



Diversity, abundance and pollination efficiency of insect pollinators of fennel (*Foeniculum vulgare* Miller) and effect of abiotic factors on insect pollinator activity

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Abstract: Biodiversity of insect pollinators on fennel cv. HF-143 (*Foeniculum vulgare* Miller), was studied in Hisar, Haryana, India. Twenty-five insect species belonging to fifteen families of five orders were recorded from fennel flowers, in which, seven belong to order Lepidoptera, nine to Hymenoptera, five to Diptera, three to Coleoptera and one to Odonata. Among the insect pollinators, *Apis florea* F., *A. cerana indica* F., *A. mellifera* L. and *A. dorsata* F. were the most frequent visitors. Among different bee species, the maximum mean population observed in case of *A. florea* (9.23 bees/m²/5 min) followed by *A. mellifera* (3.62 bees/m²/5 min) and *A. dorsata* (3.21 bees/m²/5 min), whereas, the least abundance was observed in case of *A. cerana indica*, i.e., 1.82 bees/m²/5 min. The pollination index of *A. dorsata* was highest (19715210) followed by *A. florea* (13888381), *A. mellifera* (13845052) and *A. cerana* (5586381). Hence, it was observed that *A. dorsata* was the most efficient pollinator followed by *A. florea*, *A. mellifera* and *A. cerana* on fennel cv. HF-143 flowers under agro ecological conditions of Hisar (Haryana). Hence, insect pollinators were essential to get good returns in this seed crop. The activity of different bee species on fennel varied with different abiotic factors and had significantly positive correlation with bright sun shine hours (BSS) and temperature (TEMP) in different hours of the day during foraging but had negative correlation with relative humidity (RH). It was observed that the effect of wind velocity on foraging of different bee species was not significant. Thus, the impact of abiotic environmental factors may decide the foraging activity of different insect pollinators.

Keywords: Abundance, Abiotic factors, Foraging speed, Foraging rate, Fennel cv. HF-143, Pollination index

INTRODUCTION

Fennel (*Foeniculum vulgare* Miller), commonly known as *saunf*, is one of the most important winter season seed spices, grown in northern India. It grows well under dry and cold weather conditions, and therefore, it is cultivated in Gujarat, Rajasthan, Uttar Pradesh, Madhya Pradesh, Karnataka, Haryana and Punjab. In India and neighbouring countries, it is used as masticatory or for chewing alone or in *paans*. It is also used in cough, flatulence, colic, thirst and for flavouring soups, meat dishes, sauces, bread rolls, pastries, confectionary, liquors and in making pickles (Pruthi, 1976). Seeds are being used in medicines as a carminative, stimulant, stomachic and as a cure for earaches, toothaches, coughs, asthma and rheumatism. Pollination is one of the limiting factors for crop productivity and is significantly contributing to the agricultural productivity. Pollination, which is essential for the process of fertilization and production of fruits and/or seeds, is defined as the transfer of pollens from male to female portion of a flower. In nature, only about 5 per cent of the flowers are self-pollinated and 95 per

cent animal pollinated (Tewari and Singh, 1983) out of which 90 per cent accounts Insect pollination (Richards, 1986; Buchmann and Nabhan, 1996). Since very meagre information is available on the insect pollination requirements of fennel, therefore the present study was carried out on the diversity, abundance of insect visitors/ pollinators, effect of abiotic factors on foraging activity of major insect pollinators and evaluation of their pollination efficiency on fennel, *Foeniculum vulgare* Miller, in Hisar (Haryana), India.

MATERIALS AND METHODS

Study sites and climate: The experiment comprises fennel cv. HF-143 crop with two modes of pollination viz., open-pollination (OP) and without insect pollination (WIP) was conducted at Research Farm of the Department of Vegetable Science, CCS Haryana Agricultural University, Hisar (India). The experimental site is situated at 29°-10' North latitude and 75°-46' East longitude at an altitude of 215.2 meter above mean sea level. The climate of Hisar region is semi-arid and is characterized by hot and dry winds during summer months and dry and severe cold conditions during

winter months. The maximum and minimum temperature showed wide range of fluctuations during summer, while the temperature below freezing point accompanied by frost was also recorded during winter months (December-January), which is very common feature of this region. The rainfall was confined mainly to the monsoon months from July to September but light showers cyclonic rains also occurred sometimes during winter and spring months.

