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Diversity and foraging activity of flower visitors in sunflower (*Helianthus annuus* l.) ecosystems from the lower gangetic plains of West Bengal

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ABSTRACT

The present study investigated the diversity, abundance, and foraging behaviour of insect pollinators in sunflower (Helianthus annuus L.) at Jaguli Instructional Farm, Bidhan Chandra Krishi Viswavidyalaya (BCKV), Mohanpur, Nadia, West Bengal, India, during the rabi season of 2023. A total of 16 insect species belonging to 4 orders and 7 families were recorded, with Hymenoptera being the most dominant group (56.25%). Among pollinators, Apis dorsata (17.21%), A. mellifera (16.87%), A. cerana (14.21%), and A. florea (11.83%) were the most abundant, collectively comprising over 60% of the pollinator population. The Shannon–Wiener diversity index (H′ = 2.352) and evenness index (E = 0.849) indicated moderate diversity and uniform distribution. Diurnal activity peaked between 11:00 and 13:00 h, with the highest mean visitation rate (98.36 insects/m^2/3 min), aligning with the optimal temperature and solar radiation. Foraging time varied among the species, with A. dorsata and Xylocopa fenestrata spending the longest time per flower, while Halictus sp. and Tetragonula pagdeni exhibited quicker visits. Correlation analysis revealed a strong positive association between the pollinator activity, temperature, and solar radiation, and a negative correlation with the relative humidity. A key limitation of this work was the relatively short observation window, which may not adequately reflect year-to-year changes in pollinator diversity and behaviour. Nevertheless, the study provides novel evidence on species-specific diurnal activity and underscores the complementary roles of Apis and non-Apis pollinators, offering practical guidance for developing pollinator-friendly strategies in sunflower ecosystems. These findings emphasize the ecological significance of diurnal and species-specific foraging patterns in pollination success. The dominance of Apis spp. alongside native non-Apis bees underlines the importance of pollinator diversity for sustainable sunflower production in the Lower Gangetic Plains.

Keywords: *Abiotic factors, Apis species, Conservation strategies, Diurnal behavior, Diversity, Foraging activity, Sunflower, Sustainability*

Introduction

Pollination by the insect flower visitors plays a pivotal role in sustaining biodiversity and enhancing crop productivity. Globally, around 75–90% of flowering plant species rely on pollinators for successful reproduction, underscoring their ecological and agricultural significance [5,12]. Among these, bees are regarded as the most effective pollinators due to their morphological adaptations, floral constancy, and efficient foraging behavior [6,23]. Honey bees alone are responsible for nearly 80% of insect-mediated pollination, supporting about one-third of the global human diet [18]. Sunflower (*Helianthus annuus* L.), a member of the family Asteraceae, is a prominent oilseed crop with high economic and ecological value. Its floral traits, large capitula, abundant nectar, and exposed anthers make it highly attractive to a diverse array of insect pollinators, including *Apis* spp., solitary bees, syrphid flies, butterflies, and beetles [7,19]. In India, sunflower ranks fourth in oilseed cultivation and is grown across varied agroecological regions. Despite its significance, yield gaps persist, largely due to inadequate pollination [25,26].

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Suboptimal seed set is often attributed to low visitation rates or insufficient pollinator diversity. Research indicates that bee-mediated pollination enhances seed yield, oil content, and overall crop quality [8,28]. While managed honey bees are commonly employed in hybrid seed production, wild and native pollinators contribute substantially to pollination services and system resilience. Studies in Pantnagar and Odisha have documented the dominance of *Apis* spp., particularly *A. cerana indica*, in sunflower fields [7,19]. Pollinator activity is influenced by environmental variables such as temperature, humidity, solar radiation, and floral characteristics, with peak foraging often observed between 10:00 and 11:00 AM [10]. The Lower Gangetic Plains of West Bengal, with their alluvial soils, humid climate, and extensive cultivation, represent a major agricultural region. However, information on pollinator diversity and foraging behavior in sunflower ecosystems from this region remains sparse. Preliminary observations suggest the presence of rich insect diversity, including both managed and wild species [4,15]. Against this backdrop, the present study was undertaken to assess the diversity and foraging activity of flower visitors in sunflower fields of West Bengal. The findings aim to inform pollinator-friendly management practices and support sustainable sunflower cultivation in the region.

