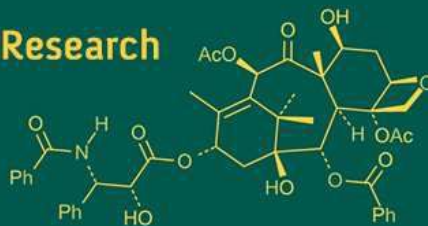
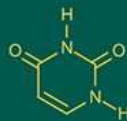


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Maske AO

Department of Entomology,
 Vasantrao Naik Marahtwada
 Krushi Vidyapeeth, Parbhani,
 Maharashtra, India

Neharkar PS

Department of Entomology,
 Vasantrao Naik Marahtwada
 Krushi Vidyapeeth, Parbhani,
 Maharashtra, India

Sonkamble MM

Department of Entomology,
 Vasantrao Naik Marahtwada
 Krushi Vidyapeeth, Parbhani,
 Maharashtra, India

Khandare RY

Department of Entomology,
 Vasantrao Naik Marahtwada
 Krushi Vidyapeeth, Parbhani,
 Maharashtra, India

Corresponding Author:**Maske AO**

Department of Entomology,
 Vasantrao Naik Marahtwada
 Krushi Vidyapeeth, Parbhani,
 Maharashtra, India

Insect pollinator diversity and their foraging behaviour in summer sunflower (*Helianthus annuus* L.)

Maske AO, Neharkar PS, Sonkamble MM and Khandare RY

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Abstract

A field study on sunflower (*Helianthus annuus* L.) in Parbhani revealed the diversity, richness, and diurnal activity of insect pollinators. Thirteen species from five orders were identified, with Hymenoptera accounting for the majority (42.0%), followed by Lepidoptera (32.1%) and Diptera, Coleoptera, and Neuroptera contributing 7.2%. *Apis mellifera*, *A. dorsata*, *A. florea*, *Trigona iridipennis*, and *Xylocopa fenestrata* were the most common Hymenoptera, with honey bees serving as key pollinators due to their frequent visits and excellent pollen transmission. Pollination was reinforced by lepidopterans (*Danaus plexippus*, *Spindasis vulcanus*, *Papilio demoleus*, *Pieris brassicae*, *Amata bicincta*), as well as infrequent Diptera, Coleoptera, and Neuroptera visitors. Hymenopterans demonstrated peak foraging between 10:00 and 14:00 hours, whereas Lepidoptera and other insect groups displayed species-specific temporal patterns. The combined action ensured continuous pollination throughout the day, which increased seed set and output. These findings support previous reports from India, Kenya, and Ukraine, demonstrating the importance of *Apis* species and pollinators in sunflower ecosystems. Understanding diurnal activity patterns helps to optimize pollination management for higher crop yields.

Keywords: Sunflower, insect pollinators, hymenoptera, lepidoptera, diurnal activity, pollination efficiency

Introduction

Pollination is an important ecosystem service that directly affects the production of many flowering plants and agricultural crops. More than 90% of the 25,000 flowering plant species depend on animals for sexual reproduction, with insects playing the most important role (Klein *et al.*, 2007) [16]. Approximately 75% of key crop species, including fruits, vegetables, oilseeds, and nuts, rely on insect pollination to increase productivity and quality (Gallai *et al.*, 2009) [7]. Insects, notably bees, provide roughly 35% of world food production by pollinating crops and giving essential nutritional resources to people (Garibaldi *et al.*, 2013) [8]. Sunflower (*Helianthus annuus* L.) is an important oilseed crop whose seed set and output are heavily controlled by insect pollinators. Although sunflowers are partially self-fertile, pollinator activity increases seed output and quality (Free, 1993; Nderitu *et al.*, 2008) [6, 19]. Honey bees are considered the most efficient and reliable insect pollinators due to their quantity, floral consistency, and foraging behavior (Said *et al.*, 2018; Sreekanth *et al.*, 2019) [21, 23]. In India, four major honey bee species *Apis mellifera* (Italian bee), *Apis dorsata* (rock bee), *Apis florea* (small bee), and *Trigona iridipennis* (stingless bee)—play important roles in pollination. Furthermore, solitary bees like carpenter bees (*Xylocopa fenestrata*) play an important role in sunflower pollination.

