

# Diversity, abundance and foraging behaviour of pollinators in early sown rapeseed-mustard genotypes



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## Summary

A study was carried out on the diversity, abundance and foraging behaviour of pollinators in early sown rapeseed-mustard genotypes through observing a total of 17 insect species visited flowers of early sown genotypes viz., 9 Hymenopterans, 3 Dipterans, 4 Lepidopterans, and 1 Coleopteran. The abundance (bees/m<sup>2</sup>/5 min) of *A. florea* was highest (8.5) followed by *A. mellifera* (3.9), *A. dorsata* (3.6) and *A. cerana* (3.1). The abundance of bee species was maximum (5.6 bees/m<sup>2</sup>/5 min) in genotypes TH 68 and SANGAM. *A. cerana* foraged a maximum number of flowers per minute (18.20) followed by *A. dorsata* (17.57), *A. mellifera* (17.32) and *A. florea* (6.45). The foraging rate (flowers/min) of all bee species was maximum (14.98 and 14.90) in genotypes TH 68 and SANGAM. Time spent per flower (sec) was maximum (5.3) by *A. florea* followed by *A. dorsata* (1.7), *A. mellifera* (1.6) and *A. cerana indica* (1.3). The maximum time spent per flower by all bee species (2.6) was in genotype PDZ 9. Nectar or pollen gatherers were maximum in *A. dorsata* (37.8% and 25.6%, respectively), while both nectar and pollen gatherers were maximum in *A. cerana* (45.3%). Nectar foraging, pollen foraging and both nectar and pollen foraging were maximum at peak flowering (36.0%), peak flowering (23.8%) and flowering cessation (42.9%), respectively. Out of the total foragers, top workers were maximum in *A. dorsata* (97.8%), while side workers were maximum in *A. florea* (41.0%).

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## INTRODUCTION

India occupies a premier position on the global oilseed map, about acreage as well as production. Rapeseed-mustard is the second most important crop of the Indian oilseed economy after soybean in terms of area (24%) and production (25%) but stands first (23%) in edible oil production.<sup>17</sup> Rapeseed-mustard is a group of crops described under the genus *Brassica* in the plant family Brassicaceae (Cruciferae). The oilseed *Brassica* species grown in India are: *Brassica juncea* (L.) Czern. (Indian mustard), *B. rapa* Linnaeus (toria, brown sarson and yellow sarson), *B. napus* L. (gobhi sarson), *B. carinata* A. Braun (Karan Rai) and *B. nigra* (L.) K. Koch (Black mustard). These are cultivated over an area of 5.75 million ha with production and productivity of 6.80 million tonnes and 1183 Kg/ha respectively in India. Rapeseed-

mustard is an important Rabi season crop of Bhiwani, Mahendergarh, Rewari, Hisar, Sirsa, Jhajjar, Mewat and Rohtak districts of Haryana state. Haryana is the third most crucial rapeseed-mustard producing state in the country with an area of 0.53 million ha, production of 0.90 million tonnes and productivity of 1721 Kg/ha (2015-2016) which is the highest in the country. Out of various *Brassica* spp., Indian mustard, commonly known as raya accounts for more than 80% of the total area under rapeseed-mustard cultivation in India.<sup>22</sup> The abundance and foraging behaviour of honey bees varies from species to species and genotype to genotype of the host plants. Other factors such as flower structure, shape, size, colour, flavor, aroma, nectar availability and nectar concentration affect the frequency and foraging behaviour of honey bees to bloom. Honey bees possess a high degree of acuteness for these cues and act according to these cues. Nectar and pollen act as primary rewards for pollinator visitation frequency to wild and cultivated plants, and calories from flower nectar affect bee growth and development.<sup>6, 24, 29</sup> Honey bees respond to specific odours of nectar (relative attractiveness to

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flowers) and the number of harvestable nectars influences the frequency of visits of honey bees to flowers. The sugar concentration in nectar and its access is an essential factor influencing bee visits.<sup>27</sup> The amount of nectar and its concentration differs in different plant species and in different genotypes of the same plant species. It also changes throughout the day and from one day to the next day.<sup>7</sup>

### Materials and Methods

The studies were conducted to determine the diversity, abundance and foraging behaviour of pollinators on different genotypes (LES 54, PDZ 9, TH 68, SANGAM, NPJ 112 and RH 725) in the following materials and methods were used for carrying out the research.

#### Diversity of insect visitors

Insect visitors of different genotypes were collected by using a cone-type hand net following the standard protocol. The collection was done through sweeps at two-hour intervals during different day hours from 0900 to 1700 hrs. Collected insects were killed and preserved dry in a wooden insect box for further identification. The

collected and preserved insects were identified by comparing them with the reference collection maintained at the Apiculture Laboratory, Department of Entomology, CCS HAU, Hisar (Haryana) (Plate. 1-4).

