

Full Length Research Paper

## Flower-visiting insect pollinators of Brown Mustard, *Brassica juncea* (L.) Czern and Coss and their foraging behaviour under caged and open pollination

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Honey bees are the primary pollinators of mustard crop because it is highly attractive to bees and provides both nectar and pollen. To analyze the diversity and foraging behavior of insect pollinators under caged and open pollination, different varieties/ lines (Kranti, Varuna, Marigold, Vardan, Vaibhav, EC399299, EC399301, EC399312 and EC399313) of *Brassica juncea* were planted during Rabi season 2010-2011 at Apiary Garden, G. B. Pant University of Agriculture and Technology, Pantnagar. It was revealed that 30 species of insect pollinators belonging to ten families under four orders visited mustard flowers. In open pollination, *Trigona laeviceps* had maximum average abundance (4.51 bees/m<sup>2</sup>/2 min) and foraging speed (18.55s) in Vardan and EC399313, respectively whereas *Apis mellifera* showed highest foraging rate (10.68 flower/min.) in EC399313 as compared to other bees in different varieties. Under caged pollination, line EC399313 was most preferred by *A. mellifera* with maximum abundance (6.24 bees/m<sup>2</sup>/2 min), foraging speed (2.33 s) and foraging rate (7.69 flower/min). The results indicated that *A. mellifera* visited all nine varieties/lines in both open and caged plots. Overall average abundance (4.09 bees/1 m<sup>2</sup>/2 min) and foraging speed (1.97s) of *A. mellifera* was found maximum under caged pollination while highest foraging rate (8.52 flower/min) was recorded in open pollination per day.

**Key words:** *Brassica juncea*, foraging behavior, Insect pollinators, caged pollination, open pollination.

### INTRODUCTION

The Brassicaceae, which contains about 338 genera and 3,709 species currently recognized (Warwick et al., 2006), is one of the 10 most economically important plant families. The oleiferous *Brassica* species, commonly known as rapeseed-mustard comprising eight different species viz. Indian mustard, toria, yellow sarson, brown sarson, gobhi sarson, karan rai, black mustard and

taramira are being cultivated in 53 countries spreading all over the globe. *Brassica juncea* is the dominant species grown for oil-seed usage in India. *B. juncea* is self compatible crop but also cross pollinated by insects. Plants of the genus *Brassica*, as with many others crucifers, are known to be very attractive to insect pollinators, serve mainly as a source

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**Figure 1.** Open pollinated plots.

of nectar and pollen. The amount of nectar secreted per 100 flowers of *B. juncea* ranged from 11.76 to 165 mg (79.85 mg on average). Sugar concentration in nectar was high enough to attract pollinating insects, reaching a maximum of 52% (Masierowska, 2003). Insect pollinators play vital role to increase productivity as proved by different reports from various parts around the world.

For a pollinating agent to be effective, its foraging behaviour should favour the transportation of anther pollen to flower stigmas on the same plant or different target species plants (Freitas and Paxton, 1996). It has been reported that there are more than 25000 described species of bees in the world and account for 70% pollination of various valuable flowering crops. Bees are the important components of agro-ecosystem as they provide free ecosystem services in the form of pollination which not only enhance the productivity of agricultural crops but also help in conservation of biological diversity. We rely on bees to pollinate 87 of the 124 (70%) most valuable crops used directly for human consumption (Klein et al., 2007).

Insect-mediated pollen transfer in mass-flowering *Brassica* crops has been particularly well studied, as insect pollinator activity can contribute significantly to pollination (Sihag 1985; Hayter and Cresswell 2006; Rader et al., 2009). A large number of insect species visit *Brassica* flowers (Howlett et al., 2009a, b, 2011), and absolute visitation rate is thought to play a central role in

the resulting quality and yield of seed (Bhalla et al., 1983). Honey bees are included in this context, whose foraging behaviour is favourable to increase the crop productivity (D'Ávila and Marchini, 2005). In Asia, the domesticated honeybee, *Apis mellifera* have been utilized to provide managed pollination systems. The present investigation was undertaken to study the diversity and foraging behaviour of honey bee pollinators visiting mustard crop, *B. juncea* under open and caged condition.

