

Studies on Insect Pollinator Fauna and Behaviour of Honeybees in Indian Mustard, [*Brassica juncea* (L.) Czern. and Coss]

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ABSTRACT

Understanding honeybee foraging behaviour optimizes pollinator usage, increasing crop yield, quality, and ecosystem biodiversity, benefiting mustard and other crops. The present investigations were carried out in the experimental field of mustard crop and the apiary at RVSKVV- Krishi Vigyan Kendra, Morena, Madhya Pradesh, during 2021-22. Results revealed that a total of 36 species belonging to 8 orders viz., Hymenoptera (12), Diptera (9), Lepidoptera (6), Coleoptera (3), Hemiptera (2), Orthoptera (2), Neuroptera (1) and Odonata (1). The comparative mean abundance among the various bees appearing on mustard flowers revealed that *Apis mellifera* (15.29 bees/m²/5 min) was the predominant visitor followed by *A. dorsata* (11.57 bees/m²/5 min) and *A. cerana indica* (6.81 bees/m²/5 min). It was found that *A. mellifera*, *A. dorsata* and *A. indica* constituted 45.40, 34.37 and 20.23 per cent, respectively. The maximum mean foraging speed during different day hours varied from 3.33 to 8.66 seconds for *A. cerana indica* 1200 hrs to 1600 hrs, respectively and for *A. mellifera* it varied from 1.46 to 3.66 seconds at 1800 hrs to 1400 hrs, respectively. Additionally, the highest mean foraging rate during different day hours varied from 10.71 to 21.43 flowers visited/min for *A. mellifera* during 1800 to 1200 hrs, respectively and the mean foraging rate was lowest for *A. cerana indica* varied from 5.14 to 12.29 flowers visited/min during 1800 to 1200 hrs, respectively.

Keywords: *Apis mellifera*, *Apis dorsata*, *Apis cerana indica*, pollinators diversity, foraging speed, foraging rate, bee abundance, bee activity, Hymenoptera.

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INTRODUCTION

Indian mustard, *Brassica juncea* (L.) Czern & Coss., commonly referred to as *sarson* or *rai* (Hindi) is the oldest cultivated dicotyledonous angiosperm plant belonging to Brassicaceae or Cruciferae family which is generally pollinated by insects (Bhowmik, Mitra, & Bhadra, 2014). It is the world's second-largest oilseed crop after groundnut with its distribution in China, Canada, India, Australia, France, Germany, United Kingdom, etc. In India, mustard is grown at an area of 66.99 Mha, with an output of 102.10 million tonnes and productivity of 1524 kg/ha with its distribution in Rajasthan, Haryana, Madhya Pradesh, Uttar Pradesh and West Bengal (Anonymous, 2021). In several cross-pollinated crops like mustard, external bioagents are required to accomplish this process and pollination in these crops so as to increase the seed production significantly. Honeybees is considered one of the effective, cheapest and eco-friendly input methods for triggering the crop yield both qualitatively and quantitatively. Pollination through honeybees ensures uniform maturity and early harvest of the crop (Anil, 2015). The mustard bloom was visited by 88 insects from 63 species belonging to 31 families and 9 orders. Order Hymenoptera formed a higher percentage of the insect visitors in scan sampling (Devi et al, 2017 and Kunjwal, Kumar, & Khan, 2014).

Further, foraging behaviour of different species of honeybee shows the efficiency of their activity in the field. Rathi & Sihag (1993) revealed that the honey bee species were more active from 11.00 h to 14.00 h, whereas, the solitary bees were more active later (12.00 to 15.00 h). Painkra & Shaw (2016) observed maximum visitation of *Apis cerana* at 1100 hrs (66.06 bees/5 min/m²). The maximum foraging activity of *Apis dorsata* was observed at 1100 hrs. (11.75 bees/5 min/m²) whereas, the lowest was observed at 1700 hrs. (0.50 bee/5 min/m²). The higher foraging activity of *Apis florea* was noticed at 1300 hrs. (4.00 bees/5 min/m²) and was found least at 0900 hrs (0.56 bee/5 min/m²). Nagpal, Yadav, & Singh, (2020) revealed that *Apis florea* had the longest average time spent per flower (6.08 sec), followed by *Apis dorsata* (3.41 sec), *Apis mellifera* (2.60 sec), and *Apis cerana indica* (2.33 sec). This indicates that *A. cerana indica* is the fastest of all the *Apis* species, whereas *A. florea* is comparatively slower, maybe as a result of the length of its tongue. Further, the average time spent per flower of various *Apis* spp. over day periods varied from 3.25 to 4.20 seconds. *Apis mellifera*, *Apis dorsata*, and *Apis cerana indica* spent the least amount of time per flower (2.02 seconds, 2.38 seconds and 2.97 seconds, respectively) at 1200-1400 h, but *Apis florea* lowest amount of time spent per flower was (4.23 sec) at 0800-1000 h on *Brassica juncea*. The timing of honeybee foraging is crucial for efficient pollination. Different species of honeybees are most active during their specific times of the day when flowers are open, ensuring optimal flower visitation. It is therefore possible to employ the most appropriate species of honeybees by understanding the visitation timing of honeybees. Therefore, the present research in Indian mustard ecosystem will be of significance to understand the importance of pollinators fauna, foraging behaviour of different honeybee species in the study area with the aim to increase the biodiversity, crop yield and quality which ultimately contributes to the

conservation of major pollinators fauna. So, in light of the facts and information stated above, the purpose of this study was to develop an understanding of the diversity of insects pollinating Indian Mustard and the knowledge of foraging behaviour of different species of honeybees to develop better understanding of the most efficient pollinator.