#### The abundance of insect visitors

The abundance of significant insect pollinators (*Apis* spp.) on different rapeseed-mustard genotypes was recorded per square meter area of the crop for two minutes using a hand tally counter following the method given by Free (1993).<sup>12</sup>

#### Foraging rate

The foraging rates of different *Apis* spp. were recorded in terms of the number of flowers visited per minute.

#### Foraging speed

The foraging speed of honeybees was recorded in terms of the time spent by each species on a flower. Twenty bees were observed for foraging speed and each flower was considered as one replication. The handling time of the flower was considered as the time spent by the floral visitor on the flower between the alighting of the honeybee and its final departure from the flower.



Plate 1: *Apis mellifera* foraging on mustard flowers



Plate 2: *Apis cerana*



Plate 3: *Apis dorsata*



Plate 4: *Apis florea*

### Foraging behaviour

Individuals of *Apis* spp. were observed for their working behaviour, i.e., whether they are working from top or side, whether foraging for nectar or pollen or both and the peak activity and cessation time of different bee species. A total of 20 bees of each species were observed for this purpose.

### Results and Discussion

#### Diversity of insect visitors/pollinators on flowers of early sown rapeseed-mustard genotypes

In the present study conducted at Hisar (Haryana) in 2018, the bloom of rapeseed-mustard genotypes was visited by a total of seventeen insect species belonging to nine families of four different orders (Table 1). Hymenopterans were the major insect visitors

comprising nine insect species from three families viz. Apidae (*Apis mellifera* Linnaeus, *Apis cerana* Fabricius, *Apis dorsata* Fabricius, *Apis florea* Fabricius, *Trigona* spp., *Xylocopa fenestra* Fabricius, *Xylocopa pubescens* Spinola), Andrenidae (*Andrena* spp.), and Halictidae (*Lasioglossum* spp.). They were followed in order of diversity by lepidopterans comprising four species from three families viz. Nymphalidae (*Danaus* spp., *Venessa cardui* Linnaeus), Pieridae (*Pieris brassicae* Linnaeus) and Crambidae (*Hymenia recurvalis* Fabricius), dipterans (three species from two families) viz. Syrphidae (*Episyrphus* spp., *Eristalinus* spp.) and Calliphoridae (*Chrysomya* spp.) and Coleoptera (*Cetonia* spp. from Scarabaeidae family). Out of these pollinators, *Hymenia recurvalis* was observed on TH 68 genotype at peak flowering and *Cetonia* spp. was observed on genotype SANGAM at flowering initiation.

**Table 1: Diversity of insect visitors on different early sown rapeseed mustard genotypes at Hisar during 2018**

| S. No. | Scientific Name                      | Family        | Order       |
|--------|--------------------------------------|---------------|-------------|
| 1      | <i>Apis mellifera</i> Linnaeus       | Apidae        | Hymenoptera |
| 2      | <i>Apis cerana</i> Fabricius         | Apidae        | Hymenoptera |
| 3      | <i>Apis dorsata</i> Fabricius        | Apidae        | Hymenoptera |
| 4      | <i>Apis florea</i> Fabricius         | Apidae        | Hymenoptera |
| 5      | <i>Trigona</i> spp.                  | Apidae        | Hymenoptera |
| 6      | <i>Xylocopa fenestrata</i> Fabricius | Apidae        | Hymenoptera |
| 7      | <i>Xylocopa pubescens</i> Spinola    | Apidae        | Hymenoptera |
| 8      | <i>Andrena</i> spp.                  | Andrenidae    | Hymenoptera |
| 9      | <i>Lasioglossum</i> spp.             | Halictidae    | Hymenoptera |
| 10     | <i>Danaus</i> spp.                   | Nymphalidae   | Lepidoptera |
| 11     | <i>Venessa cardui</i> Linnaeus       | Nymphalidae   | Lepidoptera |
| 12     | <i>Pieris brassicae</i> Linnaeus     | Pieridae      | Lepidoptera |
| 13     | <i>Hymenia recurvalis</i> Fabricius* | Crambidae     | Lepidoptera |
| 14     | <i>Episyrphus</i> spp.               | Syrphidae     | Diptera     |
| 15     | <i>Eristalinus</i> spp.              | Syrphidae     | Diptera     |
| 16     | <i>Chrysomya</i> spp.                | Calliphoridae | Diptera     |
| 17     | <i>Cetonia</i> spp.**                | Scarabaeidae  | Coleoptera  |

\* Observed foraging for nectar only on genotype TH 68 during peak flowering;

\*\* Observed foraging for pollen only on genotype SANGAM during flowering initiation

