecosystem. Similar reports were given by Ricciardelli *et al*. (1979) [23] that *Apis florea, A. cerana indica* and *Tetragonula iridipennis* were more active visitors. Interestingly, Chaudhary and Singh (2006) [8] reported 34 species of flower visiting species on coriander representing 18 families and 8 orders, but, in his report Dipterans were more active than Hymenopterans. Meena *et al*. (2015) [19] reported 24 and 25 species particularly more *Apis* species from semiarid and arid regions of Rajasthan, respectively. Bhowmik *et al.*, (2017) [4] claimed *Apis* species (66%) being more abundant on coriander followed by dipterans (29%) and coleopterans (5%), among them, honey bee species, *A. cerana* (29%) being more abundant followed by *A. dorsata* (22%) and *A. mellifera* (15%).

Table 1: Diversity of insect pollinator species of coriander at S.V. Agricultural College, Tirupati

Order	Family	Species
Hymenoptera	Apidae	*Apis cerana indica* F.
		A. florea F.
		A. dorsata F.
		Tetragonula iridipennis Smith
		Braunsapis sp.
Coleoptera	Coccinellidae	*Coccinella transversalis*
		Micraspis discolor
Diptera	Calliphoridae	*Stomorhina sp.*
Lepidoptera	Lycaenidae	*Polyommatus icarus*
	Pieridae	*Catopsilia pomona*

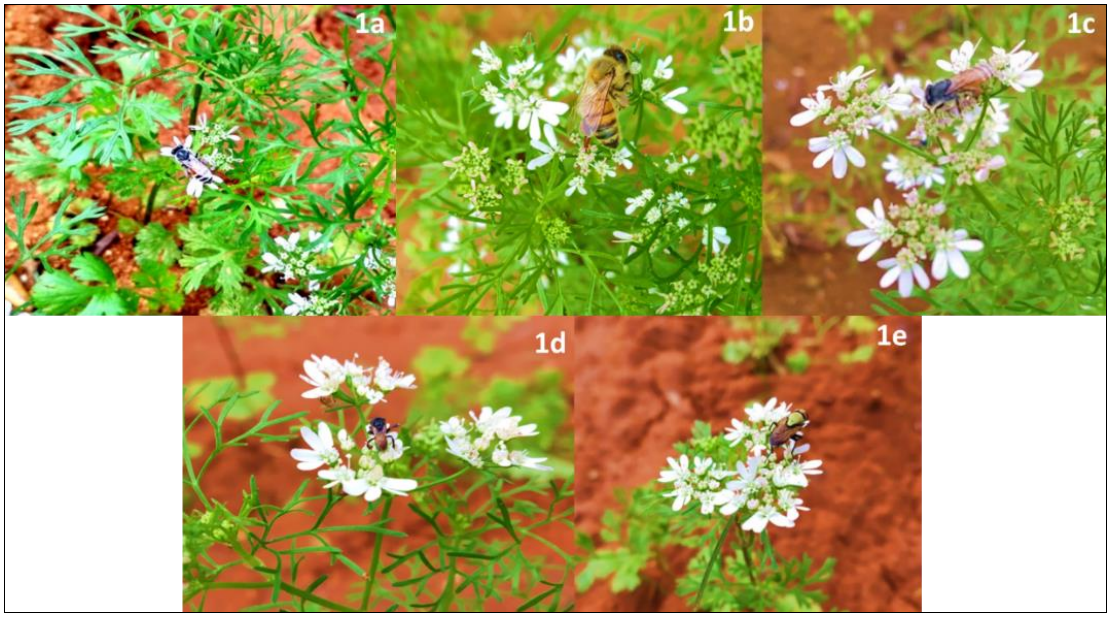

Plate 1: a. *Apis florea*, 2. *Stomorhina* sp., 3. *A. cerana indica*, 4. *Tetragonula iridipennis*, 5. *Coccinella transversalis* and 6: *A. mellifera*