Materials and Methods

Study Site

The study was conducted during the *rabi* season of 2023 at the

Jaguli Instructional Farm, Bidhan Chandra Krishi Viswavidyalaya (BCKV), Mohanpur, Nadia, located in the Lower Gangetic Plains of West Bengal, India. The region is characterized by a warm-humid subtropical climate and fertile alluvial soils, ideal for oilseed cultivation. The experimental plots were sown with sunflower (*Helianthus annuus* L.) hybrid cultivar "Arko Provo (WBSH-2021)".

Observation Period and Sampling Protocol

Field observations were carried out during the peak flowering period, when floral visitation by insects was highest (Figure 1). The diversity, abundance, and foraging behaviour of flower-visiting insects were monitored between 07:00 and 17:00 h at four-day intervals. Observations were made in four randomly selected 1 m^2 plots during each session. In each plot, all insect visitors were recorded over 3-minute intervals. Only those insects that made direct contact with the reproductive parts of the flower were considered as effective pollinators. Specimens were collected using sweep nets, euthanized in insect killing jars (containing ethyl acetate), and later pinned and preserved. Identifications were conducted at the Department of Agricultural Entomology, Bidhan Chandra Krishi Viswavidyalaya (BCKV), using authenticated reference collections.

Foraging Behaviour Assessment

To quantify foraging activity, additional observations were made in five randomly selected 1 m^2 plots during the peak flowering window. The average time (in seconds) spent per flower by individual insect visitors was measured using a stopwatch. Timing began upon landing and excluded any circling behaviour. Observations were categorized into hourly intervals to evaluate diurnal variation in foraging activity.

Pollinator Diversity Indices

Pollinator diversity was assessed using the following metrics:

- Species Richness (S): Total number of distinct insect species observed during the study.
- Relative Abundance (RA): The proportion of individuals of a particular species in relation to the total pollinator population, calculated as:

$$\text{Relative abundance RA}(\%) = \left(\frac{N_i}{N_t}\right) \times 100$$

Where:

N_i = Number of individuals of species i
N_t = Total number of individuals observed

- Shannon-Wiener Diversity Index (H′): Used to evaluate species diversity:

$$\text{Shannon} - \text{Wiener Diversity Index: } H' = -\sum_{i=1}^{S} pi \ln(pi)$$

Where:
p_i = Proportion of individuals belonging to species i
S = Total number of species

- Species Evenness (E): Reflects how evenly individuals are distributed among species, calculated using Pielou's Evenness Index:

$$\text{Species Evenness } E = \frac{H'}{\ln(S)}$$

Statistical Analysis

Descriptive statistics (mean, standard deviation) were computed for insect abundance, visitation frequency, and foraging duration. One-way ANOVA was employed to analyze temporal differences in visitation frequency and time spent per flower, followed by Tukey's test for post hoc comparison. Pearson's correlation coefficients (r) were calculated to explore the relationship between foraging parameters and weather parameters. Statistical analyses were conducted using R software (v4.2.1) and Microsoft Excel, with a significance level of $p < 0.05$.

Results and Discussion

Diversity and Relative Abundance of Flower-Visiting Insects

A total of 16 insect species representing 4 orders and 7 families were recorded from sunflower (*Helianthus annuus* L.) capitula during the flowering period at Jaguli Instructional Farm, BCKV (Table 1). The highest species richness was observed in the order Hymenoptera, which contributed 56.25% of the total species recorded, followed by Lepidoptera (18.75%), Diptera (12.50%), and Hemiptera (6.25%). Among the observed insect visitors, *Apis dorsata* (17.21%) was the most abundant species, followed by *A. mellifera* (16.87%), *A. cerana* (14.21%), and *A. florea* (11.83%). These four honey bee species alone constituted over 60% of the total pollinator assemblage, indicating their dominant role in sunflower pollination under field conditions. *Ceratina unimaculata* (8.42%), and *Tetragonula pagdeni* (3.20%) were among the more frequent non-*Apis* bees, while *Xylocopa fenestrata*, *Halictus* sp., and *Nomia* sp. contributed moderately to pollination services. Syrphid flies, butterflies, and one Hemipteran (*Creontiades dilutus*) represented the minor components. The Shannon–Wiener diversity index (H′) for the pollinator community was calculated as 2.352, indicating moderate species diversity. The evenness index (E) was 0.849, reflecting a relatively uniform distribution of individuals among species. These findings are consistent with earlier studies [19,14,7], which also observed dominance of *Apis* species in sunflower ecosystems. However, the presence of a substantial proportion of native non-*Apis* bees (e.g., *Ceratina*, *Nomia*) suggests a resilient and functionally diverse pollinator community.