Among these floral visitors, *A. mellifera*, *A. cerana*, *A. dorsata* and *A. florea* were the most frequent visitors of the crop bloom which were studied in detail. Generally, the floral visitor fauna varies according to the geographical area and it has been documented very well by many workers. Giri et al. (2018)<sup>13</sup> observed that hymenopterans (family Apidae namely; *A. dorsata*, *A. mellifera*, *Trigona irridipennis* Smith) 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)<sup>9</sup> 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* Linnaeus, *Chrysomya* spp. and *Sarcophaga* spp.) and 2 species to order Lepidoptera (*Amata bicincta* Kollar and *Pieris* spp.). Abrol & Bajjiya (2017)<sup>1</sup> found 15

species of insects belonging to 4 orders and 7 families of insects visiting mustard (*Brassica napus* L.) bloom. Hymenopterans were found to be the most abundant. Nagpal (2016)<sup>23</sup> observed sixteen species of insect pollinators belonging to nine families of four different orders visiting Indian mustard bloom and hymenopterans were the key pollinators comprising of eight species followed by five species of dipterans, two species of lepidopterans and one species of hemipterans. Pudasaini et al. (2015)<sup>26</sup> found twenty-one species of insects belonging to six different insect orders viz. Hymenoptera (77.95%), Diptera (12.23%), Lepidoptera (3.49%), Coleoptera (2.18%), Heteroptera (2.18%) and Orthoptera (1.97%). Atmowidi et al. (2007)<sup>4</sup> reported 19 species of pollinators from four orders namely Hymenoptera (95%), Lepidoptera (2.17%), Coleoptera (2.07%) and Diptera (1%) visiting the flowers of mustard out of which the following three species, i.e., *A. cerana* (43.1%), *Ceratina* spp. (37%), and *A. dorsata* (8.4%) showed the greatest abundance.

**An abundance of honey bees on flowers of early sown rapeseed-mustard genotypes**

The results corresponding to the abundance of major pollinators on flowers of different early sown rapeseed-mustard genotypes clearly indicated that the abundance (number of foragers/m<sup>2</sup>/2 min) of major flower visitors varied significantly in the genotypes at different flowering stages and time intervals of flowering. In the present study, the highest mean abundance was of *A. florea* (8.5 bees/m<sup>2</sup>/2 min), followed by *A. mellifera* (3.9 bees/m<sup>2</sup>/2 min), *A. dorsata* (3.6 bees/m<sup>2</sup>/2 min) and *A. cerana* (3.1 bees/m<sup>2</sup>/2 min) (Table 2). Among the genotypes, TH 68 and NPJ 112 had the maximum mean abundance of all the major pollinators (5.6 bees/m<sup>2</sup>/2 min), followed by SANGAM (5.2 bees/m<sup>2</sup>/2 min), RH 725 (4.6 bees/m<sup>2</sup>/2 min), PDZ 9 and LES 54 (4.0 and 3.9 bees/m<sup>2</sup>/2 min). The abundance of pollinators was maximum at peak flowering which was followed by flowering initiation and flowering cessation. Also, the peak activity of different bee species varied with time during the working hours of bee species i.e., maximum abundance of *A. mellifera* and *A. cerana* was observed at 1100 to 1300 h whereas *A. dorsata* and *A. florea* showed maximum abundance at 0900 to 1100 h of the day and thereafter, the activity of all the bee species was reported to decrease.

**Table 2: Comparative mean abundance of honey bees on different early sown rapeseed-mustard genotypes at Hisar during 2018**

| Floral visitors       | Mean number of foragers/m <sup>2</sup> /2 min |          |          |          |          |          | Mean |
|-----------------------|---|----------|----------|----------|----------|----------|------|
|                       | LES 54  | PDZ 9    | TH 68    | SANGAM   | NPJ 112  | RH 725   |      |
| <i>Apis mellifera</i> | 3.6(2.1)                                      | 3.1(2.0) | 4.4(2.3) | 4.1(2.2) | 4.8(2.3) | 3.6(2.1) | 3.9  |
| <i>Apis cerana</i>    | 2.4(1.8)                                      | 2.3(1.8) | 4.0(2.2) | 3.1(2.0) | 3.8(2.1) | 2.8(1.9) | 3.1  |
| <i>Apis dorsata</i>   | 3.0(2.0)                                      | 3.1(2.0) | 4.9(2.4) | 3.9(2.2) | 3.8(2.1) | 3.1(2.0) | 3.6  |
| <i>Apis florea</i>    | 6.6(2.7)                                      | 7.4(2.9) | 9.0(3.1) | 9.6(2.4) | 9.9(3.2) | 8.7(3.1) | 8.5  |
| <b>Mean</b>           | 3.9(2.2)                                      | 4.0(2.2) | 5.6(2.5) | 5.2(3.1) | 5.6(2.5) | 4.6(2.3) |      |
| <b>C.D. (p≤0.05)</b>  | 1.15  | 1.07     | 1.27     | 1.15     | 1.99     | 1.13     |      |
| <b>S.E (m)</b>        | 0.41  | 0.38     | 0.79     | 0.71     | 1.23     | 0.70     |      |