3.2 Relative abundance of insect pollinators during different floral density under open condition

During twenty five per cent flowering in the open pollinated crop, the most abundant species observed was *A. cerana indica* (3.40 ±1.34 to 33.40 ±5.94 visitors/ m^2) followed by *A. florea* (1.40 ±2.19 to 23.40 ±4.22 visitors/ m^2); *T. iridipennis* (1.60 ±1.67 to 9.40 ±1.14 visitors/ m^2); Fly (0.60 ±0.89 to 2.00 ±1.58 visitors/ m^2) and *A. mellifera* (0.40 ±0.55 to 1.40 ±2.19 visitors/ m^2 area) (Table 2, Figure 1). During fifty per cent flowering, the most abundant species observed was *A. cerana indica* (1.40 ±2.19 to 28.40 ±4.39 visitors/ m^2) followed by *A. florea* (0.80 ±1.30 to 19.00 ±4.64 visitors/ m^2); *T. iridipennis* (1.40 ±2.19 to 10.20 ±2.39 visitors/ m^2); Fly (1.00 ±0.7 to 2.00 ±1.5 visitors/ m^2) and *A. mellifera* (0.40 ±0.55 to 1.20 ±1.30 visitors/ m^2) (Table 2, Figure 1). During seventy five per cent flowering, the most abundant species observed was *A. cerana indica* (2.20 ±2.00 to 31.00 ±4.90 visitors/ m^2) followed by *A. florea* (0.80 ±1.30 to 19.40 ±5.08 visitors/ m^2); *T. iridipennis* (1.80 ±1.79 to 11.80 ±2.28 visitors/ m^2); Fly (1.20 ±1.30 to 2.40 ±1.67 visitors/ m^2) and *A. mellifera* (0.40 ±0.55 to 1.00 ±1.00 visitors/ m^2) (Table 2, Figure 1). During more than ninety per cent flowering in the open pollinated crop, the most abundant species observed was *A. cerana indica* (1.40 ±2.07 to 28.00 ±3.08 visitors/ m^2) followed by *A. florea* (1.40 ±2.19 to 21.61 ±3.32 visitors/ m^2); *T. iridipennis* (2.00 ±1.22 to 11.60 ±2.4 visitors/ m^2); Fly (1.00 ±0.71 to 1.80 ±1.6 visitors/ m^2) and *A. mellifera* (0.40 ±0.55 to 1.40 ±1.14 visitors/ m^2) (Table 2, Figure 1). Bhowmik *et al.*, (2017) [4] reported *A. cerana* with 9.48 bees/ 9 m2/10 min, followed by *A. mellifera* with 7.35 bees/9 m2/10 min and *A. dorsata* with 2.08 bees/9 m2/10 min in coriander ecosystem.

Table 2: Relative abundance of different insect visitors at different hours of the day at 25, 50, 75 and >95% per cent floral density of coriander during *rabi* 2018-19