Aside from bees, a variety of different insects participate to sunflower pollination. Butterflies like *Papilio demoleus* (lemon butterfly), *Pieris brassicae* (cabbage butterfly), *Spindasis vulcanus* (common silverline), and *Danaus plexippus* (monarch butterfly) are often seen visiting sunflower flowers (Mohan Rao & Suryanarayana, 2005). Moths like *Amata bicincta* (handmaiden moth) and dipterans like syrphid flies (*Ischiodon scutellaris*) promote cross-pollination by transferring pollen during nectar foraging (Ghazoul, 2005) [10]. Predatory insects such as ladybird beetles (*Cheilomenes sexmaculata*) and lacewings (*Chrysoperla* spp.) visit sunflower flowers to augment their diet with nectar and pollen while also acting as natural pest predators (Sreekanth *et al.*, 2019) [23].

Several factors influence pollinator diversity and abundance in sunflower habitats, including landscape shape, flowering season, climatic conditions, and competition for floral resources (Garibaldi *et al.*, 2011; Kennedy *et al.*, 2013)^[9, 17]. While *Apis mellifera* has been widely researched in managed pollination, there is comparatively little information on the contribution of native bees and non-bee pollinators in Indian sunflower agroecosystems (Said *et al.*, 2018; Abrol, 2012)^[22, 1]. Understanding the diversity of insect visitation, their number, and relative usefulness as pollinators is critical for developing environmentally friendly pest and pollinator management techniques.

Methodology

The current study on pollinator diversity and abundance in sunflower was carried out during the summer of 2025 at the Research Farm, Department of Entomology, College of Agriculture, VNMKV, Parbhani, Maharashtra. Veda (KSFH-666), a sunflower variety, was grown on a 10 × 10 m plot using standard techniques. Insecticidal sprays were avoided to prevent interference with pollinator activity. The crop was planted on March 4, 2025, with a spacing of 60 × 45 cm and fertilized with 60:30:30 NPK kg/ha during sowing. The experiment was conducted using a non-replicated design.

During the flowering season, the experimental plot was divided into four quadrates, and systematic observations were made on insect visitation to sunflower capitulas. Daily observations were taken at six-time intervals (08:00, 10:00, 12:00, 14:00, 16:00, and 18:00 hours). In each time slot, the number of insect visitors was counted for five minutes per square meter area in each quadrate, and the results were reported as the mean number of pollinators per square meter per minute. Insect pollinators were identified through direct observation, collection with insect nets, and comparison with established taxonomic keys, while specimens that needed additional confirmation were kept in ethanol and identified to species level by specialists.

Pollinator diversity was measured using ecological indices such as Margalef's index of richness, Shannon-Wiener diversity index, Simpson's index, Pielou's evenness index, and Berger-Parker dominance index. The dominance structure was assessed using Engelmann's dominance scale, as previously used by scholars. To discover the preferred visiting hours of different pollinators, particularly honey bees, data taken at two-hour intervals were examined to identify activity peaks of *Apis mellifera*, *Apis dorsata*, *Apis florea*, *Trigona iridipennis*, *Xylocopa fenestrata*, and other major floral visitors. The recorded data were subjected to descriptive statistics and analysis of variance (ANOVA),

with insect species and time of observation serving as the primary explanatory factors, and statistical analyses were conducted using Minitab version 18.0.

Results and Discussion

Pollinator diversity and abundance of frequent visit of pollinators, the current examination of sunflower pollinators at Department of Entomology, VNMKV, Parbhani indicated in Table No. 1 and Fig. No. 1 the presence of thirteen species from five insect orders. The most prominent order was Hymenoptera, which accounted for 42.00% of the pollinator fauna, followed by Lepidoptera (32.10%), and Diptera, Coleoptera, and Neuroptera combined for 7.21%. The Apidae family of Hymenoptera was extremely diverse and plentiful, including *Apis mellifera*, *A. dorsata*, *A. florea*, *Trigona iridipennis*, and *Xylocopa fenestrata*. Honey bees were the most successful pollinators because of their frequent visits, foraging efficiency, and capacity to transmit pollen across flowers. *A. mellifera*, *A. dorsata*, and *A. florea* were identified as the primary contributors, with *Trigona* and *Xylocopa* playing supporting but minor roles.