MATERIAL AND METHODS

The present investigations were carried out in the assigned experimental field of mustard crop and the apiary at RVSKVV- Krishi Vigyan Kendra, Morena, Madhya Pradesh, during 2021-22. The healthy seeds of mustard variety RVM- I were sown on 24-10-2021 at 5 cm depth at a row distance of 45 cm and plant to plant of 15 cm apart with the plot size of 6.0 m x 3.0 m by following recommended package of practices.

For the observations of the insects that visited and occurred on plants were surveyed using the direct count observation approach. During the peak flowering season observations were made for distinct groups of pollinators visiting the mustard crop field in each square meter area from three sites. To estimate the pollinator fauna as well as the predominance (in percent value) of a given group, the observed data were aggregated group-wise. The dominance per cent was computed by multiplying the total number of genera seen by the number of species observed in each insect order.

For the observations on the foraging behaviour of honey bees, three species were taken into consideration viz., *Apis mellifera*, *Apis dorsata*, *Apis cerana indica*. The observations began at 10% flowering and continued until the flowering phase was completed. The plots were replicated thrice for recording the observations. The data were recorded at weekly intervals on the number of honeybees visiting in each square meter area from randomly marked five spots in each of the replicated plots for five minutes at two hourly intervals from 0800 to 1800 hours. The amount of time that different honey bee species spent on live flowers and the number of flowers visited per minute was also recorded from randomly marked five spots in each of the replicated plots for five minutes at two hourly intervals from 0800 to 1800 hours. The data was averaged over time, weekly and even across species to determine which group and when it dominated over the other species. Furthermore, a two-way analysis of variance was performed on different species of honeybees to see how weeks and time hours of the day influenced their foraging behavior, as well as whether these two factors interact.

RESULTS

Diversity of insect pollinators of Indian mustard

The experimental field was observed carefully during the study period and the insect pollinators visiting the mustard crop (*Brassica juncea* L.) were collected. Unknown insects were captured using appropriate collection protocols, then identified with the help of insect collections and literature available in the department of Entomology, Central Library and with the help of members of the advisory committee. All the

identified insect visitors along with their scientific names and systemic positions are listed in Table 1.

Table 1. List of insect pollinators' fauna of mustard crop observed and collected during Rabi 2021-22 flowering season.

S. No.	Common Name	Scientific Name	Family	Order
1	European honey bee	<i>Apis mellifera</i> Linnaeus	Apidae	Hymenoptera
2	Rock bee	<i>Apis dorsata</i> Fabricius		
3	Indian honeybee	<i>Apis cerana indica</i> Fabricius		
4	Little honeybee	<i>Apis florea</i> Fabricius		
5	Stingless bee	<i>Tetragonula laeviceps</i> Smith		
6	Small carpenter bee	<i>Ceratina sexmaculata</i> Smith		
7	Leaf cutter bee	<i>Megachile disjuncta</i> Fabricius	Megachilidae	
8	Carpenter bee	<i>Xylocopa iridipennis</i> Lepeletier	Xylocopidae	
9	Digger bee	<i>Anthophora</i> sp.	Anthophoridae	
10	Scolid wasp	<i>Scolia (Discolia) binolata</i> Fabricius	Scolidae	
11		<i>Campsomeriella</i> sp.		
12	Digger wasps	<i>Sphex</i> sp.	Sphecidae	
13	Syrphid fly	<i>Syrphus corollae</i> Fabricius	Syrphidae	Diptera
14		<i>Episyrphus veltatus</i> De Geer		
15	Hover fly	<i>Episyrphus balteatus</i> De Geer		
16		<i>Metasyrphus confrater</i> Wiedemann		
17	Drone fly	<i>Eristalis</i> sp.		
18	House fly	<i>Musca domestica</i> Linnaeus		
19	Orientalis house fly	<i>Atherigona orientalis</i> (Schiner)		
20	Tephritid fruit fly	<i>Bactrocera</i> sp.	Tephritidae	
21	Blow flies	<i>Calliphora vicina</i> Robineau-Desvoidy	Calliphoridae	
22	Green stink bug	<i>Nezara viridula</i> Linnaeus	Pentatomidae	Hemiptera
23	Shield bug	<i>Bagrada hilaris</i> Burmeister		
24	Green lacewing	<i>Chrysoperla carnea</i> (Steph.)	Chrysopidae	Neuroptera
25	Lady bird beetle	<i>Coccinella septempunctata</i> Linnaeus	Coccinellidae	Coleoptera
26		<i>Cheilomenes sexmaculata</i> Fabricius		
27	Egyptian alfalfa weevil	<i>Hypera brunneipennis</i> Boheman	Curculionidae	
28	Dragon fly	<i>Hemianax ephippiger</i> Burmister	Aeshnidae	Odonata
29	Pea blue butterfly	<i>Lampides boeticus</i> Linnaeus	Lycaenidae	Lepidoptera
30	Beet armyworm	<i>Spodoptera exigua</i> Hubner		
31	Cabbage butterfly	<i>Pieris brassicae</i> Linnaeus	Pieridae	
32	Oriental hornet	<i>Vespa orientalis</i> Linnaeus		
33	Paper wasp	<i>Polistes gallicus</i> Linnaeus	Vespidae	
34	Yellow jacket	<i>Vespula squamosa</i> Drury		
35	American bird grasshopper	<i>Schistocerca americana</i> Drury	Acrididae	Orthoptera
36	Broad-tipped katydid	<i>Neoconocephalus</i> sp.	Tettigoniidae	

