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Foraging behaviour of *Bombus haemorrhoidalis* Smith on *Capsicum annuum* L. under protected cultivation

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Abstract
The *Bombus haemorrhoidalis* queens were collected while foraging on *Adhatoda vasica, Brassica juncea, Hypericum oblongifolium, Papaver rhoeas, Scutellaria linearis, Cydonia oblonga* and *Antirrhinum majus* from February to April. The laboratory reared bumble bee (*Bombus haemorrhoidalis* Smith) queens established in the field was introduced in flowering (at 5- 10% flowering) bell pepper crop and used for pollination in polyhouse. The number of bumble bees visiting bell pepper flowers were maximum (6.83 bumble bees/m^2/5min) during 1600-1800h, whereas, minimum (2.00 bumble bees) during 1200-1400h. The maximum foraging rate (6.17 flowers/min) of *B. haemorrhoidalis* was during 0800-1000h, whereas, minimum (3.40 flowers) during 1200-1400h. The bumble bees spent maximum time on a single flower (6.90 sec/flower) during 0800-1000h, whereas, minimum time (4.47 sec) during 1200-1400h.

Keywords: *B. haemorrhoidalis,* visiting flowers, foraging rate, minimum, maximum

1. Introduction
Bumble bees (family: Apidae, order: Hymenoptera) are efficient insect pollinators of many vegetable under protected condition. The genus *Bombus* comprising 250 known species the world over (Williams *et al.*, 2008) [24]. About 48 species of bumble bees are found in India. Out of these 48 species, 37 species are reported from North West Himalayas (Saini *et al.*, 2011) [20]. Bumble bees are known as reliable pollinator because they pollinate at high speed, forage at low temperature and low light intensity and vibration to burst the pollen sacs (Heinrich, 1979; Abrol, 2011) [12, 2]. They are perfect pollinator of flowers of family Solanaceae because sonication is required for pollination. Various vegetable crops (like; tomato, pepper, cucumber, strawberries etc.) are grown under plastic tunnels, polyhouses or cages need such pollinators to get low cost component (Abak *et al.*, 1997; Kwon and Saeed, 2003) [1, 15]. Bumble bees pollination improve the quantitative and qualitative parameters of crops and reduced the cost of cultivation (Klein *et al.*, 2007; Aizen *et al.*, 2008) [14, 3]. Different *Bombus* species like *B. terrestris, B. impatiens, B. occidentalis* and some others have been utilized for pollination worldwide (Kwon and Saeed, 2003; Velthuis and van Doorn, 2006; Klein *et al.*, 2007) [14, 22, 13]. Generally, these species are not use for crop pollination because of quite costly to import (Velthuis and van Doorn, 2006) [23]. The first successful small scale rearing of *Bombus hamorrhoidalis* Smith was started at Solan in India (Dayal and Rana, 2004; Thakur *et al*, 2005) [9, 22]. Bell pepper (*Capsicum annuum* L.; family Solanaceae), an important often cross pollinated vegetable crop which is excellent prospects for both domestic and export market. Bell pepper is used in many ways for home consumptions, catering and industries (Obidiebube *et al.*, 2012) [17]. The flowers of bell pepper are generally hermaphrodite, although some are monoecious, andromonoecious or dioecious and the anthers of bell pepper are poricidal, meaning that the flower's pollen is produced within the anthers and released through small pores, so bell pepper's anthers require agitation to release pollen. The greenhouse cultivated bell peppers does not achieve adequate pollination without hand and manual pollination. The hand pollination is a very time consuming and labour intensive process. Hence, pollination through bumble bees in greenhouses condition constitutes an attractive and cost-effective alternative to hand and manual pollination (Velthuis and van Doorn, 2006) [23]. Some vegetable crops (like; eggplant, seed potato, hot/sweet pepper and tomatoes) require