The second most abundant group was Lepidoptera, which included *Danaus plexippus*, *Spindasis vulcanus*, *Pieris brassicae*, *Papilio demoleus*, and *Amata bicincta*. Although they made frequent trips, their contribution to effective pollination was less than that of bees, owing to their nectar-feeding habits and limited pollen-carrying capacity. Similarly, *Cheilomenes sexmaculata* (ladybird beetle) from the Coleoptera order and *Chrysoperla* sp. (green lacewing) from the Neuroptera order were observed as occasional visitors, contributing just significantly to pollination. Hoverflies (*Ischiodon scutellaris*) from Diptera were also observed, and while their visits were brief and sporadic, they contributed to inadvertent pollen transmission.

The findings are consistent with those of Thakur *et al.* (2023)^[26], who reported 24 insect species visiting sunflower heads, with Hymenoptera being the most dominant group. Similarly, Tabassum *et al.* (2022)^[25] observed that *Apis dorsata* was the predominant pollinator in Raichur, while Shpak *et al.* (2023)^[24] emphasized the role of non-*Apis* species such as *Megachile* and *Bombus* in providing complementary pollination services. Nderitu *et al.* (2008)^[19] and in India, Jadhav *et al.* (2011)^[14] identified Hymenoptera as the primary pollinators of sunflower, with *Apis* species alone accounting for more than 85% of floral visits. Our findings are consistent with those of Goswami *et al.* (2013)^[12] and Bhowmik & Bhadra (2015)^[3], found that while honey bees are the primary pollinators, other species such as Lepidoptera, Diptera, and Coleoptera contribute to the variety and ecological balance of pollination systems.

Table 1: Diversity of pollinators in sunflower

Sr. No.	Order	Family	Common Name	Scientific Name
1	Hymenoptera	Apidae	Italian bee	<i>Apis mellifera</i>
2		Apidae	Rock bee	<i>Apis dorsata</i>
3		Apidae	Little honey bee	<i>Apis florea</i>
4		Apidae	Stingless bee	<i>Trigona iridipennis</i>
5		Apidae	Carpenter bee	<i>Xylocopa fenestrata</i>
6	Lepidoptera	Nymphalidae	Monarch butterfly	<i>Danaus plexippus</i>
7		Lycanidae	Common silverline butterfly	<i>Spindasis vulcanus Fabricius</i>
8		Pieridae	Cabbage butterfly	<i>Pieris brassicae</i>
9		Papilionidae	Lemon Butterfly	<i>Papilio demoleus</i>
10		Erebidae	Handmaiden moth	<i>Amata bicincta</i>
11	Coleoptera	Coccinellidae	Ladybird beetle	<i>Cheilomenes sexmaculata</i>
12	Neuroptera	Chrysopidae	Green lacewing	<i>Chrysoperla sp</i>
13	Diptera	Syrphidae	Yellow shouldered hover fly	<i>Ischiodon scutellaris</i>

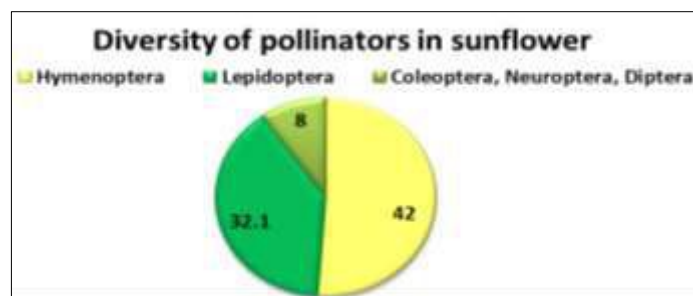


Fig 1: Diversity of sunflower pollinators

Foraging activity of insect pollinators in sunflower

Preferred visit timing of pollinators from Hymenoptera on sunflower at different times of the day Table No. 2 and Figure No. 2 provide information on hymenopteran species

preferred visit timings. More hymenopteran pollinators were noticed, and their preferred period to visit sunflowers was in the afternoon between 12.00 hrs and 14.00 hrs.