A total of 36 species belonging to 8 orders viz., Hymenoptera (12), Diptera (9), Lepidoptera (6), Coleoptera (3), Hemiptera (2), Orthoptera (2), Neuroptera (1) and Odonata (1) visited mustard flowers. The Hymenopteran visitors comprising of 12 species belonging to 6 families. These species of insect pollinators were followed in order of their diversity by Dipterans comprising 9 species belonging to 4 families. The third most diverse insect order was Lepidoptera comprising 6 species belonging to 3 families. The next diverse insect order was Coleoptera comprising 3 species belonging to 2 families. The least diversified orders were Hemiptera (comprising 2 species) and

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Orthoptera (comprising 2 species from 2 families) and Neuroptera and Odonata each comprising single species. The results also revealed that Hymenopterans were the most abundant pollinators (33.33 per cent), followed by the orders Diptera (25.00 per cent), Lepidoptera (16.67 per cent), and Coleoptera (8.33 per cent) throughout the flowering season of the mustard crop, as shown in Fig. 1. The abundance of Orthoptera and Hemiptera was found to be the same, at 5.56 per cent. The orders Neuroptera and Odonata have the least pollinators, accounting for 2.78 per cent of the total.

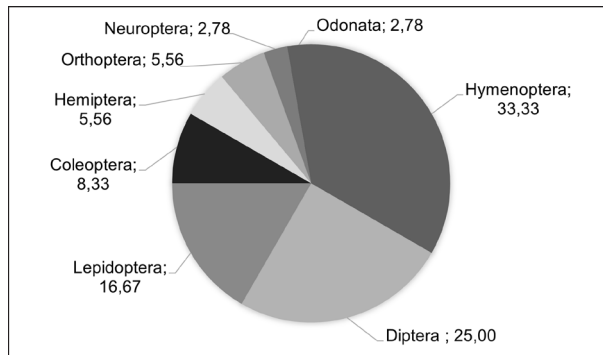


Figure 1. Per cent dominance of insect pollinators' fauna of mustard crop observed during Rabi 2021-22 flowering season.

Foraging Behaviour of Honey Bees in Mustard Crop

Bee abundance of different bee species

Observations on the abundance of different species of honey bee viz., *Apis mellifera*, *Apis dorsata*, *Apis cerana indica* on the flowers of the mustard crop are presented in Table 2. The abundance was recorded in the number of honeybees of a particular species visiting a 1 m² area of the field in 5 minutes. In general, due to very low temperatures in the morning hours in the weeks of December 2021 and January 2022, there was no honey bee activity at 0800 hrs all through the study period. However, the very negligible activity of different honey bee species was observed at 1800 hrs in the evening also.

Observations on the *Apis mellifera* abundance at weekly basis indicated that minimum abundance (10.67 bees/m²/5 min) was recorded during the first (24th December) flowering week and increased gradually with consecutive weeks up to the peak period of flowering, i.e., 4th week (15th January) with 20.50 bees/m²/5 min and later started decreasing with the cessation of flowering in the mustard crop, i.e., 7th week (5th February) with 10.83 bees/m²/5 min. The maximum abundance of *A. mellifera* bees during different day hours was reported around 1200 hrs (25.14 bees/m²/5 min), which differs considerably from typical visits at other times of the day and at 1800 hours (7.00 bees/m²/5 min), *A. mellifera* visits were at their lowest. Observations on the *Apis dorsata* abundance at weekly basis indicated that minimum abundance (5.83 bees/m²/5 min) was recorded during the first (24th December) flowering week and increased

gradually with consecutive weeks up to the peak period of flowering, i.e., 4th week (15th January) with 17.67 bees/m²/5 min and later started decreasing with the cessation of flowering in the mustard crop, i.e., 7th week (5th February) with 8.17 bees/m²/5 min. The maximum abundance of *A. dorsata* bees during different day hours was reported around 1400 hrs (19.71 bees/m²/5 min), which differs considerably from typical visits at other times of the day and at 1800 hours (3.86 bees/m²/5 min), *A. dorsata* visits were at their lowest. Observations on the *Apis cerana indica* abundance at weekly basis indicated that minimum abundance (3.50 bees/m²/5 min) was recorded during the first (24th December) flowering week and increased gradually with consecutive weeks up to the peak period of flowering, i.e., 4th week (15th January) with 9.50 bees/m²/5 min and later started decreasing with the cessation of flowering in the mustard crop, i.e., 7th week (5th February) with 4.83 bees/m²/5 min. The maximum abundance of *A. cerana indica* bees during different day hours was reported around 1000 hrs (13.14 bees/m²/5 min), which differs considerably from typical visits at other times of the day and at 1600 hrs (7.57 bees/m²/5 min), *A. cerana indica* visits were at their lowest. The comparative abundance of different bee species on the mustard crop at varied time intervals are shown in Table 3. The data revealed a significant difference and found that *A. mellifera*, *A. dorsata* and *A. indica* constituted 45.40, 34.37 and 20.23 per cent, respectively. Bees were most abundant during 1400 hrs (17.86 bees/m²/5 min) followed by the number of bees during 1200 hrs, 1000 hrs, 1600 hrs and 1800 hrs (17.14, 16.29, 12.43 and 3.62 bees/m²/5 min). As far as the abundance of different bee species at six-hour slots is concerned, it can be seen from Table 3 that the visits of different bee species varied greatly. The population density of various bees declined sharply by 1800 hrs out of three different bee species recorded during the period of investigation. The three *Apis* species were found to be fairly abundant.

Foraging speed of different bee species

Observations on the foraging speed of different honey bee species viz., *Apis mellifera*, *Apis dorsata*, *Apis cerana indica* on the flowers of the mustard crop are presented in Table 4. The foraging speed was recorded in terms of time spent (seconds) per flower. In general, due to very low temperatures in the morning hours in the weeks of December 2021 and January 2022, there was no honey bee foraging at 0800 hrs all through the study period. However, the very negligible activity of different honey bee species was observed at 1800 hrs in the evening also.