## MATERIAL AND METHODS

The experiment was conducted with 5 varieties and 4 lines of *Brassica juncea* viz., Kranti, Varuna, Vaibhav, Margold, Vardan, EC399299, EC399301, EC399312 and EC399313 respectively, during Rabi season and diversity of insect species were observed during 2010 to 2011 at G. B. Pant University of Agriculture and Technology, Pantnagar, U. S. Nagar, Uttarakhand, India. Six plots of size 3x4 m<sup>2</sup> were used to study the effect of Bee pollination (plots caged with *A. mellifera*, Figure 2) and open pollination (control, Figure 1) on foraging behavior of bees with three replications for each variety/line. Plant-plant and row-row spacing for *B. juncea* were taken 20 and 30 cm, respectively. Sowing of mustard was done on 18 November 2010 whereas the plots were caged on 24 January 2011 before plants of different variety/lines started flowering. To facilitate caged pollination, the fine muslin cloth and nylon net with the size of 4 m × 3 m × 2.5 m were used.

Abundance of insect species visiting *B. juncea* flowers was recorded during peak blooming period per 1 m<sup>2</sup> of plot for 2 min at



**Figure 2.** Caged pollinated plots.

two hours interval. Insects visiting these plots were collected by making five sweeps per plot with a hand net with 30 cm ring diameter. Foraging rate was recorded in terms of number of flowers visited by an individual forager per minute of time whereas foraging speed is the time spent on a single flower by the insect forager collecting either nectar or pollen. The observations were recorded at two hour interval starting from 10AM to 4PM during the peak blooming period of different varieties/lines of *B. juncea*. The data collected from field experiments were subjected to the analysis of variance following Randomized Block Design.

## RESULTS AND DISCUSSION

### Diversity of insect pollinators on *B. juncea*:

A total of 30 species belonging to four orders, Hymenoptera (23), Diptera (5), Lepidoptera (1) and Coleoptera (1) visited mustard flowers (Table 1 and Figure 3). Hymenopteran visitors belonged to six families namely Apidae (5), Andrenidae (1), Anthophoridae (3), Megachilidae (4), Halictidae (4) and Xylocopidae (6). From the family Apidae, honey bees (*A. cerana*, *A. florea*, *A. mellifera*, *A. dorsata*, and stingless bee *Trigona laeviceps*) were observed on the flowers of *B. juncea* whereas Andrenidae (*Andrena* sp.), Anthophoridae (*Amegilla violaeca*, *A. zonata* and *Anthophora* sp.), Megachilidae (*Megachile lanata*, *M. disjuncta*, *M. hera* and *M. bicolor*), Halictidae (*Halictus gutturosus*, *Halictus* sp., *Nomia iridescence* and *Nomia* sp.), Xylocopidae

(*Ceratina sexmaculata*, *Xylocopa iridipennis*, *X. pectinifrons*, *X. aestuans*, *X. latipes* and *X. amethystine*) were also observed during mustard blossoms. From Diptera, four species from family Syrphidae (*Episyrphus balteatus*, *Syrphus corollae*, *Melanostoma orientale* and *Spherophoria* sp.) and one species from Muscidae (*Musca domestica*) were recorded. From Lepidoptera order (*Pieris brassicae*) of family Pieridae and from Coleoptera order (*Coccinella septumpunctata*) Coccinellidae was also found to visit mustard flowers.

In the past study, Mahindru et al. (1995) found *Apis dorsata*, *A. florea*, *A. mellifera* and *Andrena* sp. on brown sarson at Ludhiana, Punjab and Chakravarty (2000) reported *Eristalis*, *Syrphus* sp., *A. cerana indica*, *A. dorsata*, *A. mellifera*, *Mellipona* sp., *Bombus* sp., *Haliotis armigera*, *Plusia orichalcea* and *Pieris brassicae* as the visitors of *Brassica napus* at Pantnagar, Uttarakhand. On the other hand, Chaudhary (2001) reported that honey bees (58%), leaf-cutter bee (*Megachile hera*; 14.4% proportion), alkali bee (*Nomia curvipes*; 14.3%), *Chalcidoma creusa* (7.8%), *Andrena sacrisissima* (2.0%), *Sphecodes fumipennis* (0.3%), *Braunaspis moderata* (0.1%), bumble bee (*Bombus* sp.; 0.1%) carpenter bee (*Xylocopa* sp.; 0.1%) syrphid fly (1.3%), house fly (0.1%) and butterfly (*Danais* sp.; 0.2%) were insect visitors on *Brassica campestris* var. Brown Sarson (cv. BSH-1), *Brassica carinata* cv. Carinata and Indian mustard cultivars RH-30, Laxmi and T-59 whereas