Table 2: Relative abundance of pollinators from Hymenopteran on sunflower at different times of the day

Time Hrs.	Number of visiting pollinators (Visits/m ² /minute)				
	<i>A. mellifera</i>	<i>A. dorsata</i>	<i>A. florea</i>	<i>Trigona iridipennis</i>	<i>Xylocopa fenestrata</i>
8.00	0.00	3.83	0.02	38.42	0.10
10.00	0.00	28.79	0.57	49.24	0.06
12.00	4.25	31.21	2.17	58.58	0.14
14.00	2.10	17.54	1.58	52.78	0.08
16.00	1.92	7.98	0.95	36.47	0.01
18.00	0.26	2.03	0.10	28.45	0.02

*Average of 14 observations.

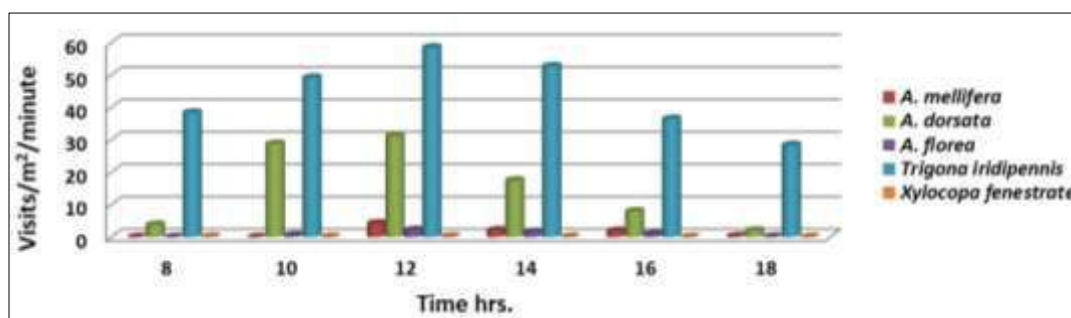


Fig 2: Relative abundance of pollinators from Hymenoptera on sunflower at different times of the day

A. mellifera had the highest visitor rate at 12.00 hrs (4.25 visits/m²/min), followed by 14.00 hrs (2.10 visits/m²/min). Lower activity levels were seen around 16.00 hrs (1.92 visits/m²/min) and 18.00 hrs (0.26 visits/m²/min). However, no visitors were detected between the hours of 8:00 hrs and 10:00 hrs. This trend reveals that *A. mellifera* prefers to forage during the midday hours, which is most likely affected by favorable light and temperature conditions.

A. dorsata peak foraging activity was at 12.00 hrs, with 31.21 visits/m²/minute, followed by 10.00 hrs (28.79 visits/m²/min) and 14.00 hrs (17.54 visits/m²/min). Moderate visitation was observed at 16.00 hrs (7.98 visits/m²/min), with lesser activity at 8.00 hrs (3.83 visits/m²/min) and 18.00 hrs (2.03 visits/m²/min). The findings show that *A. dorsata* is most active from late morning to early afternoon, indicating a predilection for higher temperatures and light intensity.

A. florea had the highest visiting rate at 12.00 hrs, with 2.17 visits/m²/minute, followed by 14.00 hrs (1.58 visits/m²/min), 16.00 hrs (0.95 visits/m²/min), and 18.00 hrs (0.10 visits/m²/min). There was little activity at 10.00 hrs (0.57 visits/m²/min), and nearly no visitors were registered at 8.00 hrs (0.02 visits/m²/min). This trend implies that *A. florea* is most active during the day, with less activity in the morning and late evening.

Trigona iridipennis showed significant foraging activity throughout the day, with the maximum visitation rate reported at 12.00 hrs (58.58 visits/m²/min), followed by 14.00 hrs (52.78 visits/m²/min), 10.00 hrs (49.24 visits/m²/min), and 8.00 hrs (38.42 visits/m²/min). Activity decreased in the late afternoon, with 36.47 visits/m²/min at 16.00 hrs and 28.45 at 18.00 hrs. This pattern demonstrates that *T. iridipennis* is a dominating and persistent pollinator, with substantial daytime activity recorded at all time intervals.

