Eco. Env. & Cons. 29 (2) : 2023; pp. (964-971)
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ISSN 0971–765X

DOI No.: http://doi.org/10.53550/EEC.2023.v29i02.070

Diversity and foraging behaviour of insect pollinators in Cauliflower

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(Received 22 February, 2023; Accepted 2 April, 2023)

ABSTRACT

Cauliflower is a cross-pollinated crop and honey bees play an important role in its pollination. In the current study, we studied we studied diversity and foraging behavior of floral visitors to floral visitors along with their visitation rate, frequency during 2019 and 2020. The data were collected at 0800–1000 hours (early morning foraging activity), 1000-1200 hours (late morning foraging activity), 1200-1400 hours (Noon foraging activity) and 1400-1600 hours (afternoon foraging activity). The results revealed that seven species of bees, five flies and three wasp species on the flowers of cauliflower. *Apis mellifera*, *Apis dorsata* and Apis florea were the dominant pollinator species with 162-214, 126-164, and 82-136 individuals, respectively in both years. The maximum foraging activity of the dominant pollinators was observed at 14:00 hrs followed by 12:00 hrs whereas the minimum foraging activity was recorded in the early morning hours 08:00. Floral visitors differed significantly in term of visitation frequency with *A. mellifera* as the most frequent visitor (14.00–15.37 visits/flower/5 min) followed by *A. dorsata* (7.50–8.90 visits/flower/5 min) and *A. florea* (9.80–10.63 visits/ flower/5 min) in both years. Similarly, *A. mellifera* had statistically highest visitation rate (26.93–27.40 flowers visited/min) followed by *A. dorsata* (12.62–15.13 flowers visited/min) and *A. florea* (15.93-16.00 flowers visited/min). The results suggested *A. mellifera, A. dorsata* and *A. florea* could be effective pollinators of cauliflower. Therefore, these three species can be effectively used on a commercial scale to increase crop yield.

Key words: *Cauliflower, Pollinator diversity and abundance, Visitation rate, Visitation frequency, Apis spp.*

Introduction

Cauliflower (*Brassica oleracea* var. *botrytis* L.) is one of the most consumed winter vegetable (Singh *et al.,* 2005). Due to its flavour, nutritional value, and many uses in addition to the alluring curd aroma, Indians prefer this vegetable. It is high in vitamin C, low in fat and calories, high in calcium, iron, and fibre. Farmers themselves may grow seeds of the open pollinated (OP) variety of cauliflower since it can produce seeds (Rouf *et al.,* 2016).

Cauliflower is a cross pollinated crop in which honeybees are responsible for the pollination (Singh *et al.,* 2005). A common issue with producing cauliflower seeds is low seed yield caused by insufficient pollination. Lack of sufficient numbers and

diversity of pollinators is the most significant of several factors that contribute to inadequate pollination (Sushil *et al.,* 2013). Due to their general incompatibility, insect pollination is required for the germination of cauliflower seeds (Sihag, 2001). Bees visit plants in search of nectar, pollen, and nourishment. Bees' preference for sugar-rich nectars and pollen with better nutritional qualities is the cause of their floral fidelity. Honey is the product that honey bees are most famous for making. However, the primary economic function of honey bees in nature is to pollinate countless numbers of flowering plants and guarantee both the quantity and quality of seed production. Because of their shared biology and life cycle, honey bees and blooming plants coexist. Honey bees receive nectar and pollen from flowering plants, and they fulfil their job by facilitating pollination and interspecies communication. However, honey bees continue to be more valuable to farmers due to the pollination services they provide, which boost crop yields both qualitatively and quantitatively (Sharmah *et al.,* 2015). In the seed fields of the cauliflower crop, supplemental pollination utilising honey bees assures good seed set, considerably increasing seed production.Researchers in open pollinated varieties have examined the efficiency of honey bees as pollinators for the production of cauliflower seeds (Adlakha and Dhaliwal, 1979: Kakar, 1981). Biopesticides, biocontrol agents and plant secondary metabolites that are relatively safer should be preferred for crop protection of during flowering stages to avoid any adverse effects on pollinator bees (Dukare *et al*., 2021; Divekar *et al*., 2022 a, b, Divekar *et al.,* 2021).