**Table 1.** Diversity of different insect visitors on flowers of mustard (*Brassica juncea*) at Pantnagar.

S/N	Common name	Scientific name	Family	Order
1	Indian honey bee	<i>Apis cerana</i> Fab.	Apidae	Hymenoptera
2	Little honey bee	<i>Apis florea</i> Fab.	Apidae	Hymenoptera
3	European honey bee	<i>Apis mellifera</i> L.	Apidae	Hymenoptera
4	Giant honey bee	<i>Apis dorsata</i> Fab.	Apidae	Hymenoptera
5	Sting less bee	<i>Trigona laeviceps</i> Smith	Apidae	Hymenoptera
6	Sand bee	<i>Andrena</i> sp.	Andrenidae	Hymenoptera
7	Digger bee	<i>Amegilla violacea</i> (Lepe.)	Anthophoridae	Hymenoptera
8	Digger bee	<i>Amegilla zonata</i> (Lin.)	Anthophoridae	Hymenoptera
9	Digger bee	<i>Anthophora</i> sp.	Anthophoridae	Hymenoptera
10	Leaf cutter bee	<i>Megachile lanata</i> (Fab.)	Megachilidae	Hymenoptera
11	Leaf cutter bee	<i>Megachile disjuncta</i> (Fab.)	Megachilidae	Hymenoptera
12	Leaf cutter bee	<i>Megachile hera</i> Bingham	Megachilidae	Hymenoptera
13	Leaf cutter bee	<i>Megachile bicolor</i> (Fab.)	Megachilidae	Hymenoptera
14	Sweat bee	<i>Halictus gutturosus</i> Vachal	Halictidae	Hymenoptera
15	Sweat bee	<i>Halictus</i> sp.	Halictidae	Hymenoptera
16	Alkali bee	<i>Nomia iridescence</i>	Halictidae	Hymenoptera
17	Alkali bee	<i>Nomia</i> sp.	Halictidae	Hymenoptera
18	Small carpenter bee	<i>Ceratina sexmaculata</i> Smith	Xylocopidae	Hymenoptera
19	Carpenter bee	<i>Xylocopa iridipennis</i> (Lepe.)	Xylocopidae	Hymenoptera
20	Carpenter bee	<i>Xylocopa pectinifrons</i>	Xylocopidae	Hymenoptera
21	Carpenter bee	<i>Xylocopa aestuans</i> (L.)	Xylocopidae	Hymenoptera
22	Carpenter bee	<i>Xylocopa latipes</i> (Drury)	Xylocopidae	Hymenoptera
23	Carpenter bee	<i>Xylocopa amethystine</i> (Fab.)	Xylocopidae	Hymenoptera
24	Hover fly	<i>Episyrphus balteatus</i> De Geer	Syrphidae	Diptera
25	Hover fly	<i>Syrphus corollae</i> Fab.	Syrphidae	Diptera
26	Hover fly	<i>Melanostoma orientale</i> L.	Syrphidae	Diptera
27	Hover fly	<i>Spherophoria</i> sp. L.	Syrphidae	Diptera
28	House fly	<i>Musca domestica</i> L.	Muscidae	Diptera
29	Cabbage butterfly	<i>Pieris brassicae</i>	Pieridae	Lepidoptera
30	Ladybird beetle	<i>Coccinella septempunctata</i>	Coccinellidae	Coleoptera

Ahmad (2005) reported 22 and 16 hymenopterans and 7 and 5 dipteran species visiting mustard flowers in Diriyah and Derab (Saudi Arabia) respectively. They observed honey bees as the dominant hymenopteran pollinators followed by other bees such as *Andrena*, *Hexachysis*, *Halictus*, *Osmia*, *Pompilus* and *Dieles* and wasps. More abundant dipteran genera on the other hand were *Agromyza*, *Chrysoma*, *Drosophila* and *Syrphus*.