Xylocopa fenestrata demonstrated little foraging activity during the day. The highest visitor rate was recorded at 12.00 hrs (0.14 visits/m²/minute), followed by 8.00 hrs (0.10 visits/m²/min), 14.00 hrs (0.08 visits/m²/min), and 10.00 hrs (0.06 visits/m²/min). Activity was extremely low at 18.00 hrs (0.02 visits/m²/min) and 16.00 hrs (0.01 visits/m²/min). These findings indicate that *X. fenestrata* has a small role in sunflower pollination, with restricted and intermittent activity during daylight hours.

In Fig. No. 3 pictorial representation of top three pollinators species. Preferred visit timing of pollinators from Lepidoptera on sunflower at different times of the day the preferred visit timings of lepidopteran species are given in Table No. 3 depicted by Fig. No. 4.

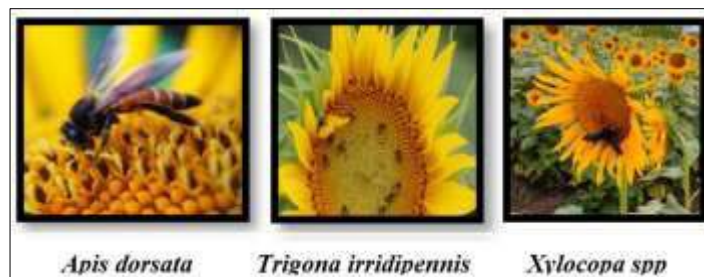


Fig 3: Pictorial representation of top three pollinators species

Table 3: Relative abundance of pollinators from Lepidoptera on sunflower at different times of the day

Time Hrs.	Number of visiting pollinators (Visits/m ² / minute)				
	<i>Spindasis vulcanus</i>	<i>D. plexippus</i>	<i>A. bicincta</i>	<i>P. demoleus</i>	<i>P. brassicae</i>
8.00	0.05	0.01	0.00	0.01	0.01
10.00	0.00	0.01	0.01	0.03	0.03
12.00	0.10	0.03	0.01	0.02	0.04
14.00	0.03	0.04	0.02	0.00	0.03
16.00	0.02	0.00	0.03	0.02	0.01
18.00	0.01	0.01	0.05	0.01	0.02

*Average of 14 observations.

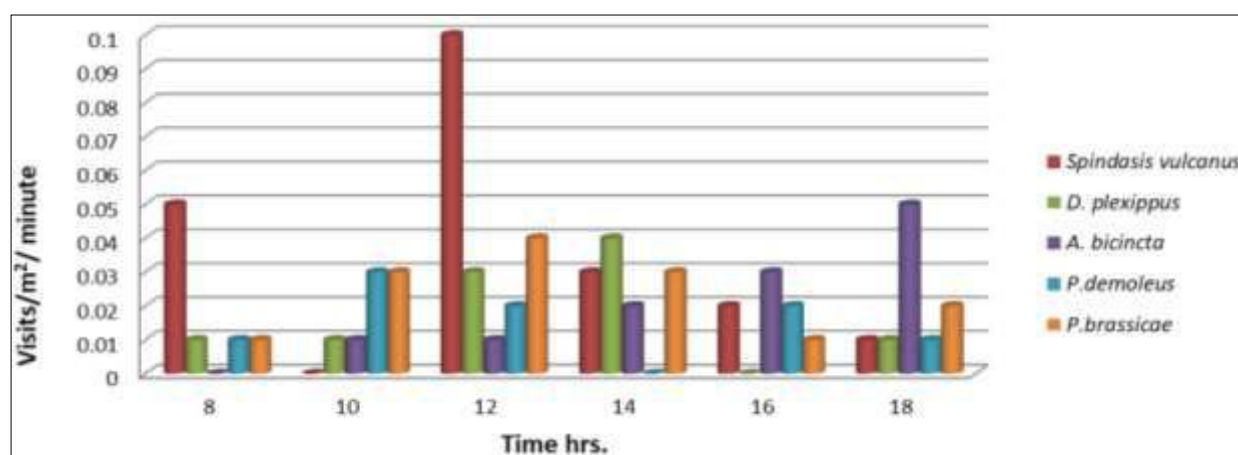


Fig 4: Relative abundance of pollinators from Lepidoptera on sunflower at different times of the day

Lepidoptera four pollinators were observed visiting the sunflower heads: *Spindasis vulcanus*, *Danaus plexippus*, *Amata bicincta*, *Papilio demoleus* and *Pieris brassicae*.