Values are means of 75 observations (No. of days= 5; Periods of observation= 5; Replications= 3); Figures in parentheses are means of √ n+1 transformed values

Giri et al. (2018)<sup>13</sup> found that *A. dorsata* dominated species with 7.25 bees/plant/5 min and the abundance of insect pollinators was maximum in the afternoon (3.00-4.00 PM) with 31.56 pollinators /plant/5 min. Abrol & Bajija (2017)<sup>7</sup> found that *A. mellifera* was most abundant (28.09, 28.31%) in *B. napus* bloom followed by *A. cerana* (25.10, 25.48%), *A. dorsata* (18.00, 18.09%), *A. florea* (8.53, 7.90%) and *X. fenestrata* (5.55, 5.71 %). Nagpal (2016)<sup>23</sup> observed that the abundance of *A. dorsata* was highest among the bee species i.e., 4.29 bees/m<sup>2</sup>/5 min followed by *A. cerana indica* (2.82 bees/m<sup>2</sup>/5 min), *A. mellifera* (2.33 bees/m<sup>2</sup>/5 min) and *A.*

*florea* (1.74 bees/m<sup>2</sup>/5 min). Pudasaini et al. (2015)<sup>26</sup> found that *A. mellifera* was the most abundant one (36.34%); followed by *A. florea* (12.45%), *A. cerana* (11.14%) and *A. dorsata* (5.68%) along with *Andrena* spp. (3.71%) and *Megachilus* spp. (0.66%). Atmowidi et al. (2007)<sup>4</sup> reported that the following three species, i.e. *A. cerana* (43.1%), *Ceratina* spp. (37%), and *A. dorsata* (8.4%) showed the greatest abundance.

**Foraging behaviour of honey bees**

Generally, the foraging activity of diurnal pollinators starts with the sunrise, but the visitation frequency and flight activity of pollinators are found to be greatly

impacted by the flowering intensity, anthesis of flowers and various weather factors such as temperature, relative humidity, wind speed, sunshine hours and rainfall. The data on the foraging period of different bee species on different genotypes at various flowering stages revealed the foraging activity of *Apis* spp. varied with the flowering stages of the crop. The earliest initiation of foraging activity by the foragers of *A. mellifera*, *A. cerana*, *A. dorsata*

and *A. florea* (0840, 0845, 0830 and 0835 h respectively in the morning) was observed at flowering initiation (Table 3). The peak activity of *A. mellifera* and *A. cerana* was observed at 1200-1400 h whereas that of *A. dorsata* and *A. florea* was observed at 1000-1200 h of the day. The activity of all bee species decreased after 1600 h in the evening during the investigation period, and no action was observed after 1800 h.

**Table 3: Initiation and cessation time of different bee species on rapeseed-mustard genotypes under early sown conditions at Hisar during 2018**

| Weeks                                | Bee species         | Activity time (h) |           |                     |
|--------------------------------------|---------------------|-------------------|-----------|---------------------|
|                                      |                     | Initiation        | Cessation | Total working hours |
| 09-11-2018<br>(Flowering initiation) | <i>A. mellifera</i> | 0840              | 1715      | 0835                |
|                                      | <i>A. cerana</i>    | 0845              | 1710      | 0825                |
|                                      | <i>A. dorsata</i>   | 0830              | 1715      | 0845                |
|                                      | <i>A. florea</i>    | 0835              | 1700      | 0825                |
| 01-12-2018<br>(Peak flowering)       | <i>A. mellifera</i> | 0915              | 1635      | 0720                |
|                                      | <i>A. cerana</i>    | 0915              | 1630      | 0715                |
|                                      | <i>A. dorsata</i>   | 0855              | 1630      | 0735                |
|                                      | <i>A. florea</i>    | 0905              | 1620      | 0715                |
| 22-12-2018<br>(Flowering cessation)  | <i>A. mellifera</i> | 0940              | 1610      | 0630                |
|                                      | <i>A. cerana</i>    | 0930              | 1615      | 0640                |
|                                      | <i>A. dorsata</i>   | 0915              | 1625      | 0715                |
|                                      | <i>A. florea</i>    | 0940              | 1545      | 0705                |