vibration to release pollen grains from flowers. The pollen grains are removed and dropped on to the insects by contracting their flight muscles rapidly, an activity called as 'buzz' pollination. The insect pollinators like bumble bees and certain solitary bees are capable of doing buzz pollination and offer valuable pollination services under protected condition (Plowright and Laverty, 1984; Cane and Payne, 1990, 1993) [19, 4, 5]. Bumble bees are able to identify the flower recently visited by other bees through detection of electric field (Clarke *et al*., 2013) [7] and identify flowers through temperature of flowers (Harrap *et al*., 2017) [11]. The experiment was carried out to study the foraging behavior of bumble bees on bell pepper that will helpful to improve fruit quality and thus increase the farmer's income.

2. Materials and Methods

The experimental field for carrying out pollination studies in bell pepper was selected at Khaltu, Department of Seed Science and Technology, Dr YSP University of Horticulture and Forestry, Nauni, Solan, Himachal Pradesh which is located at an altitude of 1250m amsl, latitude of 35.5°N and longitude of 77.8°E in the year 2017-18. The area falls in the mid- hill zone of Himachal Pradesh. Raising of bell pepper was done as per package and practices for protected cultivation in polyhouse. The total area of the polyhouse (200 m^2) was divided into two parts by using insect proof net in the middle. In one portion (100 m^2), the bumble bee colony was placed for pollination at the time of 5-10% flowering of the crop and in the second portion of polyhouse *Apis mellifera* colony was introduced. Another polyhouse (100 m^2) was kept without bumble bees (control plot). Open pollination studies were conducted in bell pepper grown under open conditions in the field. The spacing was 60cmX45cm from row to row and plant to plant. The crop was transplanted in the third week of April and came in to the flowering in second week of June. Bell pepper crop, cultivar Solan Bharpur was raised as per package and practices of the university. Artificially reared bumble bee (*B. haemorrhoidalis*) colony was utilized for pollinating bell pepper crop in polyhouse. The bumble bee colony reared under laboratory conditions and further established in the field was introduced in flowering bell pepper crop at 5-10% flowering in polyhouse by placing it inside a Langstroth bee hive. The entrance of the hive widened with the help of a drill to fix a plastic tube which served as a passage for incoming and outgoing bumble bee foragers. Bumble bee colony was fed with 50% sucrose solution and fresh/stored pollen from *A. mellifera* colonies for first two days to make it acclimatize to the polyhouse environment.

The following parameters were recorded under protected condition:

Foraging behaviour of bumble bee on bell pepper flowers inside polyhouse, from early morning hours (0600h) till late evening (1800h) at two hours interval, was recorded in flowers visited by bumble bees. For this flowers were observed visually for bumble bee visits.

2.1 Activity of bumble bees: Activity of bumble bees at hive entrance was recorded by counting the number of incoming and outgoing bumble bees per 5 minutes using the stop watch.

2.2 Foraging rate of bumble bees: Foraging rate of bumble bees was recorded by counting the number of flowers visited by each bumble bee in a minute, using stop watch.

2.3 Foraging speed of bumble bees: Foraging speed of bumble bees was recorded using stop watch in terms of the time spent in seconds by the bumble bee forager on each flower.

2.4 Abundance of bumble bees: Abundance of bumble bees on bell pepper flowers was recorded by counting the number of bumble bees per m^2 per 5 min using the stop watch.

2.5 Data analysis: The data recorded on various parameter was analysed statistically using suitable transformation (where needed) in Randomized block design (RBD). Analysis of variance for the experiment was done as per the model suggested by Panse and Sukhatme, (2000) [18]. The data to be recorded was analysed using MS-Excel, OPSTAT.

3. Results and Discussion

The bumble bee colony reared under laboratory conditions and further established in the field was introduced in flowering bell pepper crop grown in polyhouse by placing it inside a Langstroth bee hive.