By ensuring adequate pollination, pollinators can significantly contribute to increasing crop productivity. Cauliflower hybrid seed production is feasible with the use of a saprophytic self-incompatibility system. Cross-pollination is encouraged by self-incompatibility whereas self-pollination is prevented. As an entomophilous crop, cauliflower attracts a variety of insect orders (Sharma *et al.,* 1974). Honeybees are the most common insect visitors to cauliflower (Verma and Joshi, 1983). According to earlier findings, honeybees can distinguish between parental lines when foraging and usually favour one over the other. Honeybee foraging efficiency is influenced by bee population density, foraging span, foraging rate, and pollen-carrying capacity. Environmental conditions significantly influence honeybee feeding behaviour (Sihag and Abrol, 1986). Limited information is available on insect pollinators, their abundance and foraging behaviour in cauliflower from Eastern Uttar Pradesh zone. The present investigation was therefore, carried out to document the diversity and abundance of insect pollinators; to study the pollinator behaviour in terms of visitation rate and visitation frequency of the dominant insect pollinators in cauliflower.

Material and Methods

Study site and experiment design

The studies were conducted at ICAR-IIVR, Regional Research Station, Sargatia, (Latitude NS 26° 43' 56.61 and Longitude EW 84°11' 12.95) Kushinagar, India. The field experiment was conducted by growing cauliflower var. Kashi Gobhi-25 during the spring season of 2019 (season 1) and 2020 (season 2). The crop was raised as per the recommended package of practices and the plant protection measures were not taken once the initiation of flowering started.

Floral visitors' abundance (total numbers of individuals of species in an area), were observed from 100 plants in the research field by randomly placing a quadrat of 1 m during 2019 and 2020. From each quadrat, 10 plants were selected for recording in situ observations on the abundance of insect pollinators. Non-destructive method of sampling was deployed for studying the insect pollinators. Species diversity was worked out by using different indices such as Margalef's index of richness (MI), Shannon-Wiener Diversity index (H), Simpson's index (D), Pielou's evenness index (J) and Berger-Parker index of dominance (d) by using standard formula (Pielou, 1975; Simpson, 1949, Henderson PA (2003).

The Engelmann's scale of dominance was used to evaluate the dominance structure of onion ecosystem as elaborated and used by Dalal and Gupta (2016). Based on relative abundance, the dominance structure was categorized into five scales as follows: Eudominant (>31.7%), Dominant (10.1–31.6%), Subdominant (3.2–10%), Recedent (1.1– 3.1%) and Subrecedent (<1%).

Abundance, visitation frequency and rate of floral visitors

The visitation frequency (Numbers of visits/flower/5 min) and visitation rate (Numbers of flowers visited/min) of insect pollinators were determined during January-February months in 2019 and 2020

by following the methodology of Tidke and Thorat (2011) and Saeed *et al.* (2012). Abundance of floral visitors was calculated by counting the total numbers of each floral visitor captured during the season. For visitation frequency of floral visitors, the numbers of visits per flower per 5 min were recorded by targeting 25 branches from five plants at 7 days interval with a total of 150 branches from 40 plants in six observations. All the floral visitors were captured and preserved for identification. The data of visitation frequency was recorded at 08:00, 10:00, 12:00, 14:00 and 16:00 h a day. However, for visitation rate, 40 readings of each floral visitor were taken at five times of the day (08:00, 10:00, 12:00, 14:00 and 16:00 h) on weekly basis with the help of stop watch. The flower visiting insects were captured with hand net, killed in killing bottle and preserved in ethanol for later identification. The insects were identified to genus level using keys of Michener (2000), Vockeroth (1996) and by experts to reach species level.

Data analysis

Data of visitation frequencyand visitation rate were subjected to two-way analysis of variance (ANOVA) where visitation frequency, visitation rate was explained as function of species and year. The statistical analysis was performed in Minitab version 18.00.