Soils status and fertilization: The soil of the field was sandy-loam with moderate fertility and pH 8.0, indicating slightly alkaline nature of the soil. Based on soil analysis, the soil of the experimental field was low in nitrogen, medium in organic carbon (0.33%), available phosphorus (8 kg/ha) and rich in potassium (480 kg/ha). Well-decomposed two years old farmyard manure was incorporated into the soil @ 10 t/ha at the time of field preparation. The field was prepared up to fine tilth by giving repeated ploughings with disc harrow followed by planking.

Crop husbandry: For raising a healthy fennel crop, 50 kg nitrogen, 25 kg phosphorus and 25 kg potash fertilizers were applied per hectare at the time of last ploughing. The crop was raised on one acre of land under field conditions at Research Farm of the Department of Vegetable Sciences, CCS Haryana Agricultural University, Hisar. The crop was raised by following the practices recommended in Package of Practices of CCS Haryana Agricultural University, Hisar. The crop had flowering period from 5 March to 15 April 2013.

Diversity of insect visitors/pollinators: Insect visitors/pollinators of fennel flowers were collected by using a cone type hand net with 30 cm ring diameter. For this, the sweeps were made throughout flowering periods of the crop at different hours of the day after 10 per cent flowering in the crops. The crop had flowering period from 5 March to 15 April 2013. All collected insects were killed and preserved as dry specimen and were got them identified.

Abundance of insect visitors/pollinators on fennel flowers: Abundance of major insect visitors/pollinators on fennel flowers was recorded during blooming period of the crop. The crops had their flowering time from 5 March to 15 April 2013. The counts of insect visitors were made on flowers of fennel crop per square meter area for five minutes using hand tally counter between different day hours. These observations were recorded from 7:00 a.m. to 7:00 p.m. at an interval of two hours after the initiation of 10 per cent flowering in the crop, at peak flowering and before the cessation of flowering in the crop.

Working behaviour of the insect visitors/pollinators: Individual of different insect visitor species was observed for their working behaviour, *i.e.*, whether they were working from top or side of the flower. The movement of insect from one flower to another on umbels was also observed.

Different aspects of foraging behaviour of insect

pollinators of seed spice crops were recorded as follows *viz.*, initiation, peak activity and cessation time of different bee species were recorded. Observations on the insect pollinator's body contacts with anthers and/or stigma, whether working from top of the flower (top workers: the bees that stand on the anthers or receptacle and push their tongue and frontal parts of their body towards nectarines and touch the stigma and/or anthers) or side (side worker: the bees that push their tongue for obtaining nectar between the stamen filaments having gap while standing on petals with meso- and meta-thoracic legs) were also recorded. Ten individuals of each bee species were observed. The observations were recorded throughout the flowering period of fennel crop. Initiation and cessation time of activity of insect pollinators were also noted.

Determination of the foraging speed of insect pollinators: Foraging speed of bees was recorded in terms of time (seconds) spent by them on each flower (Free, 1993). Ten bees of each species were observed for recording time spent by them per flower at peak flowering period of the crop. The time spent to inject the proboscis and suck up the nectar or brushing/collecting pollens was considered as the time spent per flower, which was recorded with the help of a chronometer having an accuracy of 0.01 seconds. Ten observations were recorded for each bee species upto ten days in different hours of the day from 7:00 a.m. to 7:00 p.m. at an interval of two hours after the initiation of 10 per cent flowering in the crop, at peak flowering and before the cessation of flowering in the crop.

Determination of the foraging rate of insect pollinators: Foraging rate of bees was recorded in terms of the number of flowers visited per minute (Free, 1993). Ten bees of each species were observed for recording the number of flowers visited per minute at peak activity time of particular species at peak flowering period of the crop. The number of flowers visited per minute was recorded including the flying time from one flower to another flower. Ten observations were recorded for each bee species upto ten days in different hours of the day from 7:00 a.m. to 7:00 p.m. at an interval of two hours after the initiation of 10 per cent flowering in the crop, at peak flowering and before the cessation of flowering in the crop.