Species/Time	*A. cerana indica*	*A. florea*	*A. mellifera*	*T. irridipennis*	*Stomorhina sp*	*Coccinella transversalis*	*Micraspis discolor*	*Polyommatus icarus*	*Catopsilia pomona*	*Braunsapis sp.*
During 25% flowering										
06:30-08.05	3.40±1.34	1.40±2.19	0.40±0.55	1.60±1.67	0.60±0.89	0.20±0.45	0.00±0.00	0.00±0.00	0.00±0.00	0.40±0.55
09:30-11:05	33.40±5.94	14.20±3.56	1.40±2.19	9.40±1.14	1.60±1.14	0.40±0.55	0.20±0.45	0.20±0.45	0.20±0.45	0.60±0.89
12:30-14:05	14.40±1.95	23.40±4.22	0.60±0.89	6.00±2.65	2.00±1.58	0.40±0.89	0.00±0.00	0.20±0.45	0.00±0.00	0.40±0.55
15:30-17:05	19.00±5.57	10.60±3.65	0.00±0.00	2.40±0.55	1.20±0.84	0.00±0.00	0.00±0.00	0.20±0.45	0.20±0.45	0.60±0.89
During 50% flowering										
06:30-08.05	1.40±2.19	0.80±1.30	0.40±0.55	1.40±2.19	1.80±1.64	0.20±0.45	0.00±0.00	0.00±0.00	0.00±0.00	0.60±0.55
09:30-11:05	28.40±4.39	13.20±3.42	1.20±1.30	10.20±2.39	2.00±1.58	0.40±0.55	0.20±0.45	0.00±0.00	0.00±0.00	0.60±0.89
12:30-14:05	14.40±3.85	19.00±4.64	0.80±0.84	7.20±3.56	1.00±0.71	0.00±0.00	0.20±0.45	0.00±0.00	0.20±0.45	0.60±0.89
15:30-17:05	15.00±4.64	9.80±4.09	0.60±0.89	2.60±1.34	1.00±1.00	0.20±0.45	0.00±0.00	0.00±0.00	0.00±0.00	0.40±0.55
During 75% flowering										
06:30-08.05	2.00±2.00	0.80±1.30	0.40±0.55	1.80±1.79	1.20±1.30	0.20±0.45	0.00±0.00	0.00±0. 00	0.20±0.45	0.20±0.45
09:30-11:05	31.00±4.90	13.60±4.22	0.80±1.10	11.80±2.28	2.40±1.67	0.20±0.45	0.20±0.45	0.20±0.45	0.00±0.00	0.60±0.89
12:30-14:05	15.80±3.83	19.40±5.08	0.80±1.30	7.40±1.95	1.40±1.52	0.20±0.45	0.20±0.45	0.20±0.45	0.00±0.00	0.60±0.55
15:30-17:05	17.00±4.95	8.80±3.03	1.00±1.00	2.60±0.89	1.40±0.89	0.20±0.45	0.00±0.00	0.20±0.45	0.00±0.00	0.80±0.84
During >95% flowering										
06:30-08.05	1.40±2.07	1.40±2.19	0.40±0.55	2.00±1.22	1.20±1.30	0.20±0.45	0.00±0.00	0.00±0.00	0.20±0.45	0.40±0.55
09:30-11:05	28.00±3.08	14.00±3.32	1.00±0.71	11.60±2.41	1.80±1.64	0.20±0.45	0.00±0.00	0.20±0.45	0.20±0.45	0.80±0.84
12:30-14:05	16.40±2.61	21.60±5.22	1.40±1.14	10.00±1.41	1.60±1.14	0.00±0.00	0.20±0.45	0.00±0.00	0.00±0.00	0.60±0.89
15:30-17:05	16.40±5.22	7.80±2.95	0.60±0.55	2.40±1.14	1.00±0.71	0.20±0.45	0.00±0.00	0.00±0.00	0.00±0.00	0.60±0.55

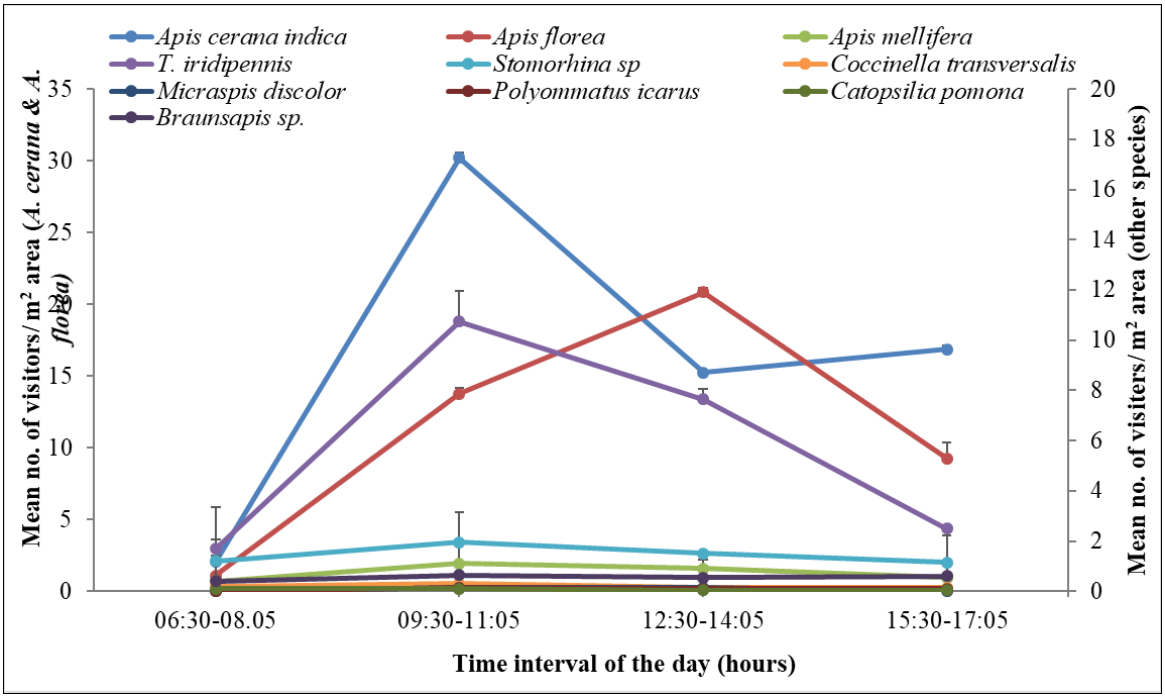

Fig 1: Abundance of insect pollinator species of coriander during flowering period