#### Foraging behaviour of insect pollinators under open pollination

It was observed that *A. mellifera* was most abundant/dominant species in all the varieties/lines of *B. juncea* than other bees under open pollination (Table 2). During the observation period at different interval hours maximum number of bees, *A. mellifera* (3.08 bees/1 m<sup>2</sup>/2 min), *A. cerana* (0.16 bees/1 m<sup>2</sup>/2 min), *A. dorsata* (0.60

bees/1 m<sup>2</sup>/2 min) and *Trigona laeviceps* (1.07 bees/1 m<sup>2</sup>/2 min) were recorded at 2.00 pm and minimum at 10.00 am with *A. mellifera* (1.50 bees/1 m<sup>2</sup>/2 min), *A. dorsata* (0.19 bees/1 m<sup>2</sup>/2 min) and *T. laeviceps*. (0.35 bees/1 m<sup>2</sup>/2 min) while *A. cerana* abundance (0.10 bees/1 m<sup>2</sup>/2 min) was found minimum at 4.00 pm. Among the varieties/lines of *B. juncea* average abundance of *A. mellifera* was found highest in Varuna and Vaibhav with 3.33 bees/1 m<sup>2</sup>/2 min each whereas *A. cerana* was observed in EC399312 (0.68 bees/1 m<sup>2</sup>/2 min, *A. dorsata* in EC399313 (2.05 bees/1 m<sup>2</sup>/2 min) and *T. laeviceps* in Vardan (4.51 bees/1 m<sup>2</sup>/2 min). In the present investigation peak activity of the most frequent pollinator *A. mellifera* on *Brassica* was recorded in the afternoon hours (2.00 h) whereas in an earlier study conducted by Thakur et al. (1982) reported higher number of *A. cerana indica* bees foraging mustard in the morning than *A. mellifera* but both species had a similar peak in the noon at Palampur, Himachal Pradesh. Brunel et al. (1994)



**Figure 3.** Foraging activity of insect pollinators on *Brassica juncea* crop.

reported that *A. c. indica* bees were the dominant (34 to 43 per cent) visitors on mustard, *Brassica juncea* L. followed by *A. dorsata* (20 to 26%).

Foraging speed was observed during the peak blooming period in different varieties/lines of *B. juncea* at different time intervals. *A. mellifera* showed maximum foraging speed which was more or less similar at 12.00 pm and 2.00 pm, 2.25 s and 2.24 s respectively while *A. cerana* at 4.00 pm (0.74 s). For *A. dorsata* it was observed highest at 2.00 pm (1.05 s) whereas *T. laeviceps* had maximum foraging speed of 9.88 s at 12.00 pm. The maximum average time spent by different insect pollinators in variety/lines of *B. juncea* was observed in EC399313 with *A. mellifera* (2.23 s), *A. dorsata* (3.03 s) and *T. laeviceps* (18.55 s) whereas *A. cerana* (3.10 s) was found highest in Kranti. Our results showed that *T. laeviceps* was found to spend maximum time on mustard flower but in an earlier study carried out by Kumar et al. (1994) revealed that *A. mellifera* exhibited higher foraging speed than solitary bees on mustard flower. More recently Sharma et al. (2001) reported that *A. mellifera* spent 1.64 s/flower followed by *A. dorsata* 2.18 s/flower and *A. florea* 3.54 s/flower on the *Brassica campestris* var. sarson.

The overall mean of foraging rate of insect pollinators observed in the present study was highest with 11.48 flowers/min by *A. mellifera*, 2.09 flowers/min by *A. cerana*, 4.03 flowers/min by *A. dorsata* and 1.93 flowers/min by *T. laeviceps* at 12.00 pm. Amongst the