Data on the foraging speed of *A. mellifera* recorded during different weeks revealed that the maximum foraging speed of *A. mellifera* (2.95 sec) was in the fourth week and minimum foraging speed was in first week (1.49 sec) of the flowering season. As far as times of the day were concerned, the mean foraging speed of *A. mellifera* bees over different day hours revealed that maximum time spent per flower (3.66 sec) was recorded at 1400 hrs and minimum time spent per flower was recorded at 1800 h (1.46 sec). Data on the foraging speed of *A. dorsata* recorded during different weeks revealed that the maximum time spent per flower (4.06 sec) was in the fourth week and minimum foraging speed was in first week (2.49 sec) of the flowering season.

As far as times of the day were concerned, the mean foraging speed of *A. dorsata* bees over different day hours revealed that the maximum time spent per flower (6.16 sec) was recorded at 1600 hrs and minimum time spent per flower was recorded at 1800 h (1.39 sec). Data on the foraging speed of *Apis cerana indica* recorded during different weeks revealed that maximum time spent per flower (4.49 sec) was in the fourth week and minimum time spent per flower was recorded in first week (3.49 sec) of the flowering season. As far as times of the day were concerned, the mean foraging speed of *A. cerana indica* bees over different day hours revealed that the maximum time spent per flower (8.66 sec) was recorded at 1600 hrs and minimum time spent per flower was recorded at 1200 hrs (3.33 sec). The foraging speed of all three bee species on the mustard crop at varied time intervals revealed a significant difference as shown in Table 5. It was found that *A. mellifera*, *A. dorsata* and *A. indica* constituted 2.14, 3.14 and 3.91 seconds per flower. Bees spent maximum time during 1600 hrs (5.90 seconds/ flower) followed by 5.14, 3.54, 2.83 and 0.95 seconds per flower at 1400 hrs, 1000 hrs, 1200 hrs and 1800 hrs, respectively. Hence, it was found to be the least effective in pollination as it spent the highest time per flower.

Foraging rate of different bee species

Observations on the foraging rate of different species of honey bee on the flowers of the mustard crop are presented in Table 6. The foraging speed was recorded in terms of the number of flowers visited per minute. In general, due to very low temperatures in the morning hours in the weeks of December 2021 and January 2022, there was no honey bee activity at 0800 hrs all through the study period. However, the very negligible activity of different honey bee species was observed at 1800 hrs in the evening also.

Observations on the foraging rate of *A. mellifera* recorded during different weeks over the times revealed that the mean weekly foraging rate ranged between 6.67 to 20.33 flowers visited/min corresponding to the first week of the blooming period and fourth week of the blooming period which was also its peak and it gradually decreased to 8.33 flowers visited /min as flowering came to an end (seventh week). At 1200 hours, *A. mellifera* had the highest foraging rate (21.43 flowers visited/min) throughout different day hours and lowest foraging rate was recorded at 1800 hours (10.71 flowers visited/min). Observations on the foraging rate of *A. dorsata* recorded during different weeks over the times revealed that the mean weekly foraging rate ranged between 3.33 to 16.17 flowers visited/min corresponding to the first week of the blooming period and fourth week of the blooming period which was also its peak and it gradually decreased to 5.00 flowers/min as flowering came to an end (seventh week). At 1200 hours, *A. dorsata* had the highest foraging rate (16.43 flowers visited/min) throughout different day hours and lowest foraging rate was recorded at 1800 hours (6.57 flowers visited/min). Observations on the foraging rate of *A. cerana indica* recorded during different weeks over the times revealed that the mean weekly foraging rate ranged between 1.17 to 10.67 flowers visited/min corresponding to the first week of the blooming period and fourth week of the blooming period which was also its peak and it gradually decreased to 2.50 flowers/min as flowering came to an end (seventh

week). At 1200 hours, *A. cerana indica* had the highest foraging rate (12.29 flowers visited/min) throughout different day hours and lowest foraging rate was recorded at 1600 hours (5.14 flowers visited/min). The foraging rate of all three bee species on the mustard crop at varied time intervals revealed a significant difference as shown in Table 7. It was found that *A. mellifera*, *A. dorsata* and *A. indica* constituted 13.02, 9.00 and 5.71 flowers visited per minute. Bees visited maximum flowers during 1200 hrs (16.71 flowers visited/min) followed by 12.52, 10.57, 9.90 and 5.76 flowers visited/min at 1000 hrs, 1600 hrs, 1400 hrs and 1800 hrs, respectively. Hence, it was found to be the least effective in pollination as it spent the lowest number of flowers/ min.

CONCLUSIONS AND DISCUSSION

Indian mustard flowers receive more visits from different pollinators since they exhibit different behaviours and have different tastes in floral characteristics. This increased pollination activity aids in more effective pollen movement between flowers, improving fertilisation and increasing seed set. From the above results, we can conclude that a total of 36 species belonging to 8 orders. Hymenopterans were the most abundant pollinators (33.33 per cent and 12 species), followed by the orders Diptera (25.00 per cent and 9 species), Lepidoptera (16.67 per cent and 6 species), and Coleoptera (8.33 per cent and 3 species) throughout the flowering season of the mustard crop. The abundance of Orthoptera and Hemiptera was found to be the same, at 5.56 per cent and each with 2 species. The orders Neuroptera and Odonata have the least pollinators, accounting for 2.78 per cent of the total and each with single species. The current findings are in line to Kunjwal et al, (2014) who discovered 30 species from the Hymenoptera, Diptera, Lepidoptera, and Coleoptera groups visiting mustard, *B. juncea* flowers. Hymenoptera were the most important insect pollinators among them. In comparison to other bees, *A. mellifera* was shown to be the most numerous species in all kinds of *B. juncea*. In addition, Kamel et al, (2015) discovered 21 insect pollinators from 14 families and four orders visiting canola, *B. napus* flowers. Similar results were also reported by Ahmad (2005) and Abrol (1989).