Counting of loose pollen grains sticking to the bee body: The loose pollen grains sticking to the body of different bee species were counted by capturing the bees gently by forceps to avoid shaking of its body on the flowers and their hind legs were amputated following the method given by Kumar (1990). The bees were captured at the time of their peak activity during peak flowering period of crop and were preserved in 70 per cent alcohol in glass vials after amputating the hind pair of legs very gently. The bees were shaken vigorously to wash out the pollen grains from their body and the rinsate containing pollen grains in 2 ml alcohol. The number of pollens in each sample was

counted in a haemocytometer using microscope. An aliquot of 1 µl of each sample was charged on WBC counting chamber of the haemocytometer and the pollens grains were counted at 10x15 magnification of the microscope. The total number of pollen grains in the whole rinsate was calculated using the formula:

$$\text{Total number of pollen grains per bee per 2 ml of solution} = \frac{\text{Average no of pollen grains counted in WBC chamber} \times 2\text{ml} \times 10^4}{2\text{ml}}$$

Identification of fennel crop pollen grains in rinsate was accomplished by comparing with standard pollen slides. Ten samples for each bee species were observed for counting the number of pollen grains. For the study of pollen grains, insects were captured between 1100 and 1300 h of the day.

Determination of the pollination efficacy: Comparison

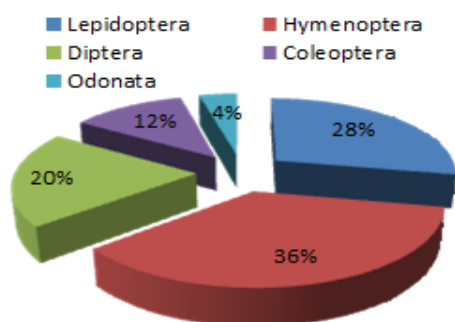


Fig. 1. Diversity of different insect pollinators in fennel flower.

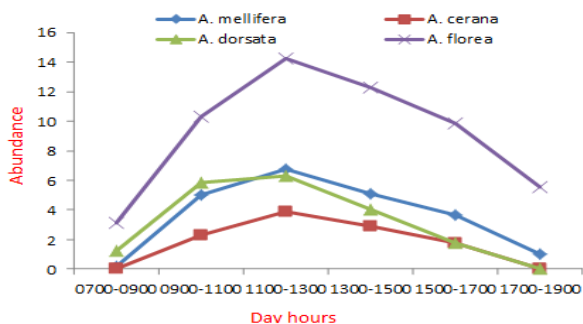


Fig. 2. Abundance of different bee species on fennel flowers at different hours of the day.

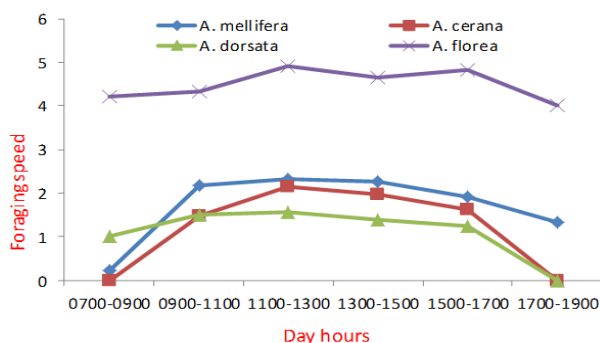


Fig. 3. Time spent by different bee species on fennel flowers at different hours of the day.

tive pollination efficiency of different bee species viz., *A. dorsata*, *A. mellifera*, *A. florea* and *A. cerana*, were calculated based on their relative abundance and foraging behaviour parameters such as foraging speed, foraging rate and the number of loose pollen grains sticking to their bodies by using the formula given below:

$$\text{Pollination efficacy} = \text{Number of loose pollen grains} \times \text{Abundance} \times \text{Foraging rate}$$

Effect of abiotic factors on insect pollinators activity:

To correlate the effect of different environmental factors such as temperature, relative humidity, wind velocity and rainfall was recorded by the Department of Meteorology, Chaudhary Charan Singh Haryana Agricultural University- Hisar during different hours of the day on bees' activities in fennel crop during flowering period.

Statistical analysis: The data pertaining to seed yield, test weight, and seed germination were statistically analysed by using standard analysis of variance (ANOVA) procedures.