Diurnal Abundance Pattern of Insect Visitors

The diurnal foraging activity of major flower-visiting insects showed significant variation across different hours of the day (Table 2). The highest mean insect visitation rate was recorded between 11:00 to 13:00 h (98.36 insects/m^2/3 min), followed by 13:00 to 15:00 h (92.18 insects/m^2/3 min). In contrast, the lowest activity was observed during the cooler morning (07:00–09:00 h) and late afternoon (15:00–17:00 h) intervals. Species-specific analysis revealed that *Apis mellifera* exhibited the highest abundance at 11:00–13:00 h (18.53 insects/m^2/3 min), followed closely by *A. dorsata* (16.87), *A. florea* (16.47), and *A. cerana* (13.81). Non-*Apis* bees such as *Ceratina unimaculata* (6.88) and *Nomia* sp. (5.14) also showed increased foraging activity during these peak hours. The significant variation across time intervals ($p < 0.001$ for most species) highlights the influence of temporal dynamics on pollination efficiency. These findings are consistent with earlier studies. Peak visitation rates on cucurbits and safflowers were reported during midday hours, which were attributed to enhanced nectar secretion and favorable microclimatic conditions [11,17].

Maximum activity of insect visitors was also documented between 12:00 and 14:00 h [24], while other studies found that species such as *A. indica*, *A. florea*, *A. mellifera*, *A. dorsata*, and *Trigona* spp. reached their foraging peak between 10:00 and 12:00 h [27]. Further evidence supports these patterns, with reports of minimum honeybee densities during early morning (08:00 h) and late afternoon (16:00 h), likely due to lower temperatures and reduced nectar flow [3,9]. These diurnal trends underline the importance of synchrony between floral resource availability and pollinator foraging behavior.

Foraging Time per Flower

The mean time spent per flower by individual pollinators varied considerably among species and across observation periods (Figure 2). *Creontiades dilutus* spent the longest time per flower (26.32 sec), although as a hemipteran, its role as an effective pollinator is questionable. Among true pollinators, *Apis dorsata* (18.20 sec), *A. mellifera* (16.72 sec), and *Xylocopa fenestrata* (17.40 sec) showed the highest mean foraging durations. Shorter durations were recorded for *Halictus* sp. (9.25 sec), *Nomia* sp. (10.22 sec), and *Tetragonula pagdeni* (10.11 sec), possibly due to their smaller body size and faster foraging behavior. The time spent by *A. cerana* and *A. florea* was intermediate, ranging between 12.65 to 14.21 seconds. This variation reflects the functional differentiation among pollinators, where longer visitation generally contributes to more effective pollen transfer. Similar patterns have been reported previously [28,8], suggesting that combining fast and slow foragers can enhance both pollination coverage and efficiency. The results are also consistent with findings that *A. mellifera* spent between 0.25 to 2 minutes on a single flower, indicating relatively longer foraging bouts that may enhance pollen deposition [21]. Furthermore, observations showed that *A. dorsata* and *A. florea* spent 8.6 and 11.2 seconds per flower, respectively, and visited 8.5 and 4 flowers per minute [13].

These previous studies support the current findings and highlight species-specific foraging strategies that can influence pollination dynamics at the flower level.

Correlation Between Foraging Activity and Weather Variables

The correlation analysis (Figure 3) revealed significant relationships between insect visitation rates and abiotic factors. Minimum temperature (MinT) showed strong negative correlations with *A. dorsata* (r = –0.94), *A. florea* (r = –0.94), and *A. cerana* (r = –0.91), suggesting these species are more active in cooler conditions. In contrast, maximum temperature (MaxT) was positively correlated with *H. pendulus* (r = 0.70), indicating a preference for warmer days. Minimum relative humidity (MinRH) showed a positive correlation with *A. dorsata* (r = 0.84), while bright sunshine hours (BriSunHR) were positively correlated with *T. pagdeni* (r = 0.95*) and *X. fenestrata* (r = 0.95), implying greater activity in dry, sunny conditions. *A. mellifera* showed strong positive associations with *A. cerana* (r = 0.88) and *T. pagdeni* (r = 0.95), indicating possible co-occurrence or similar ecological preferences. These results align with earlier findings. Maity et al. (2014) reported positive correlations of honeybee abundance with MaxT (r = 0.631) and sunshine hours (r = 0.696), and negative correlations with humidity (r = –0.736) and wind (r = –0.837). It was found that humidity positively influenced bee foraging activity but negatively affected pollen collection [22]. A positive association between *X. fenestrata* and wind speed (r = 0.301*) has also been reported [1], while a negative correlation of *Xylocopa* with rainfall (r = –0.811*) was observed [2]. Furthermore, non-significant negative correlations of *A. dorsata* and *A. florea* with minimum temperature and humidity have been documented, supporting the present observations [20,17].