varieties/lines of *B. juncea* highest number of flower visited by *A. mellifera* (10.6 flowers/min), *A. dorsata* (9.40 flowers/min) and *T. laeviceps* (3.67 flowers/min.) was observed in EC399313 whereas foraging rate of *A. cerana* (7.13 flowers/min) was found maximum in Kranti. Benedek et al. (1972) recorded that individual honey bee (*A. mellifera*) took on an average of 4.4 min to visit 39 flowers on oilseed rape. One bee visited 342 flowers on 186 plants in 35.5 min. while Abrol and Kapil (1996) at Hisar, India, found that the foraging rates of different bee species varied greatly in different oilseed crops. On an average, *A. florea* visited 4.2 to 8.5 flowers per min in different cruciferous crops and 10.2 in sunflower, whereas *A. dorsata* visited 4.9 to 13.5 flowers per min on cruciferous crops. Rana et al. (1997) observed higher foraging activity at 12.00 h of both *A. mellifera* and *A. c. indica* than at 09.00 h. However, in both the species, there were no significant differences of the population of bees between 12.00 and 15.00 h.

#### **Foraging behaviour of *A. mellifera* under caged condition**

Data presented in Table 3 revealed that under caged pollination the average abundance of *A. mellifera* was maximum (5.04 bees/1 m<sup>2</sup>/2 min) at 2.00 pm and minimum (2.19 bees/1 m<sup>2</sup>/2 min) at 10.00 am. The maximum number of *A. mellifera* was recorded in the line

**Table 2.** Foraging behaviour of pollinators in different varieties/lines of *B. juncea* under open pollination.

Varieties /Lines	Abundance of bees at different hours per day (no. of bees/1 m <sup>2</sup> /2 min)																			
	<i>A. mellifera</i>					<i>A. cerana</i>					<i>A. dorsata</i>					<i>T. laeviceps</i>				
	10 am	12 pm	2 pm	4 pm	Avg.	10am	12pm	2pm	4 pm	Avg.	10am	12 pm	2pm	4pm	Avg.	10am	12pm	2pm	4 pm	Avg.
Kranti	1.74	4.09	3.33	3.46	3.16	0.66	0.68	0.68	0.36	0.59	0.00	0.00	0.00	0.00	0.00	0.76	0.76	0.94	0.98	0.86
Varuna	1.88	3.59	3.99	3.86	3.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Margold	1.85	1.96	2.42	1.77	2.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Vardan	1.18	3.01	3.42	3.48	2.77	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.82	5.74	6.14	5.35	4.51	
Vaibhav	1.70	3.45	4.41	3.76	3.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
EC399299	1.39	1.90	1.95	1.68	1.73	0.00	0.00	0.00	0.00	0.00	0.68	0.85	0.85	0.63	0.75	0.00	0.00	0.00	0.00	
EC399301	1.38	2.99	2.82	2.52	2.43	0.00	0.00	0.00	0.00	0.00	0.68	1.58	1.75	1.40	1.35	0.80	0.99	1.16	0.65	