RESULTS

Diversity of insect visitors/pollinators on fennel flowers:

The data on diversity of insect visitors/pollinators on fennel cv. HF-143 flowers are presented in Table 1 and Fig. 1. Twenty five insect species belonging to fifteen families of five orders were recorded from fennel cv. HF-143 flowers, in which, seven belong to order Lepidoptera, nine to Hymenoptera, five to Diptera, three to Coleoptera and one to Odonata. Hymenopterans were the major floral visitors comprising of four families viz., Apidae (*Xylocopa virginica* L., *Apis florea* F., *A. cerana indica* F., *A. mellifera* L. and *A. dorsata* F.), Megachilidae (*Megachile* sp.), Halictidae (*Halictus* sp.) and Vespidae (*Vespa orientalis* L. and *Polistes olivaceus* F.). They were followed in order of diversity by dipterans from four families viz., Muscidae (*Musca domestica* L.), Calliphoridae (*Chrysomya megacephala* F.), Sarcophagidae



Fig. 4. *A. mellifera* foraging on fennel flower.

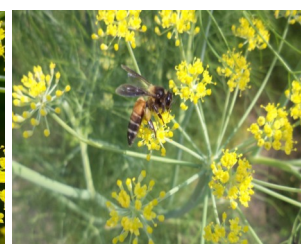


Fig. 5. *A. dorsata* foraging on fennel flower



Fig. 6. *A. florea* foraging on fennel flower.

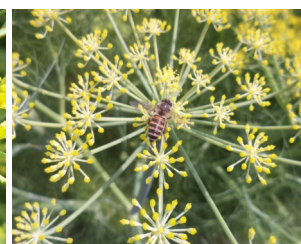


Fig. 7. *A. cerana* foraging on fennel flower.

Table 1. List of insect visitors/pollinators of fennel cv. HF-143 flowers.

S. N.	Scientific name	Family	Order	Working behavior
1.	<i>Danaus chrysippus</i> L.	Nymphalidae	Lepidoptera	Top and Side
2.	<i>Tirumala</i> sp.	Nymphalidae	Lepidoptera	Top and Side
3.	<i>Papilio demoleus</i> L.	Papilionidae	Lepidoptera	Top and Side
4.	<i>Pieris brassicae</i> L.	Pieridae	Lepidoptera	Top and Side
5.	<i>Terias hecabe</i> L.	Pieridae	Lepidoptera	Top and Side
6.	<i>Utethesia pulchella</i> L.	Arctiidae	Lepidoptera	Top and Side
7.	<i>Lampides boeticus</i> L.	Lycaenidae	Lepidoptera	Top and Side
8.	<i>Megachile</i> sp.	Megachilidae	Hymenoptera	Top
9.	<i>Halictus</i> sp.	Halictidae	Hymenoptera	Top
10.	<i>Xylocopa virginica</i> L.	Apidae	Hymenoptera	Top
11.	<i>Apis florea</i> F.	Apidae	Hymenoptera	Top
12.	<i>Apis cerana indica</i> F.	Apidae	Hymenoptera	Top
13.	<i>Apis mellifera</i> L.	Apidae	Hymenoptera	Top
14.	<i>Apis dorsata</i> F.	Apidae	Hymenoptera	Top
15.	<i>Vespa orientalis</i> L.	Vespidae	Hymenoptera	Top
16.	<i>Polistes olivaceus</i> F.	Vespidae	Hymenoptera	Top
17.	<i>Chrysomya megacephala</i> F.	Calliphoridae	Diptera	Top
18.	<i>Sarcophaga</i> sp.	Sarcophagidae	Diptera	Top
19.	<i>Eristalinus aeneus</i> Scopoli	Syrphidae	Diptera	Top
20.	<i>Eristalinus tabanoides</i> Jaennicke	Syrphidae	Diptera	Top
21.	<i>Musca domestica</i> L.	Muscidae	Diptera	Top
22.	<i>Coccinella septempunctata</i> L.	Coccinellidae	Coleoptera	Top
23.	<i>Cheilomenes sexmaculata</i> Chevrolat	Coccinellidae	Coleoptera	Top
24.	<i>Brumoides suturalis</i> F.	Coccinellidae	Coleoptera	Top
25.	<i>Ceriagrion coromandelanum</i> F.	Coenagrionidae	Odonata	Top and Side

Table 2. Abundance of different bee species on fennel cv. HF-143 flowers at different hours of the day.