The genetic diversity of populations of Indian mustard can be increased by a variety of pollinator fauna. Indian mustard's productivity is positively impacted by a diverse pollinator fauna, resulting in encouraged and efficient cross pollination and increased agricultural production. Honeybees are extremely effective pollinators and can visit a lot of flowers in one foraging trip. Since they are plentiful, more bees will visit mustard flowers, which promotes efficient and effective pollen transfer between blooms. This greater fertilisation and higher seed set as a result of the increased pollination efficiency contribute to quantifiable gains in mustard production. As in the present study, the comparative mean abundance among the various bees appearing on mustard flowers revealed that *A. mellifera* (15.29 bees/m²/5 min) was the predominant visitor followed by *A. dorsata* (11.57 bees/m²/5 min). *A. cerana indica* (6.81 bees/m²/5 min) was the least abundant visitor of mustard flowers. It was found that *A. mellifera*, *A. dorsata* and *A. indica* constituted 45.40, 34.37 and 20.23 per cent,

respectively. However, bees were most abundant during 1400 hrs (17.86 bees/m²/5 min) and least abundant during 1800 hrs (3.62 bees/m²/5 min). The current results correspond the previous findings by Singh, Dubey, Rana, & Chandrakar (2018), who found that the order Hymenoptera contributed the most percent relative abundance and average insect population, and honeybee activity was maximum at 1200 h and 1500 h, respectively. The abundance and diversity of various insect pollinators on mustard (*Brassica juncea*) were researched by Goswami & Khan (2014) and reported that the mustard bloom was visited by 19 insect pollinators from the two orders viz., Hymenoptera and Diptera, with Hymenopterans having the maximum abundance (percent of insect/ m²/2 min), followed by Dipterans and others. The most frequent Hymenopterans were honeybees (*Apis* bees), followed by non-*Apis* bees and scolid wasps. In contrast to the current findings, Roy, Gayen, Mitra, & Duttagupta (2014) indicated that insect visits were most active during the middle of the day, from 12 p.m. to 2 p.m. The abundance of *A. dorsata* was the highest (18%) among the three honey bee species, followed by *A. cerana* (15%) and *A. florea* (12%). Similar results were also reported by Khatkar (1996) and Priti (1996).

Faster foraging honeybees promote both qualitative and quantitative growth in mustard. As in the present investigation, the mean foraging speed during different hours of the day varied from 1.46 to 3.66 seconds for *A. mellifera* at 1800 hrs to 1400 hrs, respectively which was the lowest among the three species. In the end, the mean foraging speed during different hours of the day varied from 3.33 to 8.66 seconds for *A. cerana indica* 1200 hrs to 1600 hrs, respectively which was the maximum time spent per flower. The current findings are in support with the findings of Nagpal et al, (2020) who found that the average duration spent per flower by different *Apis* spp. throughout different day periods ranged from 3.25 to 4.20 seconds. Over various day periods, the average duration spent per flower by several *Apis* spp. ranged from 3.25 to 4.20 seconds. At 1200-1400 h on *Brassica juncea*, *Apis mellifera*, *Apis dorsata*, and *Apis cerana indica* spent the least amount of time per flower (2.02 seconds, 2.38 seconds, and 2.97 seconds, respectively). The present results are also supported by the previous studies conducted by Painkra & Shaw (2016) and Manhare, Painkra, Painkra, & Bhagat (2017).

Honeybees that forage more frequently can visit more flowers in a given amount of time. The probability of efficient pollen transfer between flowers rises due to this floral visitation efficiency, which boosts pollination rates. Higher foraging rates enable honeybees to travel farther and discover more flowering plants that ultimately aids in synchronising the flowering of mustard plants and increases flower density. As in the present investigation, the mean foraging rate during different hours of the day varied from 10.71 to 21.43 flowers visited/min for *A. mellifera* during 1800 to 1200 hrs, respectively which was the highest among the three species. Hence, it was found to be most effective in pollination as it spent the highest number of flowers/min. In the end, the mean foraging rate during different hours of the day varied from 5.14 to 12.29 flowers visited/min for *A. mellifera* during 1800 to 1200 hrs, respectively being the lowest. The current findings are in agreement with those of the other researchers.

According to Choudhary & Singh (2007) the mean foraging rate of *A. mellifera* (5.0) was greater than that of *A. dorsata* (3.92) and *A. florea* (2.91). Because of the low temperature and fog water deposited on the floral parts, *A. mellifera* was not seen on coriander flowers until 07:00 h, but its population grew afterwards. At 14:00 h, the greatest foraging rate of *A. mellifera* was reported (13.6 umbels visited min⁻¹). This species visited an average of 1 plant and a maximum of 3.10 plants per five minutes. Also, Kumar, Singh, & Chand (2003), found that the foraging rate (number of capitulum visited by bees/minutes) indicated that *Apis mellifera* visited a larger number of capitulum (12.85) as compared to *Apis cerana indica* (10.98). For both species, the foraging rate was highest at 1:00 p.m. and lowest at 10:00 a.m.

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Table 2. Abundance of different honeybee species on the flowers of mustard under open pollination during Rabi 2021-22.