3.1 Activity of bumble bees (*B. haemorrhoidalis*):

Data recorded on activity of bumble bees at hive entrance under protected cultivation is presented in Fig. 1. It was found that the maximum incoming bumble bees (3.70 bumble bees/5min) were recorded during 1600-1800h. The least number of incoming bumble bees (1.00 bumble bees) was recorded during 1200-1400h. Data also indicated that the maximum outgoing bumble bees (3.89 bumble bees/5min) were recorded during 1400-1600h. The least number of outgoing bumble bees (1.52 bumble bees) were recorded during 1200-1400h, which was significantly same with the activity during 1600-1800h (1.63 bumble bees).

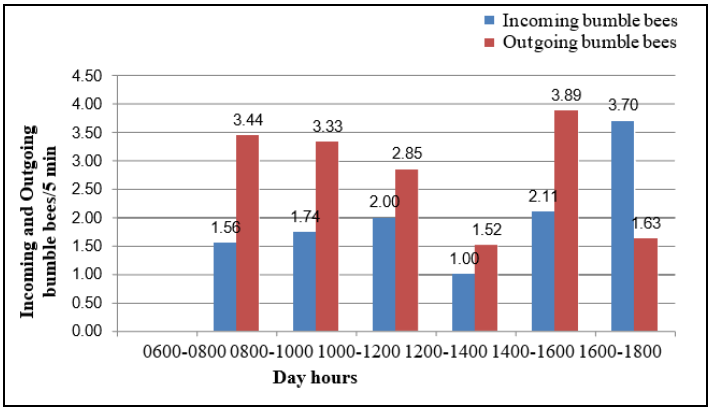

Fig 1: Activity of *B. haemorrhoidalis* at hive entrance under protected cultivation

The results also showed that mean activity of bumble bees was more (3.00 bumble bees/5min) during 1400-1600h at hive entrance in polyhouse. The minimum mean activity (1.26 bumble bees) was observed during 1200-1400h. These findings are corroborated with Chauhan (2011) [6], who reported the maximum (8.24 bumble bees/5 min) activity of bumble bees on cucumber plants grown under greenhouse during late evening hours and minimum (4.41 bumble bees/5 min) activity was during noon time. The maximum activity of *B. haemorrhoidalis* on protected tomato was observed during 1800-1900hr and minimum activity during noon time (Yankit, 2016) [25]. The results are in line with the observations of Nayak *et al.* (2019) [16]. who observed the peak activity of bumble bees on kiwifruit under caged condition during evening time and least activity during noon time.

3.2 Abundance of bumble bees

The data on abundance of *B. haemorrhoidalis* on bell pepper flowers grown under protected cultivation presented in Table 1 showed that the number of bumble bees visiting bell pepper bloom was maximum (6.83 bumble bees/m^2/5min) during 1600-1800h. The minimum numbers of bumble bees visiting flowers of bell pepper (2.00 bumble bees/m^2/5min) were recorded during 1200-1400h. The results of present findings are similar to Yankit (2016) [25], who found that maximum abundance of *B. haemorrhoidalis* was during evening hours and minimum during noon time. Nayak *et al.* (2019) [16] also reported that bumble bee foragers preferred to visit kiwifruit bloom during morning and evening hours than mid-hours with more activity and abundance.

Table 1: Abundance of *B. haemorrhoidalis* on bell pepper flowers grown under protected cultivation

Day hours	Number of *B. haemorrhoidalis*/m^2/5min
0600-0800	3.37
0800-1000	4.53
1000-1200	2.70
1200-1400	2.00
1400-1600	5.93
1600-1800	6.83
Mean	**4.23**
CD (0.05)	0.61

B. haemorrhoidalis foraging on bell pepper flower

3.3 Foraging rate of bumble bees

The data on number of flowers visited by bumble bees on bell pepper flowers grown under protected cultivation is presented in Fig. 2. Number of flowers visited by bumble bees varied significantly from 3.40 flowers to 6.17 flowers/min. The maximum numbers of flowers (6.17 flowers) were visited by bumble bees during 0800-1000h. The minimum numbers of flowers (3.40 flowers) were observed to be visited by bumble bees during 1200-1400h. The results are in conformity with Yankit (2016) [25], who recorded the maximum foraging rate during morning hours and minimum during noon hours. These findings also corroborated with the results of Nayak *et al.* (2019) [16] who reported that foraging rate of *Bombus haemorrhoidalis* was maximum during morning hours as compared to evening hours inside caged condition on kiwifruit.