EC399312	0.52	2.34	1.68	1.47	1.50	0.70	0.68	0.80	0.56	0.68	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
EC399313	1.88	3.36	3.70	3.28	3.05	0.00	0.00	0.00	0.00	0.00	0.37	2.35	2.88	2.60	2.05	0.74	1.56	1.46	1.15	
GM	1.50	2.97	3.08	2.81	2.58	0.15	0.15	0.16	0.10	0.14	0.19	0.53	0.60	0.52	0.46	0.35	1.00	1.07	0.90	
SEm±	0.15	0.22	0.15	0.13	0.21	0.03	0.03	0.02	0.06	0.02	0.02	0.05	0.18	0.02	0.19	0.05	0.13	0.15	0.10	
CD at 5%	0.43	0.66	0.46	0.38	0.64	0.09	0.11	0.06	0.18	0.08	0.07	0.18	0.57	0.07	0.57	0.16	0.38	0.44	0.30	
Foraging speed of bees at different hours per day (time (s)/flower)																				
Kranti	1.43	2.51	2.65	2.11	2.17	2.58	3.18	3.17	3.47	3.10	0.00	0.00	0.00	0.00	0.00	11.33	17.62	14.48	13.10	14.13
Varuna	1.29	2.08	2.26	2.14	1.94	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
Margold	0.96	2.07	1.92	2.02	1.74	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
Vardan	1.02	2.15	1.98	1.84	1.75	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	14.06	22.08	17.40	15.37	17.22	
Vaibhav	1.22	2.29	2.36	1.80	1.91	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
EC399299	0.99	1.76	1.93	1.68	1.59	0.00	0.00	0.00	0.00	0.00	2.11	2.85	3.11	2.88	2.73	0.00	0.00	0.00	0.00	
EC399301	1.30	2.39	2.16	2.11	1.99	0.00	0.00	0.00	0.00	0.00	2.09	3.01	2.85	2.78	2.68	15.34	25.73	15.00	13.56	
EC399312	1.20	2.39	2.35	2.33	2.06	2.68	3.25	3.11	3.25	3.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
EC399313	1.44	2.64	2.57	2.30	2.23	0.00	0.00	0.00	0.00	0.00	2.36	3.32	3.56	2.85	3.03	16.15	23.48	18.60	15.96	
GM	1.21	2.25	2.24	2.04	1.93	0.58	0.71	0.06	0.74	0.69	0.72	1.02	1.05	0.94	0.93	6.32	9.88	7.27	6.44	
SEm±	0.02	0.35	0.04	0.04	0.06	0.03	0.04	0.01	0.04	0.07	0.06	0.77	0.23	0.15	0.12	0.55	0.67	0.28	0.36	
CD at 5%	0.79	0.10	0.15	0.14	0.18	0.09	0.12	0.05	0.12	0.21	0.18	0.23	0.69	0.43	0.34	1.66	1.99	0.84	1.06	
Foraging rate of bees at different hours per day (flowers visited/min.)																				
Kranti	5.50	14.79	12.95	8.90	10.54	4.38	9.92	7.89	6.33	7.13	0.00	0.00	0.00	0.00	0.00	2.93	4.47	3.42	3.13	3.49
Varuna	4.60	12.67	11.62	6.97	8.97	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
Margold	4.27	8.57	7.58	5.81	6.56	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
Vardan	4.98	12.33	11.64	8.11	9.27	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.95	4.67	3.15	3.08	3.46	
Vaibhav	3.44	10.45	10.55	7.22	7.92	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
EC399299	2.93	7.74	6.31	4.68	5.42	0.00	0.00	0.00	0.00	0.00	2.93	9.36	7.67	5.81	6.44	0.00	0.00	0.00	0.00	
EC399301	4.30	12.80	13.16	8.98	9.81	0.00	0.00	0.00	0.00	0.00	3.77	12.27	13.00	7.18	9.06	2.22	3.59	4.49	2.85	