SMW	Bee Abundance of <i>Apis mellifera</i> (No. of bees/ m ² / 5min) Hours of the day						Bee Abundance of <i>Apis dorsata</i> (No. of bees/ m ² / 5min) Hours of the day						Bee Abundance of <i>Apis cerana indica</i> (No. of bees/ m ² / 5min) Hours of the day													
	800	1000	1200	1400	1600	1800	Mean	800	1000	1200	1400	1600	1800	Mean	800	1000	1200	1400	1600	1800	Mean	800	1000	1200	1400	1600
52	0.00 (1.0)	13.00 (3.74)	20.00 (4.58)	17.00 (4.24)	14.00 (3.87)	10.00 (3.07)	10.67 (3.07)	0.00 (1.0)	9.00 (3.16)	8.00 (3.0)	7.00 (3.46)	7.00 (2.83)	0.00 (1.0)	5.83 (2.41)	0.00 (3.0)	8.00 (3.0)	7.00 (2.83)	6.00 (2.65)	0.00 (1.0)	3.50 (1.91)						
1	0.00 (1.0)	19.00 (4.47)	25.00 (5.1)	23.00 (4.9)	17.00 (4.24)	10.00 (3.45)	14.00 (4.02)	0.00 (1.0)	18.00 (4.36)	15.00 (4.0)	20.00 (4.58)	10.00 (3.32)	0.00 (1.0)	10.50 (3.04)	13.00 (3.74)	11.00 (3.46)	9.00 (3.16)	9.00 (3.16)	0.00 (1.0)	7.00 (2.59)						
2	0.00 (1.0)	21.00 (4.69)	26.00 (5.2)	30.00 (5.57)	18.00 (4.36)	10.00 (3.32)	17.50 (4.02)	0.00 (1.0)	22.00 (4.8)	17.00 (4.24)	24.00 (5.0)	14.00 (3.87)	0.00 (1.0)	14.17 (3.65)	16.00 (4.12)	13.00 (3.74)	11.00 (3.46)	10.00 (3.32)	0.00 (1.0)	8.33 (2.77)						
3	0.00 (1.0)	23.00 (4.9)	33.00 (5.83)	20.00 (5.74)	15.00 (4.58)	10.00 (4.0)	20.50 (4.34)	0.00 (1.0)	26.00 (5.2)	23.00 (4.9)	27.00 (5.29)	20.00 (4.58)	0.00 (1.0)	17.67 (4.05)	18.00 (4.36)	15.00 (4.0)	13.00 (3.74)	11.00 (3.46)	0.00 (1.0)	9.50 (2.93)						
4	0.00 (1.0)	19.00 (4.47)	31.00 (5.66)	30.00 (5.57)	19.00 (4.47)	13.00 (3.74)	18.67 (4.15)	0.00 (1.0)	21.00 (4.69)	18.00 (4.36)	22.00 (4.8)	16.00 (3.61)	0.00 (1.0)	14.33 (3.69)	17.00 (4.24)	14.00 (3.87)	12.00 (3.61)	10.00 (3.32)	0.00 (1.0)	8.83 (2.84)						
5	0.00 (1.0)	15.00 (4.0)	24.00 (5.0)	22.00 (4.8)	17.00 (4.24)	11.00 (3.75)	14.83 (3.75)	0.00 (1.0)	17.00 (4.24)	14.00 (3.87)	19.00 (4.47)	12.00 (3.61)	0.00 (1.0)	10.33 (3.03)	11.00 (3.46)	9.00 (2.83)	7.00 (2.83)	6.00 (2.38)	0.00 (1.0)	5.87 (2.38)						
6	0.00 (1.0)	13.00 (3.74)	17.00 (4.24)	19.00 (4.47)	16.00 (4.12)	10.83 (3.1)	10.83 (3.1)	0.00 (1.0)	14.00 (3.87)	12.00 (3.61)	15.00 (4.0)	8.00 (3.0)	0.00 (1.0)	8.17 (2.75)	9.00 (3.16)	8.00 (3.0)	6.00 (2.65)	6.00 (2.65)	0.00 (1.0)	4.83 (2.24)						
Mean	0.00 (1.0)	17.57 (4.29)	25.14 (5.09)	24.71 (5.04)	17.29 (4.27)	7.00 (2.5)	-	0.00 (1.0)	18.14 (4.33)	15.29 (4.0)	19.71 (4.52)	12.43 (3.62)	3.86 (1.93)	-	0.00 (1.0)	13.14 (3.73)	11.00 (3.44)	9.14 (2.82)	7.57 (2.82)	0.00 (1.0)						

*figures in parentheses are square root transformed values.

Table 3. Comparative abundance of different honey bee species on the flowers of mustard crop under open pollination during Rabi 2021-22.

Foraging time (Hours of the day)	Bee Abundance (No. of bees/ m ² / 5min)					
	<i>Apis mellifera</i>		<i>Apis dorsata</i>		<i>Apis cerana indica</i>	
	SE(m)	C.D. (p= 0.05)	SE(m)	C.D. (p= 0.05)	SE(m)	C.D. (p= 0.05)
800	0.00 ± 0.00		0.00 ± 0.00		0.00 ± 0.00	
1000	17.57 ± 1.49		18.14 ± 2.11		13.14 ± 1.50	
1200	25.14 ± 2.13		15.29 ± 1.80		11.00 ± 1.18	
1400	24.71 ± 2.24		19.71 ± 2.04		9.14 ± 1.10	
1600	17.29 ± 0.75		12.43 ± 1.74		7.57 ± 1.43	
1800	7.00 ± 2.54		3.86 ± 1.83		0.00 ± 0.00	
Mean	15.29		11.57		6.81	
% of total bees	45.40		34.37		20.23	

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Table 4: Foraging speed of different honeybee species on the flowers of mustard crop under open pollination during Rabi 2021-22.