Results

Percent Abundance and Engelmann abundance of insect pollinators

The most abundant species on the flowers of cauliflower were *A. mellifera* (162-214 individuals) and *A. dorsata* (126-164 individuals) followed by *A. florea* (82-136 individuals) in the study duration years. The least abundant species were wasps, *V. vulgaris* (5-16 individuals), *V. cincta* (8-24 individuals) and Polystes spp. (13-21 individuals) (Table 1). On the basis of Engelmann abundance classification, the insect pollinators namely, *A. mellifera, A. dorsata* and *A. florea* were found to be in dominant class, *A. cerana*, *Tetragonula* spp. and *Xylocopa* spp. were observed in the Subdominant class. Pollinators namely, *Andreina* spp. *Megachile* spp, *Eristalinus aeneus, Ishiodon scutellaris, Eupeodes corolla, Stomorhina discolour, Vespa cincta*, and *Polystes* spp. were in Recedent class. However, *Vespula vulgaris* was found in Subrecedent class in 2019 as well as 2020.

Diversity indices of insect pollinators in cauliflower

The results of the assessment of insect pollinators using the different diversity index for in Kushinagar was summarized in Table 2. The index of alpha di-

Table 1. Diversity and Abundance of pollinators in Cauliflower at Sargatia, Kushinagar

Sr. No.	Group of insect pollinator	Insect Pollinator	Season 1			Season 2		
			No. of individuals	Percent Abundance	Engelmann abundance class	No. of individuals	Percent Abundance	Engelmann abundance class
1	Apis Hymenoptera/ group	Apis mellifera	162	25.31	D	214	25.00	D
2		*Apis dorsata*	126	19.69	D	164	19.16	D
3		*Apis florea*	82	12.81	D	136	15.89	D
4		*Apis cerana*	52	8.13	SD	52	6.07	SD
5		*Tetragonula* spp	43	6.72	SD	34	3.97	SD
6		*Xylocopa* spp	46	7.19	SD	46	5.37	SD
7		*Andreina* spp	17	2.66	R	24	2.80	R
8		*Megachile* spp	19	2.97	R	20	2.34	R
9	Flies	*Episyrphus balteatus*	24	3.75	SD	54	6.31	SD
10		*Eristalinus aeneus*	9	1.41	R	24	2.80	R
11		*Ischiodon scutellaris*	10	1.56	R	21	2.45	R
12		*Eupeodes corollae*	16	2.50	R	20	2.34	R
13	Syrphidae	*Stomorhina discolor*	19	2.97	R	23	2.69	R
14	Wasps	*Vespula vulgaris*	4	0.63	SR	8	0.93	SR
15		*Vespa cincta*	6	0.94	SR	9	1.05	SR
16		*Polystes* spp	5	0.78	SR	7	0.82	SR

D-Dominant; SD-Subdominant; RD- Recedent; SR- Subrecedent

versity including Shannon-Weiner, Berger-Parker, Margalef richness and Pielou'seveness index values were recorded as 1.00, 0.25, 2.31 and 0.36 during 2019 and 1.22, 0.22, 2.18 and 0.44 during 2020. Higher diversity index indicated a rich and even distribution of the species under order Hymenoptera.

Table 2. Diversity indices of insect pollinators in Sargatia, Kushinagar

Diversity indices	Season 1	Season 2
Margalef's Richness Index	2.31	2.18
Shannon-Weiner Diversity index	0.97	1.07
Pielou's Evenness Index	0.35	0.39
Berger-Parker dominance index	0.25	0.22

Visitation frequency

Significant differences were observed for the visitation frequency (no. of bees visited per flower per 2 min) at different time intervals (*A. mellifera*: F = 91.79, p<0.001; *A. dorsata*: F = 16.03, p<0.001; *A. florea*: F = 19.79, p<0.001). The data revealed that the visitation frequency of the *Apis* pollinators during different day hours varied between 3.53 to 10.00 for *A. mellifera*; 1.97-7.50 for *A. dorsata* and 2.80-9.80 for *A. florea* during 2019. Similarly, the treatment were significantly different in terms of visitation frequency for all the dominant insect pollinators during 2020 (*A. mellifera*: F = 51.73, p<0.001; *A. dorsata*: F = 24.45, p<0.001; *A. florea*: F = 30.04, p<0.001). The data revealed that the visitation frequency of the *Apis* pollinators during different day hours varied between 4.93-15.37 for *A. mellifera*; 1.90-8.90 for *A. dorsata* and 3.07-10.63 for *A. florea* during 2019 (Table 3).