Table 2. contd.

EC399312	4.01	9.03	10.41	6.76	7.55	3.70	8.96	7.15	6.23	6.51	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
EC399313	5.34	14.96	13.27	9.15	10.68	0.00	0.00	0.00	0.00	0.00	4.00	14.67	10.02	8.89	9.40	3.57	4.69	3.62	2.78	3.67
GM	4.37	11.48	10.83	7.40	8.52	0.89	2.09	1.67	1.39	1.51	1.19	4.03	3.41	2.43	2.76	1.29	1.93	1.63	1.31	1.54
SEm±	0.25	0.28	0.28	0.22	0.51	0.09	0.10	0.11	0.09	0.50	0.06	0.19	0.22	0.20	1.00	0.18	0.14	0.13	0.17	0.24
CD at 5%	0.77	0.85	0.85	0.66	1.51	0.27	0.31	0.34	0.27	1.46	0.20	0.58	0.66	0.62	2.92	0.56	0.43	0.38	0.51	0.70

Table 3. Foraging behaviour of *A. mellifera* in different varieties/lines of *B. juncea* under caged condition.

Varieties /Lines	Abundance of bees at different hours per day (no. of bees/1 m <sup>2</sup> /2 min)					Foraging speed of bees at different hours per day (time (s)/flower)					Foraging rate of bees at different hours per day (Avg. no. of flower visited/ min.)				
	10am	12pm	2pm	4pm	Avg.	10am	12pm	2pm	4pm	Avg.	10am	12pm	2pm	4pm	Avg.
Kranti	3.19	6.86	7.62	5.23	5.73	1.49	2.60	2.72	2.09	2.23	3.40	10.27	9.61	7.43	7.68
Varuna	2.09	4.65	5.50	4.49	4.18	1.36	2.08	2.39	2.08	1.98	2.51	9.88	8.53	5.65	6.64
Margold	1.05	2.31	3.09	3.53	2.49	0.98	2.02	1.86	2.11	1.74	1.86	5.60	4.43	3.24	3.78
Vardan	1.87	3.31	3.81	3.74	3.18	1.15	2.12	2.02	1.94	1.80	3.00	9.36	9.63	5.69	6.92
Vaibhav	1.71	4.44	6.41	5.29	4.46	1.27	2.36	2.39	1.73	1.94	2.67	9.63	8.44	5.89	6.66
EC399299	1.80	2.41	2.44	2.71	2.34	0.88	1.83	1.97	1.68	1.59	2.02	5.98	4.63	3.93	4.14
EC399301	2.05	4.15	4.27	4.47	3.73	1.34	2.62	2.26	1.97	2.05	2.93	6.09	7.02	5.40	5.36
EC399312	2.47	5.99	4.74	4.72	4.48	0.97	2.47	2.41	2.33	2.05	2.98	9.53	8.51	5.87	6.72
EC399313	3.48	7.29	7.47	6.74	6.24	1.53	2.72	2.63	2.43	2.33	3.75	10.55	9.64	6.83	7.69
GM	2.19	4.59	5.04	4.54	4.09	1.22	2.31	2.29	2.04	1.97	2.79	8.54	7.82	5.54	6.17
SEm±	0.09	0.21	0.15	0.18	0.36	0.14	0.04	0.04	0.042	0.08	0.45	0.91	0.30	0.40	0.42
CD at 5%	0.29	0.62	0.46	0.55	1.04	0.42	0.13	0.15	0.13	0.25	1.35	2.75	0.90	1.20	1.23

EC399313 (6.24 bees/1 m<sup>2</sup>/2 min) and minimum in EC399299 (2.34 bees/1 m<sup>2</sup>/2 min). Average time of foraging speed 2.31s was recorded highest at 12.00 pm and lowest 1.22 s at 10.00 am. On the other hand foraging speed of 6.24 s in EC399313 was found maximum among different varieties/lines of *B. juncea* and minimum in EC399299 with 2.34 s. In caged condition the highest number of flowers visited per minute by *A. mellifera* was 8.54 at 12.00 pm while it was minimum 2.79 flowers/min. at 10.00 am. Maximum foraging rate was observed in EC399313 (7.69 flowers/min) which was more or less similar to Kranti (7.68 flowers/min) whereas minimum flowers visited by *A. mellifera* was found 3.78 flowers/min in Margold.

After recorded open and caged pollination data, it was concluded that *A. mellifera* visited all the nine varieties/lines of *B. juncea* both in open and caged plots but with variable preference. Under open pollination, varieties Varuna and Vaibhav (3.33 bees/1 m<sup>2</sup>/2 min) were more preferred by *A. mellifera* while in caged highest abundance was recorded in line EC399313 (6.24 bees/1 m<sup>2</sup>/2 min). In caged pollination overall average abundance of *A. mellifera* 4.09 bees/1 m<sup>2</sup>/2 min was more as compared to open pollination which was only 2.58 bees/1 m<sup>2</sup>/2 min per day. Foraging speed of *A. mellifera* was recorded 1.97 s in caged and 1.93 s in open pollinated plots. However, foraging rate of *A. mellifera* was found more (8.52 flower/min) in open pollination when compared to caged pollination which was calculated as 6.17 flower/min per day. Under open and caged pollination, line EC399313 was most preferred by *A. mellifera* with foraging speed of 2.33 s in both and foraging rate of 10.6 flower/min and 7.69 flower/min, respectively.

The aim of this study were to measure diversity and foraging behaviour of important insect pollinators to help plant pollination, including mustard an important oilseeds crop in Uttarakhand district. Enhancement of insect pollinators as part of crop management should be considered by farmers. Our result indicates that diversity and foraging behaviour on mustard will help in finding the most efficient pollinators for enhancing the crop yield, especially *Apis* and non *Apis* bees, plays a significant role to enhancing the productivity of mustard crop.

### Conflict of Interests

The author(s) have not declared any conflict of interests

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