3.3 Relative abundance of flower visitors within a day

The observations showed that, within a day the abundance of flower visiting species was more between 0930-1105 h for most of the species except for *A. florea* which was comparatively more abundant during hotter hours of the day between 1230-1405 h. The species belonging to genus *Apis* was more dominant when compares to other species visiting coriander flower, but, interestingly stingless bee was equally abundant with little bees. The remaining species visiting coriander flowers namely coccinellids, lycanids and some species of wasps were negligible in abundance. The overall species abundance was higher between 0900 to 1400 h (Figure 1).

Devi *et al.*, (2015) [11] mentioned dipterans being most abundant and the relative abundance (by visual sampling) and diversity (by sweep net method) in general was statistically higher at 1000 h than at 1200 and 1500 h. Bhowmik *et al.*, (2017) [4] reported that flower visitors on coriander were active all along the day but a peak was observed between 1000-1100 h. In other study, the activity of flower visitors were more at 1100 h followed by at 1000 h. Among different bee species, the abundance of *A. florea* was reported from 0900 to 1200 h and from 1600 to 1800 h with maximum abundance at 1000 h. The abundance of *A. dorsata* was observed from 0900 h to 1200 h and from 1500 h to 1800 h with maximum abundance at 1100 h (Patil and Patagia, 2016) [21]. In the present study, the relative abundance of different species of honeybee's *viz.*, *A. cerana indica*, *T. iridipennis* and other pollinators during the study period were in increasing trend from 0700 h onwards and reached maximum during 0930-1105 h. Within two species, *viz.*, *A. cerana indica* and *A. florea*, the former species was the first to start its activity than latter and the peak activities of *A. cerana indica* was observed during 0930-1105 h and 1530-1705 h, whereas, for *A. florea*, activity reached peak during hotter hours (1230-1405 h) of the day. There was a perfect interspecific temporal competition avoidance within a day for resource was observed between these two species in coriander ecosystem. In case of *T. iridipennis*, the foraging activity reached peak 0930-1330 h. and the other insect pollinators were active more or less throughout the day with negligible numbers.

3.4 Shannon-Weiner Diversity index (H) of flower visitors during different floral density across flowering period in coriander

The Shannon-Weiner Diversity Index (H) of flower visitors in coriander remained more or less same across floral density period (Table 3). The H value during 25 per cent flowering was 0.01, 0.50, 0.35 and 0.24 during 6:30-8:05, 9:30-11:05, 12:30-14:05 and 15:30-17:05 h, respectively. The H value during 50 per cent flowering was 0.00, 0.49, 0.35 and 0.21 during 6:30-8:05, 9:30-11:05, 12:30-14:05 and 15:30-17:05 h, respectively. The H value during 75 per cent flowering was 0.00, 0.51, 0.34 and 0.21 during 6:30-8:05, 9:30-11:05, 12:30-14:05 and 15:30-17:05 h, respectively. The H value during >90 per cent flowering was 0.00, 0.47, 0.41 and 0.19 during 6:30-8:05, 9:30-11:05, 12:30-14:05 and 15:30-17:05 h, respectively. At each floral density, the index was more during late morning and forenoon hours i.e., 09:00 to 14:00 h (H value, 0.47 to 0.51) and it was decreased as time approached towards evening (Figure 2). Sharma *et al.* (2018) [25] reported that in coriander, the maximum foraging rate of *A. mellifera* was recorded (13.6 umbels visited min^{-1} and 3.10 plants per five minutes) followed by *A. dorsata* (10.66 and 2.80) and *A. florea* (9.80 and 2.55). Bhowmik *et al.*, (2017) [4] calculated H index for different orders and was 1.19 for Hymenoptera and 1.085 for order Diptera and he mentioned that higher H index for the order Hymenoptera indicated a rich and even distribution of its species.