The present findings agree with the findings of Akhtar et al. (2018)<sup>3</sup>, who reported that the peak activity of *Apis* spp. was observed at noon. Dalio (2018)<sup>8</sup> said that *Apis* species reached the highest foraging rate at 1200 h on the parental lines of *B. napus*. Mandal et al. (2018)<sup>20</sup> reported a maximum abundance of pollinators at 11.00 h of the day. Srivastava et al. (2017)<sup>30</sup> found that the activity of *A. mellifera*, *A. dorsata* and *A. cerana* started from 10.00 a.m. in considerable numbers, while *A. florea* and syrphids started foraging at 10:00 h in a few numbers. The foraging activity of *A. mellifera* kept on increasing from 10.00 to 02.00 p.m. and gradually declined after that to 05.00 p.m.; on the other hand, the movement of *A. cerana* was reported highest in the morning hours at 10.00 - 11.00 a.m. gradually declined at 01.00 - 02.00 p.m. and rose again in the evening hours (04.00 - 05.00). Similar trends were observed for the activity of *A. dorsata* and *A. florea*. Ahmad et al. (2017)<sup>2</sup> found that the peak hours of foraging activity for *A. cerana* were reported between 1000 to 1300 hours, whereas *A. mellifera* showed maximum foraging activity between 1200 to 1600 hours. Singh et al. (2005)<sup>28</sup> and Haldhar et al. (2021a&b)<sup>14, 15</sup> said that the action of *A. cerana indica*,

*A. mellifera*, *A. dorsata* and *A. florea* on *B. napus* flowers was maximum at 1200 h followed by 1000, 1400 and 1600 h of the daytime.

### Foraging rate of honey bees

In the present investigation, foraging rates (number of flowers visited per minute) of different bee species were observed to vary in different genotypes at different time intervals and at different flowering stages. However, the maximum mean foraging rate was observed in the case of *A. cerana* (18.20 flowers visited/min), which was followed by that in *A. dorsata* (17.57 flowers visited/min), *A. mellifera* (17.32 flowers visited/min) and *A. florea* was found to visit minimum flowers (6.45 flowers/min) throughout the study (Table 4). Among the genotypes, TH 68 and SANGAM were observed to experience the highest mean flower visits (14.98 and 14.90 flowers visited/min) of *Apis* spp. collectively, followed by NPJ 112 and RH 725 (14.88 and 14.87 flowers visited/min) and PDZ 9 and LES 54 (14.85 and 14.82 flowers/min). The peak foraging rate of *Apis* spp. was observed during 1100-1300 h of the day which decreased during evening hours.

**Table 4: Comparative foraging rates of honey bees in different early sown rapeseed-mustard genotypes at Hisar**

| Floral visitor        | Mean number of flowers visited/minute |              |              |              |              |              | Mean  |
|-----------------------|---------------------------------------|--------------|--------------|--------------|--------------|--------------|-------|
|                       | LES 54                                | PDZ 9        | TH 68        | SANGAM       | NPJ 112      | RH 725       |       |
| <i>Apis mellifera</i> | 17.23 (4.27)                          | 17.12 (4.26) | 17.46 (4.30) | 17.39 (4.29) | 17.35 (4.28) | 17.35 (4.28) | 17.32 |
| <i>Apis cerana</i>    | 18.13 (4.37)                          | 18.19 (4.38) | 18.26 (4.38) | 18.28 (4.39) | 18.24 (4.38) | 18.10 (4.36) | 18.20 |
| <i>Apis dorsata</i>   | 17.57 (4.29)                          | 17.62 (4.29) | 17.68 (4.30) | 17.48 (4.28) | 17.41 (4.27) | 17.67 (4.30) | 17.57 |
| <i>Apis florea</i>    | 6.35 (2.70)                           | 6.47 (2.72)  | 6.51 (2.73)  | 6.47(2.72)   | 6.51 (2.73)  | 6.41 (2.71)  | 6.45  |
| Mean                  | 14.82 (3.91)                          | 14.85 (3.91) | 14.98 (3.93) | 14.90 (3.92) | 14.87 (3.91) | 14.88 (3.91) |       |
| CD (p≤0.05)           | 0.38                                  | 1.10         | 1.35         | 1.15         | 1.18         | 1.11         |       |
| SE (m)                | 1.08                                  | 0.39         | 0.48         | 0.41         | 0.42         | 0.40         |       |

Values are mean of 75 observations (No. of days= 5; Periods of observation= 5; Replications= 3);

\*\* Figures in parentheses are√ n+1 values

The results of the present investigation got support the findings of Dalio (2018)<sup>8</sup>, who observed that the Asian bee, *A. cerana* visited more numbers of flowers per minute (18.10), followed by *A. mellifera* (17.36) and *A. dorsata* (13.87). The foraging rate of *A. florea* (7.53 flowers/min) was comparatively low. Srivastava et al. (2017)<sup>30</sup> found that the mean foraging rate was the maximum for *A. dorsata* (5.35 ± 0.33 flowers/min) followed by that *A. mellifera* (4.87 ± 0.34 flowers/min), *A. cerana* (1.75 ± 0.23 flowers/min) and lowest foraging rate was recorded of *A. florea* (0.11 ± 0.09 flowers/ min). Vishwakarma & Chand (2017)<sup>31</sup> observed that the average maximum foraging rate of *A. cerana*, *A. mellifera*, *A. dorsata*, and *A. florea* was observed during 1100-1300, 1300-1500, 1100-1300 and 0900-1100 h of the day respectively. Devi et al. (2016)<sup>10</sup> observed highest foraging rate in Broccoli bloom (18.54 flowers visited/minute) was of *A. cerana* (12.67), followed by that *A. mellifera* (12.07), *A. dorsata*(10.55) and *A. florea* (1.89) and mean foraging rate (irrespective of honey bee species) during different day hours was highest between 1100-1300h (10.74) and minimum between 1700-1900h (7.31).