Overall, the findings highlight the species-specific influence of climatic factors on pollinator activity and behavior.

Table 1: Diversity of pollinator fauna on sunflower crop at Jaguli Instructional Farm

Sl. No	Order	Family	Common name	Scientific name	Total Population	Abundance (%)
1	Hymenoptera	Apidae	Rock bee	*Apis dorsata* Fabricius	758	17.21
2			Dwarf honeybee	*Apis floria* Fabricius	521	11.83
3			Indian bee	*Apis cerana* Fabricius	626	14.21
4			Italian bee	*Apis mellifera* Linnaeus	743	16.87
5			Stingless bee	*Tetragonula pagdeni* Schwarz	141	3.20
6			Carpenter bee	*Xylocopa fenestrate* Fabricius	58	1.32
7			Carpenter Bee	*Ceratina unimaculata* Smith	371	8.42
8		Halictidae	Sweat bee	*Halictus* sp.	251	5.70
9			Alkali bee	*Nomia* sp.	289	6.56
10		Megachilidae	Leaf cutter bee	*Megachile disjuncta* Fabricius	232	5.27
11	Lepidoptera	Erebidae	Handmaiden moth	*Amata bicincta* Kollar	109	2.48
12		Nymphalidae	Common crow	*Euploea core* Cramer	22	0.50
13			Blue moon butterfly	*Hypolimnas bolina* Linnaeus	121	2.75
14	Hemiptera	Miridae	Green mirid bug	*Creontiades dilutus* Stål	73	1.66
15	Diptera	Syrphidae	Tiger hoverfly	*Helophilus pendulus* Linnaeus	52	1.18
16			Marmalade hoverfly	*Episyrphus balteatus* De Geer	37	0.84
Shannon-Wiener Diversity Index: 2.352; Species Evenness (E): 0.849						

Table 2: Diurnal foraging activity of different insect visitors on sunflowers.

Sl. No.	Pollinators	Insect visitors/m²/3 min at different time interval							
		7.00-9.00	9.00-11.00	11.00-13.00	13.00-15.00	15.00-17.00	MEAN	F	Sig.
1	*Apis dorsata*	0.13±0.35[c]	11.67±3.44[b]	16.87±4.96[a]	18.80±4.87[a]	3.07±1.83[c]	**10.11**	80.429	0.000
2	*Apis floria*	0.53±0.64[d]	4.93±2.25[c]	16.47±3.96[a]	11.27±4.03[b]	1.53±1.06[d]	**6.95**	89.493	0.000
3	*Apis cerana*	0.93±0.96[c]	14.27±5.26[a]	12.53±3.50[ab]	9.93±2.94[b]	4.07±2.71[c]	**8.35**	42.361	0.000
4	*Apis mellifera*	0.47±0.64[e]	10.47±3.31[c]	18.53±3.27[a]	15.33±3.35[b]	4.73±1.91[d]	**9.91**	111.631	0.000
5	*Tetragonula pagdeni*	1.73±1.22[b]	2.13±1.36[ab]	2.93±1.28[a]	1.53±0.92[b]	1.07±0.70[b]	**1.88**	5.879	0.000
6	*Xylocopa fenestrata*	0.20±0.41[c]	0.87±0.64[b]	1.87±0.64[a]	0.67±0.62[bc]	0.27±0.46[c]	**0.77**	21.358	0.000
7	*Ceratina unimaculata*	0.67±0.72[d]	7.33±1.88[b]	11.20±3.34[a]	3.47±2.03[c]	2.07±1.83[cd]	**4.95**	60.809	0.000
8	*Halictus* sp.	1.07±0.96[c]	3.47±2.07[b]	8.53±2.75[a]	2.40±1.64[bc]	1.27±1.16[c]	**3.35**	41.718	0.000
9	*Nomia* sp.	1.40±1.30[c]	6.13±2.59[b]	8.87±2.88[a]	1.93±1.44[c]	0.93±1.03[c]	**3.85**	46.032	0.000
10	*Megachile disjuncta*	0.87±1.06[c]	4.67±4.22[b]	7.40±3.27[a]	1.87±1.64[c]	0.67±0.72[c]	**3.09**	19.056	0.000
11	*Amata bicincta*	1.07±0.96[a]	1.60±1.30[a]	1.33±1.40[a]	1.53±1.25[a]	1.73±1.53[a]	**1.45**	0.598	0.665
12	*Euploea core*	0.13±0.35[a]	0.33±0.62[a]	0.53±0.74[a]	0.27±0.46[a]	0.20±0.41[a]	**0.29**	1.228	0.307
13	*Hypolimnas bolina*	0.20±0.41[c]	0.93±0.88[bc]	4.33±2.64[a]	2.07±1.67[b]	0.53±0.74[c]	**1.61**	18.737	0.000
14	*Creontiades dilutus*	2.27±1.79[a]	1.07±1.10[b]	0.73±0.70[b]	0.20±0.41[b]	0.60±0.63[b]	**0.97**	8.464	0.000
15	*Helophilus pendulus*	1.73±1.49[a]	0.53±0.64[b]	0.87±0.74[b]	0.20±0.41[b]	0.13±0.35[b]	**0.69**	9.163	0.000
16	*Episyrphus balteatus*	0.93±0.96[a]	0.40±0.63[ab]	0.67±0.72[ab]	0.13±0.13[b]	0.33±0.49[ab]	**0.49**	3.289	0.016