Spindasis vulcanus had the highest visiting rate at 12.00 hrs, with 0.10 visits/m²/minute, followed by 14.00 hrs (0.03 visits/m²/min), 16.00 hrs (0.02 visits/m²/min), and 18.00 hrs (0.01 visits/m²/min). At 8.00 hrs, there was minimal activity (0.05 visits/m²/min), and no visitors were registered at 10.00 hrs. This pattern suggests a preference for noon foraging, with less activity in the early morning and late evening hours.

D. plexippus had the highest visitation rate at 14.00 hrs, with 0.04 visits/m²/minute, followed by 12.00 hrs (0.03 visits/m²/min), and minor activity at 8.00 hrs and 18.00 hrs (0.01 visits/m²/min) each. Low activity was also detected at 10.00 hours (0.01 visits/m²/min), with no visitors observed at 16.00 hrs. The data indicate that *D. plexippus* prefers midday foraging, with low activity in the early morning and late afternoon.

A. bicincta had the highest visitor rate at 18.00 hrs, with 0.05 visits/m²/minute, followed by 16.00 hrs (0.03 visits/m²/min) and 14.00 hrs (0.02 visits/m²/min). There was little activity at 10.00 hrs and 12.00 hrs (0.01 visits/m²/min)

each, and no visitors were recorded at 8.00 hrs. This shows that *A. bicincta* forages more actively in the late afternoon and early evening.

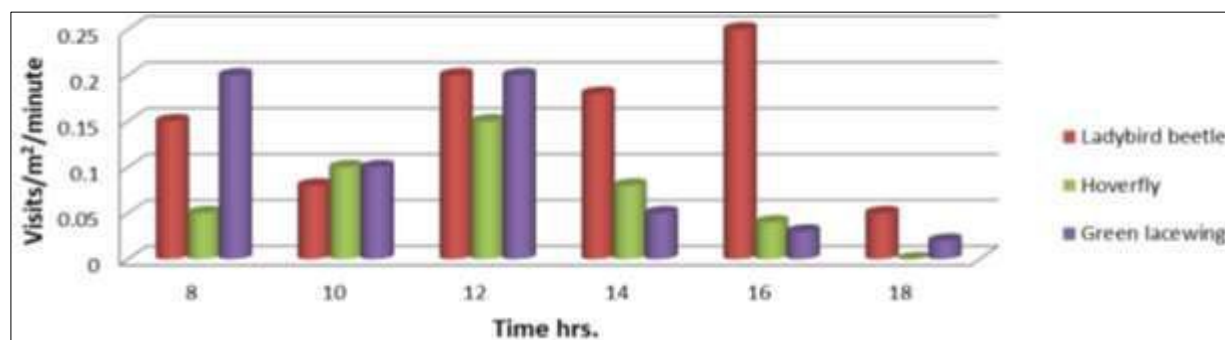
P. demoleus had the highest visitation rate at 10.00 hrs, with 0.03 visits/m²/minute, followed by 12.00 hrs and 16.00 hrs (0.02 visits/m²/min) each. Minimal activity was detected at 8.00 hrs and 18.00 hrs (0.01 visits/m²/min) each, with no visits at 14.00 hrs. This trend indicates that *P. demoleus* prefers late morning to early afternoon foraging, with less activity during early morning and late evening.