On the contrary, Kunjwal et al. (2014)<sup>19</sup> observed the highest mean foraging rate of *A. mellifera* i.e., 11.48

flowers/min followed by that of *A. dorsata* (4.03 flowers/min), *A. cerana* (2.09 flowers/min), and *T. laeviceps* (1.93 flowers/min) at 12:00 pm. Brar et al. (2008)<sup>5</sup> also observed the highest foraging rate of *A. mellifera* and *A. cerana indica* at 1200 h in radish crop bloom. The findings of Singh et al. (2005)<sup>28</sup> also strongly support the present recordings that the foraging rate of *Apis* spp. was maximum at 1200 h and minimum at 1600 h. Kakar (1981)<sup>18</sup> recorded the highest foraging rate of *A. dorsata* (9.95 flowers/min) followed by *A. mellifera* (8.05 flowers/min) and *A. cerana indica* (7.60 flowers/min) and these were recorded at 1200 to 1400 h on flowers of *B. oleracea*.

**Foraging speed of *Apis* spp.**

The results of experiments on foraging speed (time spent per flower) of *Apis* spp. on different early sown genotypes of rapeseed-mustard during 2018 revealed that *A. florea* spent the maximum time per flower (5.3 sec), which was followed by that of *A. dorsata* (1.7 sec), *A. mellifera* (1.6 sec) and *A. cerana* (1.3 sec) collectively on the genotypes throughout the period of study (Table 5).

**Table 5: Comparative mean foraging speed of honey bees in early sown rapeseed-mustard genotypes**

| 3                     | Mean foraging speed (time spent per flower in a sec) |          |          |          |          |          | Mean |
|-----------------------|--|----------|----------|----------|----------|----------|------|
|                       | LES 54   | PDZ 9    | TH 68    | SANGAM   | NPJ 112  | RH 725   |      |
| <i>Apis mellifera</i> | 1.6(1.6)   | 1.6(1.6) | 1.6(1.6) | 1.5(1.6) | 1.5(1.6) | 1.5(1.6) | 1.6  |
| <i>Apis cerana</i>    | 1.3(1.5)   | 1.3(1.5) | 1.3(1.5) | 1.3(1.5) | 1.3(1.5) | 1.3(1.5) | 1.3  |
| <i>Apis dorsata</i>   | 1.7(1.6)   | 1.7(1.6) | 1.6(1.6) | 1.8(1.7) | 1.7(1.6) | 1.5(1.6) | 1.7  |
| <i>Apis florea</i>    | 5.4(2.5)   | 5.6(2.5) | 5.3(2.5) | 5.2(2.5) | 5.2(2.5) | 5.2(2.5) | 5.3  |
| Mean                  | 2.5(1.8)   | 2.6(1.8) | 2.4(1.8) | 2.5(1.8) | 2.4(1.8) | 2.4(1.8) |      |
| CD (p≤0.05)           | 0.87   | 0.94     | 1.01     | 0.94     | 1.06     | 0.90     |      |
| SE (m)                | 0.31   | 0.34     | 0.36     | 0.330    | 0.38     | 0.32     |      |

Values are mean of 75 observations (No. of days= 5; Periods of observation= 5; Replications= 3);

Figures in parentheses are√ n+1 values

The foraging speed of *Apis* spp. was observed to peak at the peak flowering stage of the crop and was the lowest at flowering cessation. The collective average time spent by *Apis* spp. on different genotypes was highest in PDZ 9 (2.6 sec), followed by LES 54 and SANGAM (2.5 sec,) whereas the bees spent equal time (2.4 sec) on the flowers of genotypes TH 68, NPJ 112 and RH 725. Also, the foraging speed of *Apis* spp. varied during different day hours, and it was observed to increase from 0900 h to 1100 h and peaked during 1100-1300, h which then decreased afterwards.