The visitation frequency was relatively low in the early morning, 0800-1000 h (3.53 for *A. mellifera*; 1.97 for *A. dorsata* and 2.80 for *A. florea*) but rapidly increased throughout the afternoon and reached to an its peak at 1200-1400 h (10.00-14.00 for *A. mellifera*; 6.17-7.50 for *A. dorsata* and 7.53- 9.80 for *A. florea*) which differed significantly with other times of the day. Similar findings were observed in the second season. The highest visitation frequency was observed for *A. mellifera* followed by *A. dorsata* followed by *A. florea*. The higher visitation frequency indicates the higher efficiency in pollination of the crop.

Visitation rate

There is a significant difference in the visitation rate (no of flowers visited per 2 min) of Apis pollinators at different time intervals during 2019(*A. mellifera*: F = 81.85, p<0.001; *A. dorsata*: F = 53.72, p<0.001; *A. florea*: F = 116.35, p<0.001). The data revealed that the visitation rate of all the Apis species varied at different day hours between 4.37-26.93 for*A. mellifera*; 2.50-12.62 for *A. dorsata* and 2.43-15.93 for *A. florea* during 2019. Significant differences were noted in the visitation rate of Apis pollinators varied at different day time intervals during 2020 (*A. mellifera*: F = 59.96, p<0.001; *A. dorsata*: F = 41.78, p<0.001; *A. florea*: F = 40.41, p<0.001). The visitation rate of all the Apis species was varied at different day hours between 6.43-27.40 for *A. mellifera*; 1.67-15.13 for *A. dorsata* and 3.00-16.00 for *A. florea* during 2020.

The visitation frequency was relatively low in the early morning, 0800-1000 h (4.37 for *A. mellifera*; 2.50 for *A. dorsata* and 2.43 for *A.florea*) but rapidly increased throughout the afternoon and reached to an its peak at 1200-1400 h (18.10-26.93 for *A. mellifera*; 11.60-12.62 for *A. dorsata* and 14.13-15.93 for *A. florea*) which differed significantly with other times

Table 3. Mean values of visitation frequency of dominant pollinators *Apis mellifera, Apis dorsata* and *Apis florea* in cauliflower

Species	Visitation frequency			Visitation frequency		
Time interval	Season 1			Season 2		
	Apis mellifera	*Apis dorsata*	*Apis florea*	*Apis mellifera*	*Apis dorsata*	*Apis florea*
8.00	3.53±0.23	1.97±0.36	2.80±0.26	4.93±0.29	1.90±0.32	3.07±0.18
10.00	6.50±0.64	3.97±0.42	5.03±0.25	6.23±0.41	4.07±0.43	4.60±0.54
12.00	10.00±0.74	6.17±0.63	7.53±0.87	12.50±0.82	7.50±0.35	9.13±0.43
14.00	14.00±0.87	7.50±0.85	9.80±1.10	15.37±1.04	8.90±1.00	10.63±1.09
16.00	4.57±0.48	3.13±0.41	3.23±0.35	5.80±0.31	3.53±0.58	4.23±0.40
LSD	1.234	1.42	1.88	1.451	1.6	1.634
F	91.79	16.03	19.79	51.73	24.45	30.04
P	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

of the day. Similar findings were observed in the second season.

The highest visitation rate was observed for *A. mellifera* followed by *A. dorsata* followed by *A. florea.* The higher visitation rate indicates the higher efficiency in pollination of the crop.