Figure 1: Diversity of insect pollinators photographed on sunflower capitula during observation period

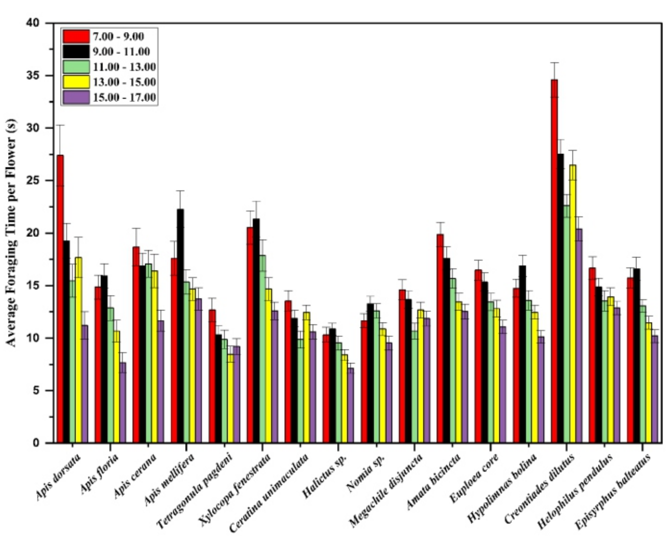

Figure 2: Average foraging duration of insect visitors on sunflower at different times of day

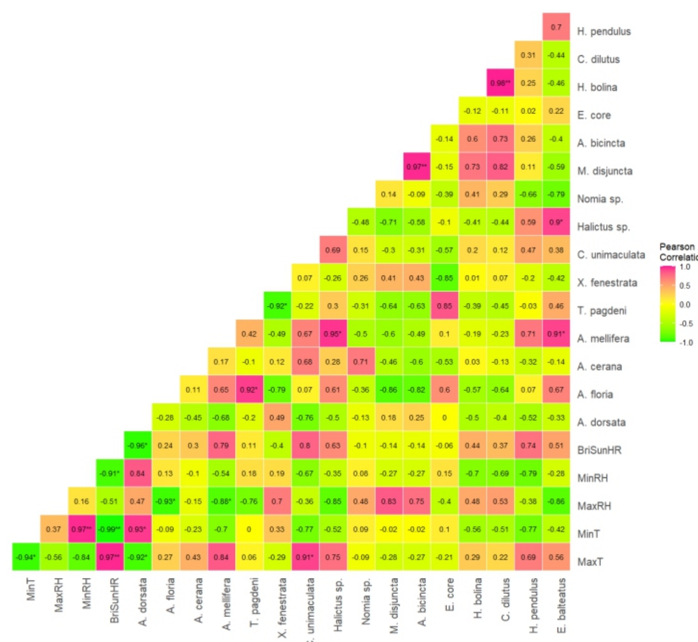

Figure 3: Correlation between abiotic environmental factors and pollinator activity

Conclusion

This study demonstrates that sunflower (*Helianthus annuus* L.) in the Lower Gangetic Plains supports a moderately diverse and functionally rich pollinator community. *Apis* species are dominant, but the presence and activity of native solitary bees and non-bee pollinators highlight the need for diversified pollinator conservation strategies. The clear diurnal patterns in visitation rate and the strong influence of weather parameters emphasizes the importance of time-sensitive pollination dynamics in sunflowers. Moreover, documenting these trends is crucial for optimizing hybrid seed production, improving pollinator-friendly practices, and enhancing agroecosystem sustainability.

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Declarations

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