SMW	Foraging Speed of <i>Apis mellifera</i> (sec/ flower) Hours of the day					Foraging Speed of <i>Apis dorsata</i> (sec/ flower) Hours of the day					Foraging Speed of <i>Apis cerana indica</i> Hours of the day										
	800	1000	1200	1400	1600	1800	Mean	800	1000	1200	1400	1600	1800	Mean	800	1000	1200	1400	1600	1800	Mean
52	0.00 (1)	2.19 (1.79)	2.01 (1.73)	2.51 (1.87)	2.22 (1.79)	0.00 (1)	1.49 (1.53)	0.00 (1)	3.21 (2.05)	2.51 (1.87)	4.22 (2.28)	5.01 (2.45)	0.00 (1)	2.49 (1.78)	0.00 (1)	4.21 (2.28)	3.01 (2)	6.22 (2.69)	7.51 (2.92)	0.00 (1)	3.49 (1.98)
1	0.00 (1)	2.43 (1.85)	2.22 (1.79)	2.98 (1.99)	2.59 (1.89)	0.00 (1)	1.70 (1.59)	0.00 (1)	3.51 (2.12)	2.72 (1.93)	4.59 (2.36)	5.48 (2.55)	0.00 (1)	2.72 (1.83)	0.00 (1)	4.51 (2.35)	3.22 (2.05)	6.59 (2.75)	7.98 (3)	0.00 (1)	3.72 (2.03)
2	0.00 (1)	2.62 (1.9)	2.43 (1.85)	3.82 (2.2)	3.15 (2.04)	2.54 (1.88)	2.43 (1.81)	0.00 (1)	3.62 (2.15)	2.93 (1.98)	5.15 (2.48)	6.32 (2.71)	3.14 (2.03)	3.53 (2.06)	0.00 (1)	4.62 (2.37)	3.43 (2.1)	7.15 (2.85)	8.82 (3.13)	0.00 (1)	4.00 (2.08)
3	0.00 (1)	2.92 (1.98)	2.62 (1.9)	5.97 (2.64)	3.42 (2.1)	2.75 (1.94)	2.95 (1.93)	0.00 (1)	3.92 (2.22)	3.12 (2.03)	5.42 (2.53)	8.47 (3.08)	3.42 (2.1)	4.06 (2.16)	0.00 (1)	4.92 (2.43)	3.62 (2.15)	7.42 (2.9)	10.97 (3.46)	0.00 (1)	4.49 (2.16)
4	0.00 (1)	2.59 (1.89)	2.53 (1.88)	4.12 (2.26)	3.22 (2.05)	2.55 (1.88)	2.50 (1.83)	0.00 (1)	3.59 (2.14)	3.03 (2.01)	5.22 (2.49)	6.62 (2.76)	3.16 (2.04)	3.60 (2.07)	0.00 (1)	4.59 (2.36)	3.53 (2.13)	7.22 (2.87)	9.12 (3.18)	0.00 (1)	4.08 (2.09)
5	0.00 (1)	2.42 (1.85)	2.39 (1.84)	3.51 (2.12)	2.99 (2)	2.39 (1.84)	2.28 (1.78)	0.00 (1)	3.71 (2.17)	2.89 (1.97)	4.99 (2.45)	6.01 (2.65)	0.00 (1)	2.93 (1.87)	0.00 (1)	4.71 (2.39)	3.39 (2.1)	6.99 (2.83)	8.51 (3.08)	0.00 (1)	3.93 (2.07)
6	0.00 (1)	2.25 (1.8)	2.14 (1.77)	2.74 (1.93)	2.57 (1.89)	0.00 (1)	1.62 (1.57)	0.00 (1)	3.41 (2.1)	2.64 (1.91)	4.57 (2.36)	5.24 (2.5)	0.00 (1)	2.64 (1.81)	0.00 (1)	4.41 (2.33)	3.14 (2.03)	6.57 (2.75)	7.74 (2.96)	0.00 (1)	3.64 (2.01)
Mean	0.00 (1)	17.42 (1.87)	16.34 (1.83)	25.65 (2.15)	20.16 (1.97)	10.23 (1.51)	-	0.00 (1)	24.96 (2.14)	19.84 (1.96)	34.16 (2.42)	43.15 (2.67)	9.71 (1.45)	-	0.00 (1)	31.96 (2.36)	23.34 (2.08)	48.16 (2.81)	60.65 (3.1)	0.00 (1)	-

*figures in parentheses are square root transformed values.

Factors	<i>Apis mellifera</i>		<i>Apis dorsata</i>		<i>Apis cerana indica</i>	
	SE(m)	C.D. (p= 0.05)	SE(m)	C.D. (p= 0.05)	SE(m)	C.D. (p= 0.05)
SMW	0.027	0.076	0.024	0.068	0.023	0.065
Time	0.025	0.070	0.022	0.063	0.021	0.061
SMW x Time	0.066	0.186	0.059	0.167	0.057	N/A

Table 5. Comparative foraging speed of different honey bee species on the flowers of mustard crop under open pollination during Rabi 2021-22.

Foraging time (Hours of the day)	Foraging Speed (sec/ flower)		
	<i>Apis mellifera</i>	<i>Apis dorsata</i>	<i>Apis cerana indica</i>
800	0.00 ± 0.00	0.00 ± 0.00	0.00
1000	2.49 ± 0.09	3.57 ± 0.08	4.57 ± 0.08
1200	2.33 ± 0.08	2.83 ± 0.08	3.33 ± 0.08
1400	3.66 ± 0.44	4.88 ± 0.16	6.88 ± 0.16
1600	2.88 ± 0.16	6.16 ± 0.44	8.66 ± 0.44
1800	1.46 ± 0.52	1.39 ± 0.65	0.00 ± 0.00
Mean	2.14	3.14	3.91

Table 6. Foraging rate of different honeybee species on the flowers of mustard crop under open pollination during Rabi 2021-22.