P. brassicae had the highest visiting rate at 12.00 hrs, with 0.04 visits/m²/minute, followed by 10.00 hrs and 14.00 hrs (0.03 visits/m²/min) each. Lower activity was noted between 8.00 hrs and 18.00 hrs (0.01 visits/m²/min and 0.02 visits/m²/min, respectively), with less visits recorded at 16.00 hrs (0.01 visits/m²/min). This suggests a propensity for mid-morning to early afternoon foraging, with little activity in the early morning and late afternoon.

Preferred visit timing of Coleoptera, Diptera and Neuroptera on sunflower at different times of the day the preferred visit timings of coleoptera, diptera and neuroptera species are given in Table No. 4 depicted by Fig. No. 5.

Table 4: Relative abundance of Coleoptera, Diptera and Neuroptera on sunflower at different times of the day

Time Hrs.	Number of visiting pollinators (Visits/m ² /minute)		
	Coleoptera	Diptera	Neuroptera
	Ladybird beetle	Hoverfly	Green lacewing
8.00	0.15	0.05	0.20
10.00	0.08	0.10	0.10
12.00	0.20	0.15	0.20
14.00	0.18	0.08	0.05
16.00	0.25	0.04	0.03
18.00	0.05	0.00	0.02
*Average of 14 observations.			

**Fig 5:** Relative abundance of Ladybird beetle, Hoverfly and Green lacewing on sunflower at different times of the day

From Coleoptera the ladybird beetle had the highest visitation rate at 16.00 hrs, with 0.25 visits/m²/min., followed by 12.00 hrs (0.20 visits/m²/min) and 14.00 hrs (0.18 visits/m²/min). Activity was moderate at 8.00 hrs (0.15 visits/m²/min), but lower rates were recorded at 10.00 hrs (0.08 visits/m²/min) and 18.00 hrs (0.05 visits/m²/min). This trend reveals that coleopteran activity, particularly that of ladybird beetles, peaks in the mid to late afternoon, implying a predilection for warmer weather.

From Diptera the Hoverflies had the highest visitor rate at 12.00 hrs (0.15 visits/m²/minute), followed by 10.00 hrs (0.10 visits/m²/min) and 14.00 hrs (0.08 visits/m²/min). Lower activity was detected at 8.00 hrs (0.05 visits/m²/min) and 16.00 hrs (0.04 visits/m²/min), with no visits seen at 18.00 hrs. This pattern shows that dipteran activity peaks around midday, indicating a preference for moderate light and temperature conditions.

From Neuroptera the Green lacewings had the highest visitor rates during 8.00 and 12.00 hrs, with 0.20 visits/m²/min, followed by 10.00 hrs (0.10 visits/m²/min). Activity fell dramatically in the afternoon, reaching 0.05 visits/m²/min at 14.00 hrs, 0.03 visits/m²/min at 16.00 hrs, and 0.02 visits/m²/min at 18.00 hrs. This tendency indicates that Neuroptera prefer early-day foraging, which is likely affected by colder temperatures and reduced light intensity.

Hymenopteran pollinators, particularly *Trigona iridipennis*, *Apis dorsata*, and *A. mellifera*, visited sunflowers at the highest rates, with peak activity happening between 10.00 and 14.00 hours. Their dominance underlines their critical role in sunflower pollination throughout the noon hours. Lepidopteran pollinators demonstrated lower and more varied activity. *Spindasis vulcanus* and *Pieris brassicae* were active about midday, whereas *Amata bicincta* preferred late afternoon, indicating a limited but supplemental involvement in pollination. Pollinators such as Coleopterans, Dipterans, and Neuropterans had unique temporal patterns. Ladybird beetles (Coleoptera) were most active at 16.00 hrs, hoverflies (Diptera) at 12.00 hrs, and green lacewings (Neuroptera) in the mornings and middays.

The combined activity of these varied pollinator groups ensures continuous pollination throughout the day, resulting in higher seed output and overall productivity in sunflower crops.