Table 3: Shannon-Weiner Diversity Index (H) of insect visitors at different floral densities of coriander during *rabi* 2018-19

Floral density (%)/Time	25% Flowering	50% flowering	75% flowering	>90% flowering
06:30-08.05	0.01	0.00	0.00	0.00
09:30-11:05	0.50	0.49	0.51	0.47
12:30-14:05	0.35	0.35	0.34	0.41
15:30-17:05	0.24	0.21	0.21	0.19

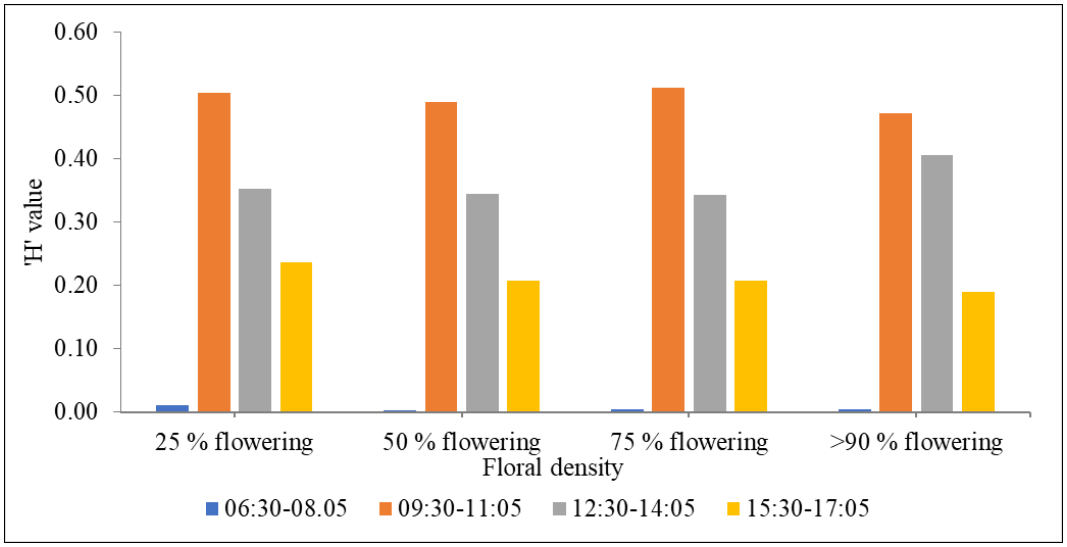

Fig 2: Shannon-Weiner Diversity Index (H) of insect visitors at different floral densities of coriander during *rabi* 2018-19

3.5 Dominance of flower visiting species on coriander at different floral density

The dominance (in numbers) of species across floral density period was varied. Among all the species of flower visitors *A. cerana indica* was more dominant (d = 0.29 to 0.54) followed by *A. florea* (d = 0.15 to 0.44) and *T. iridipennis* (d = 0.08 to 0.24). Other insect pollinator species were less dominant. Interestingly, stingless bees were more dominant during initial period of flowering than it came down as floral percent increased, whereas, this case is vice-versa in case of Indian and little bees. Both "d" and "1/d" values showed that the abundance (1/d values) of all the flower visitors increased with increase in flowering percentage across different weeks, whereas dominance (d) of major species decreased with increase in flowering percentage across different weeks (Table 4 and Figure 3).

The reports regarding dominance of coriander flower visitors except on report from Chaudhary and Singh (2006) [8] that Italian honeybee, *A. mellifera* was the most dominant species, followed by *E. balteatus* and unidentified Hymenopteran species. In other crops like onion, the observed Berger-Parker index was 0.288 (Karuppaiah *et al.*, 2018) [14]. In present study, during 25, 50, 75 and 90 per cent flowering, honeybee species were dominant visitors compared to other insect pollinators. Among honeybees, *A. cerana indica* was found to be dominant visitor, followed by *A. florea* and *T. iridipennis*. Insect pollinator foraging activity in coriander began from 07.00 h, the combined activity of *A. cerana indica*, *A. florea*, *T. iridipennis*, *Stomorhina sp.*, *A. mellifera* and other species remained more or less same throughout the day which H value to remain constant throughout the day as similarly reported by Revanasidda and Belavadi, V. V. (2019) [22].