The findings of other workers strongly support the results of the present study. Ahmad et al. (2017)<sup>2</sup> found that *A. cerana* spent 6.24±0.12 seconds per apple flower and visited 10.50±0.18 flowers per minute, whereas *A. mellifera* spent 8.44±0.38 seconds per flower and visited 9.40±0.12 flowers per minute. Devi et al. (2016)<sup>10</sup> reported that the maximum foraging speed was of *A. florea* (44.70 s) followed by *A. dorsata* (6.05 s), *A. mellifera* (5.64 s) and *A. cerana* (4.71 s). The mean maximum foraging speed of pollinators such as *A. florea*, *A. dorsata*, *A. mellifera* and *A. cerana* was observed during 1700-1900, 1500-1700, 1500-1700 and 1500-1700 hours of the day, respectively. Nagpal (2016)<sup>23</sup> and Jat et al. (2013)<sup>16</sup> also reported that *A. florea* spent the maximum time per flower (6.08 sec), which was followed by *A. dorsata* (3.41 sec), *A. mellifera* (2.60 sec) and *A. cerana indica* (2.33 sec). Pandey and Tripathi (2003)<sup>25</sup> observed that *A. florea* worker spent maximum time per flower (43.9 sec) followed by *A. cerana*

*indica* (33.3 sec), *A. mellifera* (31.7 sec) and *A. dorsata* (31.4 sec).

On the contrary, Kunjwal et al. (2014)<sup>19</sup> found that *A. mellifera* showed the highest foraging speed, 2.25 s and 2.24 s (at 12:00 pm and 2:00 pm), followed by *A. dorsata* (1.05 s at 2:00 pm.) and *A. cerana* (0.74 s at 4:00 pm) on brown mustard flowers respectively.

**Working behaviour of *Apis* spp.**

In the present study, the bee species were found to visit the crop bloom of early sown genotypes for collecting pollen and nectar, whereas the lepidopteran and dipteran collected nectar predominantly and the coleopteran visitor foraged for pollen only. Among the *Apis* spp., the percentage of nectar plus pollen foragers remained the maximum (41.8, 40.3 and 42.9%, respectively, at flowering initiation, peak and cessation) throughout the course of the study whereas the proportion of nectar (35.6, 36.0 and 34.6%) and pollen foragers (22.7, 23.8 and 22.5%) was comparatively low (Table 6). The maximum proportion of nectar foragers was observed for *A. dorsata* and *A. florea* (37.8 and 36.7%) followed by *A. cerana* and *A. dorsata* (34.3 and 32.7%) whereas the maximum proportion of pollen foragers was observed in *A. dorsata* and *A. mellifera* (25.6 and 24.1%) followed by *A. florea* and *A. cerana* (21.8 and 20.4%). The percentage of nectar plus pollen foragers varied from 36.6% in *A. dorsata* to 45.3% in *A. cerana*.

**Table 6: Percentage of nectar and/or pollen visitors of *Apis* spp. in early sown rapeseed-mustard genotypes**

| Stage of flowering | Floral visitor      | Nectar      | Pollen      | Nectar + pollen |
|--------------------|---------------------|-------------|-------------|-----------------|
| Initiation         | <i>A. mellifera</i> | 32.6 (34.8) | 21.4 (27.4) | 45.9 (42.7)     |
|                    | <i>A. cerana</i>    | 34.3 (35.9) | 23.3 (28.8) | 42.5 (40.4)     |
|                    | <i>A. dorsata</i>   | 38.3 (38.2) | 24.5 (29.5) | 37.3 (37.5)     |
|                    | <i>A. florea</i>    | 37.1 (37.4) | 21.4 (27.4) | 41.5 (40.4)     |
|                    | Mean                | 35.6 (36.6) | 22.7 (28.4) | 41.8 (40.2)     |
| Peak               | <i>A. mellifera</i> | 33.8 (35.6) | 25.5 (30.0) | 40.8 (39.1)     |
|                    | <i>A. cerana</i>    | 35.3 (36.4) | 19.8 (26.2) | 45.0 (42.0)     |
|                    | <i>A. dorsata</i>   | 38.0 (38.0) | 26.3 (31.0) | 35.8 (36.2)     |
|                    | <i>A. florea</i>    | 37.0 (37.4) | 23.5 (28.9) | 39.5 (39.1)     |
|                    | Mean                | 36.0 (36.9) | 23.8 (29.1) | 40.3 (39.2)     |
| Cessation          | <i>A. mellifera</i> | 31.6 (34.0) | 25.4 (30.2) | 42.9 (40.8)     |
|                    | <i>A. cerana</i>    | 33.3 (35.4) | 18.3 (25.4) | 48.5 (44.1)     |
|                    | <i>A. dorsata</i>   | 37.3 (37.6) | 26.0 (30.6) | 36.8 (36.9)     |
|                    | <i>A. florea</i>    | 36.1 (36.9) | 20.4 (26.6) | 43.5 (41.2)     |
|                    | Mean                | 34.6 (36.0) | 22.5 (28.4) | 42.9 (40.8)     |
| CD (p≤0.05)        |                     | N.S.        | 4.21        | 5.02            |
| SE (m)             |                     | 1.27        | 1.63        | 1.68            |