Gore *et al.* (2024) ^[11] undertook a field study to investigate sunflower pollinator diversity and feeding behavior. *Apis dorsata* reached its peak activity at 18.00 hrs (28.96 visits/m²/min), followed by 12.00 hrs (4.33 visits/m²/min). *Apis florea* also reached its peak at 18.00 hours (0.40 visits/m²/min). *Trigona iridipennis* was most active between 12.00 hrs (1.43 visits/m²/min) and 14.00 hrs (1.40 visits/m²/min), while *Xylocopa fenestrata* peaked at 12.00 hrs (0.10 visits/m²/min). *Cheilomenes sexmaculata* and *Ischiodon scutellaris* demonstrated more activity at 16.00 hrs (0.14 visits/m²/min) and 12.00 hrs (0.08 visits/m²/min), respectively. Moths were busy at night, while butterflies and skippers foraged in the morning. Kasina *et al.* (2007) ^[15] conducted field research in the semi-arid Makueni district of Eastern Kenya between 2004 and 2005 to investigate pollinator diversity and its impact on sunflower (*Helianthus annuus* L.) seed yield. The study discovered that, whereas seasonal fluctuation had no significant influence, the diurnal activity of *Apis mellifera* and non-*Apis* bees changed dramatically throughout the day. *A. mellifera* was the most common visitor, with peak activity for both *Apis* and non-*Apis* bees occurring between 10:00 and 14:00 hours, highlighting this time frame as crucial for pollination.

Emerson *et al.* (2011) ^[5] investigated the pollination efficiency and feeding behavior of Africanized *Apis mellifera* L. on sunflower genotypes using both open and restricted pollination. Nectar foraging trips peaked between 7:00 and 08:30 on the second and third days of flowering. The average bee density per capitulum was between 2.27 and 2.94. Nectar collectors (2.28 bees/capitulum) outnumbered pollen collectors (0.40 bees/capitulum), indicating a strong preference for nectar. Roy *et al.* (2014) ^[20] undertook a study from 2012 to 2013 to describe the diversity, activity, and quantity of diurnal insect visitors to mustard (*Brassica juncea* L.) blooms in Phaldi, near

Duttapukur, West Bengal, India. The findings revealed that insect visitation peaked between 12:00 and 14:00 hours, indicating that noon was the peak period for pollination activity.

Bhowmik and Bhadra (2015)^[3] investigated the variety and feeding behavior of insect pollinators on *Helianthus annuus* L. (PAC-361) in South Bengal from late 2012 to 2014. Peak foraging times differed among insect orders, with Hymenoptera at 10:00 hours, Diptera at 11:30 hrs, Coleoptera at 13:30 hrs, Hemiptera at 11:00 hrs, and Lepidoptera at 08:30 hrs. *Apis* and non-*Apis* bee activity peaked about 10:00 a.m., dropped after 13:00 p.m., then surged again after 15:00 p.m., lasting until 17:30 p.m. Said *et al.* (2015)^[22] investigated the foraging behavior of Himalayan honeybees (*Apis cerana*) on *Helianthus annuus* L. at Pakistan's New Developmental Farm (NDF) in 2012-2013. The study found that *A. cerana* began foraging early in the morning and continued until late afternoon, for a total of about ten hours. Two different peaks in activity were observed one at 10:00 a.m. and a higher peak at 12:00 p.m. both of which were deemed necessary for effective pollination. Foraging activity gradually decreased in the late afternoon, reaching a low point by evening.

Basavaraj *et al.* (2016)^[2] reported bee pollinator diversity in hybrid sunflower (cv. KBSH-53) from 6:00 to 18:00 hrs. *Apis dorsata* was the most plentiful and active during the day, followed by *A. cerana* and *A. florea*. Peak activity for *A. dorsata*, *A. cerana*, *A. florea*, *Trigona* sp., and *X. aestuans* occurred between 11:00 and 12:00 hrs, but *X. latipus* displayed peak activity between 16:00 and 17:00 hrs, demonstrating species-specific foraging habits.

Hymenopteran pollinators, particularly *Trigona iridipennis*, *Apis dorsata*, and *A. mellifera*, were most active between 10:00 and 14:00 hrs, while Lepidoptera activity varied, with some species feeding in the late afternoon. Coleoptera, Diptera, and Neuroptera exhibited distinct temporal patterns, ensuring continued pollination throughout the day. Overall, noon hours were crucial for sunflower pollination, emphasizing species-specific diurnal preferences that lead to successful pollination and increased crop yield.

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