Table 4: Dominance of insect species at different floral densities of coriander during *rabi* 2018-19

Floral density & Dominance/Species of visitor	25% Flowering		50% flowering		75% flowering		>90% flowering	
	d	1/d	d	1/d	d	1/d	d	1/d
A. c. indica	0.29	3.49	0.51	1.96	0.32	3.09	0.54	1.85
Apis florea	0.15	6.50	0.23	4.30	0.44	2.26	0.30	3.37
Apis mellifera	0.06	17.88	0.02	53.73	0.02	52.39	0.02	56.73
T. iridipennis	0.24	4.21	0.18	5.50	0.16	6.16	0.08	12.48
Stomorhina sp	0.17	5.96	0.03	30.31	0.03	31.43	0.04	27.13
Coccinella transversalis	0.03	35.75	0.01	197.00	0.00	314.33	0.00	208.00
Micraspis discolor	0.00	0.00	0.00	394.00	0.00	314.33	0.00	0.00
Polyommatus icarus	0.00	0.00	0.00	394.00	0.00	471.50	0.00	312.00
Catopsilia pomona	0.01	71.50	0.00	591.00	0.00	943.00	0.00	624.00
Braunsapis sp.	0.06	17.88	0.01	90.92	0.01	85.73	0.02	52.00

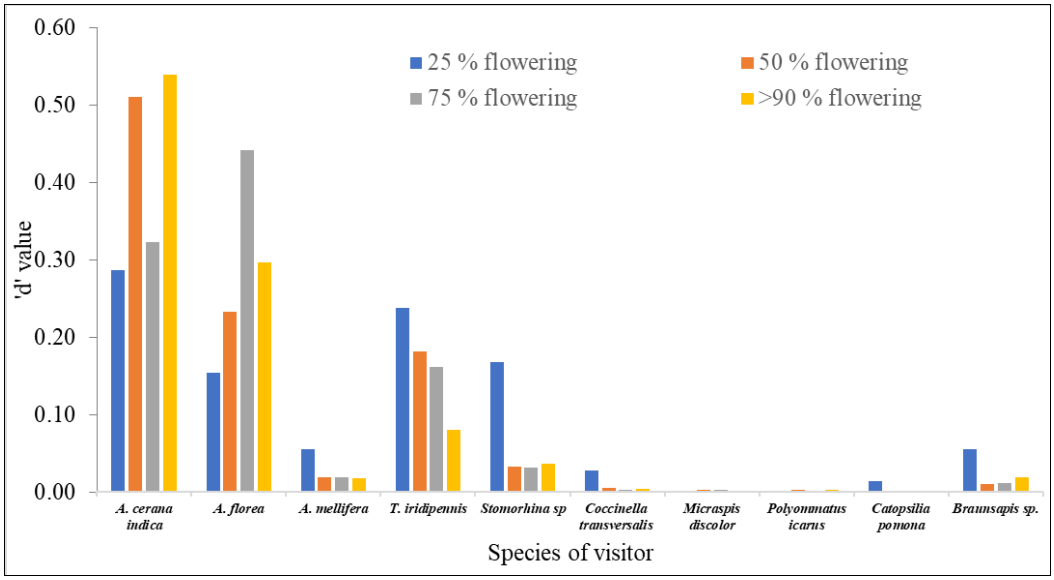

Fig 3: Dominance of insect visitors at different floral densities of coriander during *rabi* 2018-19

5. Conclusion

In the present study, coriander flowers visited by a set of pollinator species. Interestingly, variations between previous reports and results of the present study related to coriander pollinators fauna is may be due to change in the crop species, type of variety used, floral color, floral reward, climatic condition, existing foraging source and native pollinator's guilds. In this study, we observed both by-choice and by-chance floral visitors during the observation. The five insect species belongs to order Hymenopterans were major among total pollinators guild and *A. cerana indica* being most abundant. Present observations on the type of pollinator species helps to know about native pollinators species and to conserve the pollinators naturally or artificially by rearing them and to schedule specific agrochemical practices that could encourage insect pollinators and enhance the yield of coriander. This study further opens a window to know foraging behavior of pollinators, efficient species and the local flora which can encourage more pollinators on this cross pollinated crop.

6. References

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