Bee species	Number of bees/m ² /5 min during different day hours						
	0700-0900	0900-1100	1100-1300	1300-1500	1500-1700	1700-1900	Mean
<i>A. mellifera</i>	0.20 (1.08)	5.00 (2.41)	6.73 (2.77)	5.13 (2.46)	3.67 (2.11)	1.00 (1.39)	3.62(2.04)
<i>A. cerana</i>	0 (1.00)	2.33 (1.78)	3.87 (2.19)	2.93 (1.95)	1.80 (1.64)	0 (1.00)	1.82(1.59)
<i>A. dorsata</i>	1.27 (1.46)	5.87 (2.57)	6.33 (2.69)	4.00 (2.20)	1.80 (1.64)	0 (1.00)	3.21(1.93)
<i>A. florea</i>	3.13 (1.98)	10.33 (3.30)	14.27 (3.89)	12.27 (3.61)	9.87 (3.23)	5.53 (2.48)	9.23(3.08)
Mean	1.15 (1.38)	5.88 (2.51)	7.80 (2.89)	6.08 (2.56)	4.28 (2.16)	1.63 (1.47)	

Each value represents mean of 15 observations at each sampling time; Figures in parentheses are $\bar{O}(x+1)$ transformed values.

Factors	SE(m)	C.D. (p= 0.05)
Bee species	0.04	0.10
Day hours	0.04	0.12
Bee species x Day hours	0.09	0.24

(*Sarcophaga* sp.) and Syrphidae (*Eristalinus aeneus* Scopoli and *Eristalinus tabanoides* Jaennicke), lepidopterans from five families viz., Nymphalidae (*Danaus chrysippus* L. and *Tirumala* sp.), Pieridae (*Pieris brassicae* L. and *Terias hecabe* L.), Papilionidae (*Papilio demoleus* L.), Lycaenidae (*Lampides boeticus* L.) and Arctiidae (*Utethesia pulchella* L.), coleopteran from one family viz., Coccinellidae (*Coccinella septempunctata* L., *Cheilomenes sexmaculata* Chevrolat and *Brumoides suturalis* F.) and one species from one family of order Odonata viz., Coenagrionidae (*Ceriagrion coromandelanum* F.). Among the insect pollinators, *Apis florea*, *A. cerana indica*, *A. mellifera* and *A. dorsata* were the most frequent visitors.

Abundance of insect visitors/pollinators on fennel

flowers: The data on abundance statistically analysed with two factors analysis of different honeybee species on fennel cv. HF-143 flowers at different hours of the day are presented in Table 2 and Fig. 2. Variations in abundance were recorded over time and space. Among different bee species, the maximum mean population observed in case of *A. florea* (9.23 bees/m²/5 min) followed by *A. mellifera* (3.62 bees/m²/5 min) and *A. dorsata* (3.21 bees/m²/5 min), whereas, the least abundance was observed in case of *A. cerana indica*, i.e., 1.82 bees/m²/5 min. Irrespective of different bee species, the maximum population was observed during 1100-1300 hrs of the day (7.80 bees/m²/5 min) followed by 1300-1500 hrs (6.08 bees/m²/5 min), 0900-1100 hrs (5.88 bees/m²/5 min), 1500-1700 hrs (4.28 bees/m²/5 min) and 1700-

Table 3. Foraging activity of different bee species on fennel cv. HF-143 flowers at different hours of the day.