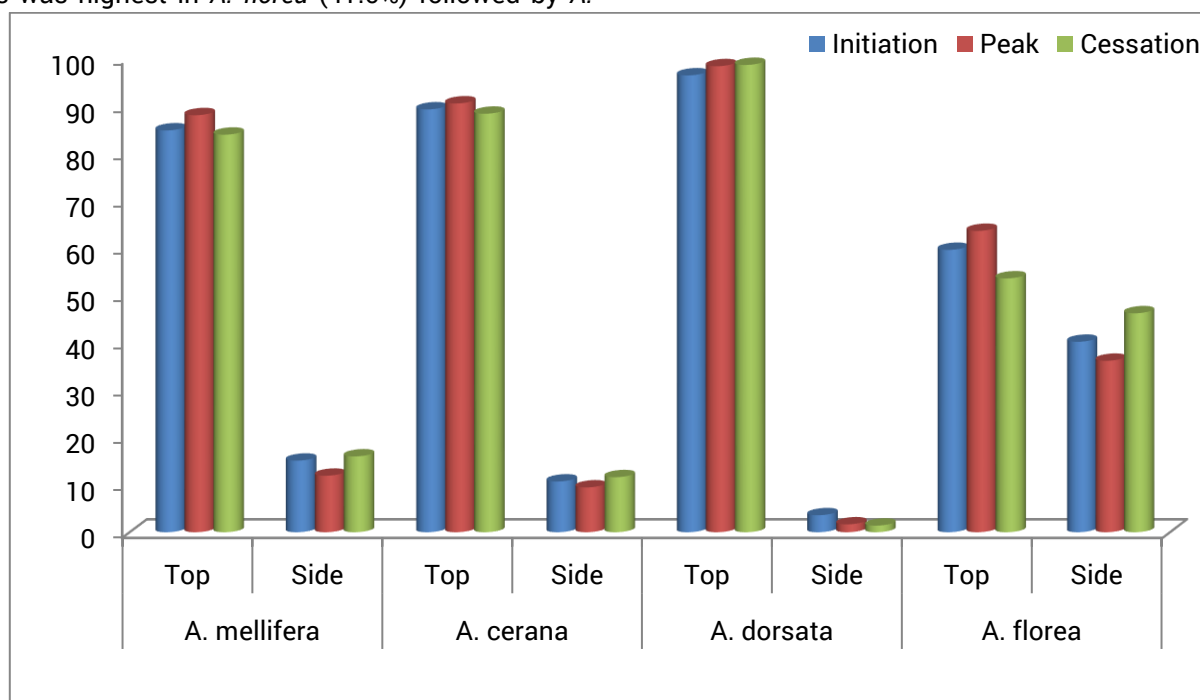
Figures in parentheses represent angular transformed values

Results obtained by Nagpal (2016)<sup>23</sup> indicated that maximum nectar foraging was in *A. dorsata* (37.25%), followed by *A. florea* (36.08%), *A. cerana indica* (33.25%) and *A. mellifera* (31.63%); On the contrary, maximum pollen foraging was recorded in case of *A. dorsata* (26.00%) followed by *A. mellifera* (25.44%), *A. florea* (20.42%) and *A. cerana indica* (18.25%). Records by many research workers suggest that nectar collection by *A. mellifera* and *A. cerana indica* is more during the latter part of the day due to comparatively higher nectar sugar concentration on *B. napus* crop bloom.

In the current study, the results of investigations on the working behaviour of *Apis* spp. revealed that the maximum proportion of top workers was constituted by *A. dorsata* (average 97.8%), which was followed by *A. cerana* (89.4%), *A. mellifera* (85.6%) and the least was of *A. florea* (59.0%), whereas the maximum proportion of side workers was highest in *A. florea* (41.0%) followed by *A.*

*mellifera* (14.4%), *A. cerana* (10.6%) and the lowest in case of *A. dorsata* (2.2%) (Fig.1). The collective proportion of top foragers increased from 82.5% at flowering initiation to a maximum 85.1% at peak flowering and decreased to 81.1% at flowering cessation, while the proportion of side workers reduced initially (17.5 to 14.9 %) and later increased (18.9 %).

Nagpal (2016)<sup>23</sup> observed that all the bees of *A. dorsata* worked from the top while the proportion of top and side workers in other species was as follows: *A. cerana indica* (90.25 and 9.75%), *A. mellifera* (82.94 and 17.06%) and *A. florea* (59.50 and 40.50%). Sharma et al. (2001)<sup>27</sup> found that all the bee species worked from the top except for *A. florea*, which foraged as side workers on *Brassica* flowers at CCS Haryana Agricultural University, Hisar. On the contrary, Free and Fergusson (1983)<sup>17</sup> found that all the foragers of *A. mellifera* worked from the top of the flower.



**Fig. 1: Percentage of top and side workers of honey bees on flowers of early sown rapeseed-mustard genotypes**

**Declaration of interests**

The authors have no conflict of interest to declare.

**Data sharing**

All relevant data are within the manuscript.

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