Discussion

In the present investigation, honeybees, syrphids, flies and wasps were observed as insect pollinators in cauliflower. Sharma et al., 2019 also revealed that the pollination of the cauliflower seed crop was carried out by honeybees, syrphid flies, wild bees, and other insect pollinators (butterflies, moths, beetles, etc.). Among different pollinators, honeybees were most frequent visitors. The maximum number of honeybees were observed followed by syrphid flies and other insect pollinators (other wild bees). Pollinator foraging behaviour was favourably impacted by the maximum temperature (Sharma *et al.,* 2019). Karuppaiah *et al.,* 2017 reported that *A. dorsata, A. cerana indica*, *A. mellifera* and *A. florea* were the frequent insect pollinators in onion. Of which, *A. dorsata* was the predominant one. Similarly, Chaudhary 2002 reported that *Apis dorsata* was most dominant species (44.48%) followed by *Apis cerena indica* (41.86%) and *A. florea* (4.59%).

Our results showed that honeybees, A. *mellifera, A. dorsata* and *A. florea* were the predominant agents of pollination in hybrid cauliflower seed production. Similarly, Sinha and Chakraborti, 1980, Kumar *et al.* 1989 reported that honeybees were dominant pollinators of cauliflower. According to the region, the floral visitor fauna often differs, and this has been thoroughly investigated by many investigators. Giri *et al.* (2018) observed that hymenopterans (family Apidae namely; *A. dorsata, A. mellifera, Trigona irridipennis*) were the major floral visitors on mustard (*Brassica campestris* var. toria) with *A. dorsata* and *A. mellifera* being the most frequent visitors. Das and Jha (2018) recorded 13 insect species on Indian mustard out of which 6 species belonged to the order Hymenoptera (*A. dorsata, A. mellifera, A. cerana indica, A. florea, Ceratina* spp. and *Halictus* spp.), 5 species to order Diptera (*Episyrphus* spp., *Eristalinus tabanoides*, *Musca domestica*, *Chrysomya* spp. and *Sarcophaga* spp.) and 2 species to order Lepidoptera (*Amata bicincta* and *Pieris* spp.). Abrol and Bajiya (2017) found 15 species of insects belonging to 4 orders and 7 families of insects visiting mustard (*Brassica napus*) bloom. The majority of species were discovered to be hymenopterans.

The maximum foraging activity of honeybees was noted in the afternoon hours 12:00-14:00 whereas the minimum foraging activity was noted in the early morning hours 08:00. Our results are corroborated with the findings of Selvakumar et al 2006 who reported that honeybees visited more flowers per plant in the afternoon (17.79) than morning (15.16) in 2001–2002. The finding of Murrell and Nash (1981) provide strong support for the findings of the current investigation, reporting that nectar foragers in *B. campestris* were only low (16%) in the morning (0900 h) but quickly grew throughout the afternoon to an average of over 40%. The present findings are also in line with the findings of Verma (1983) [18] who reported peak period of nectar collection by *A. cerana indica* between 1200 to 1400 h. Many workers have noted that *A. mellifera* and *A. cerana indica* collect nectar in the afternoon because there is a higher concentration of sugar on *Brassica* crops at that period of the day. (Free, 1970, Mohr and Jay, 1988). Similar results were documented by

Table 4. Mean values of visitation rate of dominant pollinators *Apis mellifera, Apis dorsata* and *Apis florea* in cauliflower

Species	Visitation Rate			Visitation Rate		
	Season 1			Season 2		
Time interval	*Apis mellifera*	*Apis dorsata*	*Apis florea*	*Apis mellifera*	*Apis dorsata*	*Apis florea*
8.00	4.37±0.36	2.50±0.22	2.43±0.37	6.43±0.68	1.67±0.20	3.00±0.36
10.00	9.47±1.07	7.03±0.58	8.20±0.74	11.73±1.15	6.20±0.69	8.67±1.04
12.00	18.10±1.14	11.60±0.89	14.13±0.43	18.80±1.23	12.90±1.32	13.83±1.12
14.00	26.93±1.66	12.62±0.82	15.93±0.57	27.40±1.86	15.13±1.41	16.00±1.06
16.00	5.10±0.56	3.13±0.41	4.27±0.56	5.67±0.48	2.93±0.22	4.50±0.61
LSD	2.64	1.384	1.527	2.624	2.31	2.235
F	81.85	53.72	116.35	59.96	41.78	40.41
P Value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