Bee species	Activity time (h)		
	Initiation	Peak	Cessation
<i>A. mellifera</i>	0830(1)	1100-1300 (9)	1810 (2)
<i>A. cerana</i>	0915 (5)	1100-1300 (6)	1630 (1)
<i>A. dorsata</i>	0805 (3)	1100-1300 (9)	1630 (2)
<i>A. florea</i>	0800 (5)	1100-1300 (18)	1820 (1)

Figures in parentheses are the number of bees observed at respective time

1900 hrs (1.63 bees/m²/5 min). The lowest population was recorded during 0700-0900 hrs, i.e., 1.15 bees/m²/5 min. The mean bee species population over different day hours on fennel flowers ranged from 1.82 bees/m²/5 min in case of *A. cerana* to 9.23 bees/m²/5 min in case of *A. florea*. For *A. florea*, the maximum bee population was observed at 1100-1300 hrs (14.27 bees/m²/5 min), followed by 1300-1500 hrs (12.27 bees/m²/5 min) and 0900-1100 hrs (10.33 bees/m²/5 min). The least population of *A. florea* was observed during 0700-0900 hrs, i.e., 3.13 bees/m²/5 min. For *A. mellifera*, the maximum bee population was observed at 1100-1300 hrs (6.73 bees/m²/5 min), followed by 1300-1500 hrs (5.13 bees/m²/5 min) and 0900-1100 hrs (5.00 bees/m²/5 min). The least population of *A. mellifera* was observed during 0700-0900 hrs, i.e., 0.20 bees/m²/5 min. For *A. cerana*, the

maximum bee population was observed at 1100-1300 hrs (3.87 bees/m²/5 min), followed by 1300-1500 hrs (2.93 bees/m²/5 min) and 0900-1100 hrs (2.33 bees/m²/5 min). No population of *A. cerana* was observed during 0700-0900 and 1700-1900 hrs of the day. For *A. dorsata*, the maximum bee population was observed at 1100-1300 hrs (6.33 bees/m²/5 min), followed by 0900-1100 hrs (5.87 bees/m²/5 min) and 1300-1500 hrs (4.00 bees/m²/5 min). No population of *A. dorsata* was observed during 1700-1900 hrs of the day. The cumulative mean abundance of important bee species revealed that *A. florea* was the most abundant visitor with a mean population of 9.23 bees/m²/5 min followed by *A. mellifera* (3.62 bees/m²/5 min), *A. dorsata* (3.21 bees/m²/5 min) and *A. cerana* was least frequent (1.82 bees/m²/5 min) visitor of fennel flowers in the present investigations.

Foraging activity: The foraging activity of different bee species on fennel flowers is presented in Table 3 and Fig. 4,5,6 and 7. From the visual observations, it was observed that all the four *Apis* species viz., *A. florea*, *A. mellifera*, *A. dorsata* and *A. cerana*, were found to be top workers while foraging on fennel flowers. *A. florea* initiated foraging activity little earlier in the morning and ceased its activity little later in the evening when compared with *A. cerana*, *A. mellifera* and *A. dorsata*.

Results presented in Table 3 depict that *A. florea* started

Table 4. Time spent by different bee species on fennel cv. HF-143 flowers at different hours of the day.

Bee species	Time spent (sec)/ umbelet						Mean
	0700-0900	0900-1100	1100-1300	1300-1500	1500-1700	1700-1900	
<i>A. mellifera</i>	0.23 (1.08)	2.19 (1.77)	2.31 (1.82)	2.27 (1.81)	1.90(1.67)	1.33(1.48)	1.71 (1.60)
<i>A. cerana</i>	0 (1.00)	1.48 (1.53)	2.16 (1.78)	1.97 (1.70)	1.63(1.59)	0(1.00)	1.21 (1.43)
<i>A. dorsata</i>	1.01 (1.37)	1.50 (1.57)	1.56 (1.60)	1.38 (1.53)	1.23(1.47)	0(1.00)	1.11 (1.42)
<i>A. florea</i>	4.21 (2.24)	4.34 (2.27)	4.92 (2.43)	4.64 (2.37)	4.83(2.41)	4.01(2.16)	4.49 (2.31)
Mean	1.36 (1.42)	2.38 (1.78)	2.74 (1.91)	2.57 (1.85)	2.40(1.79)	1.34(1.41)	

Each value represents mean of 10 observations at each sampling time; Figures in parentheses are $\bar{O}(x+1)$ transformed values.

Factors	SE(m)	C.D. (p= 0.05)
Bee species	0.03	0.09
Day hours	0.04	0.11
Bee species x Day hours	0.08	0.23

Table 5. Number of flowers visited by different bee species on fennel cv. HF-143 flowers at different hours of the day.