SMW	Foraging Rate of <i>Apis mellifera</i> (No. of flower/ min) Hours of the day						Foraging Rate of <i>Apis dorsata</i> (No. of flower/ min) Hours of the day						Foraging Rate of <i>Apis cerana indica</i> (No. of flower/ min) Hours of the day							
	800	1000	1200	1400	1600	1800	Mean	800	1000	1200	1400	1600	1800	Mean	800	1000	1200	1400	1600	1800
52	0.00 (1)	9.00 (3.16)	13.00 (3.74)	7.00 (2.83)	11.00 (3.46)	0.00 (1)	6.67 (2.53)	0.00 (1)	6.67 (2.65)	8.00 (3)	4.00 (2.24)	2.00 (1.73)	0.00 (1)	3.33 (2.08)	0.00 (1)	2.00 (1.73)	4.00 (2.24)	1.00 (1.41)	1.00 (1)	1.17 (1.4)
1	0.00 (1)	14.00 (3.87)	21.00 (4.69)	13.00 (3.74)	17.00 (4.24)	0.00 (1)	10.83 (3.09)	0.00 (1)	11.00 (3.46)	16.00 (4.12)	9.00 (3.16)	8.00 (3)	0.00 (1)	7.33 (2.89)	0.00 (1)	8.00 (3)	12.00 (3.61)	6.00 (2.65)	5.00 (2.45)	5.17 (2.28)
2	0.00 (1)	17.00 (4.24)	26.00 (5.2)	16.00 (4.12)	22.00 (4.8)	18.00 (4.36)	16.50 (3.95)	0.00 (1)	17.00 (4.24)	21.00 (4.69)	12.00 (3.61)	11.00 (3.46)	0.00 (1)	14.00 (3.87)	0.00 (1)	13.00 (3.74)	17.00 (4.24)	10.00 (3.32)	8.00 (2.72)	8.00 (2.72)
3	0.00 (1)	22.00 (4.8)	30.00 (5.57)	19.00 (4.47)	27.00 (5.29)	24.00 (5)	20.33 (4.35)	0.00 (1)	22.00 (4.8)	25.00 (5.1)	17.00 (4.24)	14.00 (3.87)	0.00 (1)	16.17 (4.47)	0.00 (1)	18.00 (4.36)	21.00 (4.69)	14.00 (3.87)	11.00 (3.46)	10.67 (3.06)
4	0.00 (1)	16.00 (4.12)	25.00 (5.1)	15.00 (4)	22.00 (4.8)	19.00 (4.47)	16.17 (3.92)	0.00 (1)	17.00 (4.24)	20.00 (4.58)	11.00 (3.32)	10.00 (3.46)	0.00 (1)	11.83 (3.58)	0.00 (1)	15.00 (4)	16.00 (4.12)	11.00 (3.46)	7.00 (2.83)	8.17 (2.74)
5	0.00 (1)	12.00 (3.61)	19.00 (4.47)	18.00 (3.46)	14.00 (4.36)	14.00 (3.87)	12.33 (3.46)	0.00 (1)	12.00 (3.61)	14.00 (3.87)	9.00 (3.16)	6.00 (2.65)	0.00 (1)	6.83 (2.8)	0.00 (1)	9.00 (3.16)	10.00 (3.32)	4.00 (2.24)	3.00 (2)	4.33 (2.12)
6	0.00 (1)	11.00 (3.46)	16.00 (4.12)	10.00 (3.32)	13.00 (3.74)	0.00 (1)	8.33 (2.77)	0.00 (1)	8.00 (3)	11.00 (3.46)	6.00 (2.65)	5.00 (2.45)	0.00 (1)	5.00 (2.45)	0.00 (1)	4.00 (2.24)	6.00 (2.65)	3.00 (2)	2.00 (1.73)	2.50 (1.77)
Mean	0.00 (1)	101.00 (3.9)	150.00 (4.7)	91.00 (3.71)	130.00 (4.36)	75.00 (2.96)	-	0.00 (1)	93.00 (3.78)	115.00 (4.17)	68.00 (3.27)	56.00 (3)	46.00 (2.75)	-	0.00 (1)	9.86 (3.18)	12.29 (3.55)	7.00 (2.71)	5.14 (2.35)	0.00 (1)

*figures in parentheses are square root transformed values.

Factors	<i>Apis mellifera</i>		<i>Apis dorsata</i>		<i>Apis cerana indica</i>	
	SE(m)	C.D. (p= 0.05)	SE(m)	C.D. (p= 0.05)	SE(m)	C.D. (p= 0.05)
SMW	0.013	0.037	0.018	0.050	0.024	0.068
Time	0.012	0.034	0.016	0.046	0.022	0.063
SMW x Time	0.032	0.090	0.043	0.123	0.059	0.168

Table 7. Comparative foraging rate of different honey bee species on the flowers of mustard crop under open pollination during Rabi 2021-22.

Foraging time (Hours of the day)	Mean number of flowers visited/ min		
	<i>Apis mellifera</i>	<i>Apis dorsata</i>	<i>Apis cerana indica</i>
800	0.00 ± 0.00	0.00 ± 0.00	0.00
1000	14.43 ± 0.09	13.29 ± 0.08	9.86 ± 0.08
1200	21.43 ± 0.08	16.43 ± 0.08	12.29 ± 0.08
1400	13.00 ± 0.44	9.71 ± 0.16	7.00 ± 0.16
1600	18.57 ± 0.16	8.00 ± 0.44	5.14 ± 0.44
1800	10.71 ± 0.52	6.57 ± 0.65	0.00 ± 0.00
Mean	13.02	9.00	5.71