Rana *et al.* (1997) that the highest percentage of nectar gatherers of *A. cerana indica* and *A. mellifera* were recorded at 1500 h and the lowest at 0900 h on *B. campestris* bloom. The diversity indices of insect pollinators in the present investigation were observed as Margalef's Richness Index (2.25), Shannon-Weiner Diversity index (1.02), Pielou's Evenness Index (0.37) and Berger-Parker dominance index (0.24). Karuppaiah *et al.,* 2017 also reported the diversity indices of insect pollinators in onion as follows: Shannnon-Weiner (1.805), Berger-Parker (0.288) and Margalef Richness (1.846).

One of the most crucial elements in plant pollination is the presence of insects. They have been employed profitably to boost yield in both self-compatible and incompatible plants. *A. mellifera, A. dorsata* and *A. florea,* were considered as the most efficient pollinators of cauliflower based on their higher abundance, visitation frequency, and visitation rate. In chickpea, *A. florea*, *A. dorsata*, *Amigella* sp. and *E. aeneus* were recorded as the most efficient pollinators based on their higher abundance, visitation frequency, visitation rate and pollen load by Latif *et al.,* 2019. Additionally, among 15 pollinator species on bitter gourd, Saeed *et al.* (2012) noted that *A. dorsata* and *A. florea* were the most prevalent. Another study reported that *A. florea* and *A. dorsata* bees were the second and third most abundant bee species on *Brassica napus*, respectively (Akhtar *et al.,* 2018). Our results are similar to Kumar and Singh (2005) and Ali *et al.* (2011) who reported *A. florea* and *A. dorsata* as the most abundant species respectively on canola crop. Among the 14 insect species that were collected on chickpea during both years, two floral visitors, *A. florea* and *E. aeneus*, visited the most flowers and did so at significantly higher visitation rates (Latif *et al.,* 2019). According to Saeed *et al.* (2012), *A. florea* and *A. dorsata* are the two species that visit the bitter gourd blooms the most frequently.

A floral visitor's frequency and rate of visits are typically key indicators of how effective it is at pollinating (Zameer *et al.,* 2017). The species with high visitation rates and frequencies are considered as effective pollinators (Singh *et al.,* 2006). The maximum visitation rate and visitation frequency was observed for *A. mellifera* followed by *A. dorsata* and *A. florea* in the present study. The maximum foraging was noticed 36.90 to 45.56 bees/m^2/5min of *Apis dorsata* in between 1000 to 1600 hrs of the day reported by Dhurve (2008). Selvakumar *et al.* (2001) also recorded the activity of *Apis dorsata* on cauliflower constituted 28.23 per cent and the pollen gatherers reached to its peak at 1400 hrs while nectar collectors remained constant throughout the day.

Conclusion

Cauliflower flowers are visited by a variety of insects including bees, flies and wasps, but all were not effective pollinators. Bees were the most abundant floral visitors as compared to all other groups. *A. mellifera*, *A. dorsata* and *A. florea* were the major insect pollinators. Based on the highest values of visitation rate, visitation frequency, *A.mellifera* was considered as the efficient pollinators of cauliflower. These predominant insect pollinators can be effectively deployed to improve the cauliflower seed production in both the qualitative as well as quantitative manner.

Author Contributions

Conceptualization: PAD; formal analysis: PAD, SGK, KS, SY; investigation: PAD and SKP; data curation: PAD and SGK, KS and SY; writing-original draft preparation: PAD and KS; writing review and editing: SM, SY and VS; supervision: MC, VS. All authors have read and agreed to the published version of the manuscript.

Acknowledgements

The authors would like to acknowledge the Director, ICAR-Indian Institute of Vegetable Research, Varanasi for providing the necessary facilities required for the research and the help received in insect pollinators identification from Dr. N. Muthukumaran, Assistant Professor, Department of Entomology, Faculty of Agriculture, Annamalai University, Annamalai Nagar, Tamil Nadu, India.

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