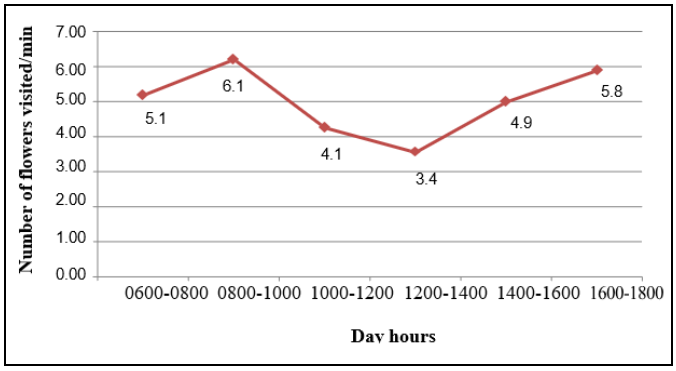

Fig 2: Foraging rate of *B. haemorrhoidalis* on bell pepper flowers grown under protected cultivation

Foraging speed of bumble bees

The data on foraging speed of bumble bees on bell pepper flowers grown under protected cultivation is presented in Table 2. The maximum time (6.90 sec) spent on a single flower of bell pepper was observed during 0800-1000h. The minimum time on single flower (4.47 sec) was spent during 1200-1400h which was statistically same with time spent on a single flower during 1400-1600h (5.03sec).

Table 2: Foraging speed of *B. haemorrhoidalis* on bell pepper flowers grown under protected cultivation

Day hours	Time spent/flower (in sec)
0600-0800	5.77
0800-1000	6.90
1000-1200	5.27
1200-1400	4.47
1400-1600	5.03
1600-1800	6.27
Mean	5.62
CD (0.05)	0.60

The foraging speed of *B. haemorrhoidalis* in present findings on bell pepper is similar to foraging speed of *B. haemorrhoidalis* in tomato (Yankit, 2016) [25]. She found that time spent per flower in tomato was maximum (6.82 sec/flower) during 0800-0900h and minimum (3.19 sec) during 1200-1300h. The present results showed variations with the observations of Kashyap (2007) [13] in cucumber, who reported that *B. haemorrhoidalis* spent maximum time per flower during 0600-0700h and minimum during 1200-1300h. Average foraging speed of *B. haemorrhoidalis* recorded in present studies is in the range of *B. terrestris* (8.5±9.0 sec) on greenhouse sweet pepper (Dag and Kammer, 2001) [8]. In general foraging rate and foraging speed on crops depends upon different species, size of workers, cultivar, prevailing weather conditions (Free, 1955; Spaethe and Weidenmuller, 2002) [10, 21].

4. Conclusion

The mean activity of bumble bees was maximum (3.00 bumble bees/5min) during 1400- 1600h and minimum (1.26

bumble bees) during 1200-1400h at hive entrance in polyhouse. The number of bumble bees visiting bell pepper flowers were maximum (6.83 bumble bees/m^2/5min) during 1600-1800h, whereas, minimum (2.00 bumble bees) during 1200- 1400h. The maximum foraging rate (6.17 flowers/min) of *B. haemorrhoidalis* was during 0800-1000h, whereas, minimum (3.40 flowers) during 1200-1400h. The bumble bees spent maximum time on a single flower (6.90 sec/flower) during 0800-1000h, whereas, minimum time (4.47 sec) during 1200-1400h.

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