Bee species	Number of umbelets visited/min						Mean
	0700-0900	0900-1100	1100-1300	1300-1500	1500-1700	1700-1900	
<i>A. mellifera</i>	2.06(1.37)	17.68(4.19)	20.62(4.65)	20.40(4.63)	15.82(3.85)	11.66(3.11)	14.71(3.63)
<i>A. cerana</i>	0(1.00)	16.46(3.92)	20.36(4.62)	18.60(4.29)	16.50(3.92)	0(1.00)	11.99(3.12)
<i>A. dorsata</i>	14.96(3.28)	26.36(5.05)	29.68(5.54)	26.78(5.09)	23.84(4.64)	0(1.00)	20.27(4.10)
<i>A. florea</i>	6.44(2.61)	7.24(2.81)	8.28(3.05)	8.02(3.00)	7.84(2.97)	6.22(2.57)	7.34(2.83)
Mean	5.87(2.06)	16.94(3.99)	19.74(4.46)	18.45(4.25)	16.00(3.84)	4.47(1.92)	

Each value represents mean of 10 observations at each sampling time; Figures in parentheses are $\bar{O}(x+1)$ transformed values.

Factors	SE(m)	C.D. (p= 0.05)
Bee species	0.13	0.38
Day hours	0.17	0.46
Bee species x Day hours	0.33	0.92

Table 6. Number of loose pollen grains sticking on the body of different bee species on fennel cv. HF-143 flowers.

Bee species	Loose pollen grains sticking on the body of different bee species (Mean)
<i>A. mellifera</i>	260,000
<i>A. cerana</i>	256,000
<i>A. dorsata</i>	303,000
<i>A. florea</i>	205,000
Each value represents mean of 10 observations.	
C.D. (p= 0.05)	22,624
SE(m)	7,755

collecting pollen grains from 0800 hrs of the day, whereas, *A. dorsata* initiated its activity from 0805 hrs followed by *A. mellifera* (0830 hrs of the day). *Apis cerana* started its activity little later from 0915 hrs of the day. However, all four *Apis* species attained their peak activity during 1100-1300 hrs of the day and *A. dorsata* as well as *A. cerana* both ceased their activity little earlier in evening, i.e., 1630 hrs of the day followed by *A. mellifera* (1810 hrs of the day), whereas, *A. florea* ceased its activity little later, i.e., 1820 hrs of the day.

Foraging speed of insect visitors/pollinators on fennel flowers: The data on foraging speed statistically analysed with two factors analysis, i.e. time spent by different bee species on fennel flower, during March-April 2013 have been narrated in Table 4 and Fig. 3. Among different *Apis* species, *A. florea* spent maximum time (4.49 sec/umbelet) followed by *A. mellifera* (1.71 sec/umbelet) and *A. cerana* (1.21 sec/umbelet). The least time per umbelet was recorded in case of *A. dorsata*, i.e., 1.11 seconds. The time spent per umbelet by different bee species differed significantly. The mean foraging speed [time spent (sec)/umbelet] varied from 4.01 to 4.92 seconds in case of *A. florea* during different hours of the day, while in case of *A. mellifera* and *A. cerana*, it was 0.23 to 2.31 and 1.48 to 2.16 seconds, respectively and no population of *A. cerana* was observed during 0700-0900 and 1700-1900 hrs of the day, whereas, in case of *A. dorsata*, it varied from 1.01 to 1.56 seconds and no population of *A. dorsata* was observed during 1700-1900 hrs of the day. Irrespective of different bee species, the mean time spent during different day hours differed significantly. The mean time spent by four bees during 1100-1300 hour of the day (2.74 sec/umbelet) was significantly higher than the mean time spent during 0700-0900 hrs (1.36 sec/umbelet), 0900-1100 hrs (2.38 sec/umbelet), 1300-

1500 hrs (2.57 sec/umbelet), 1500-1700 hrs (2.40 sec/umbelet) and 1700-1900 hrs (1.34 sec/umbelet) of the day.

Foraging rate of insect visitors/pollinators on fennel flowers: The data on flowers visited per minute by different bee species on fennel flowers statistically analysed with two factors analysis is given in Table 5. The number of flowers visited by four bee species differed significantly. Among different bees, *A. dorsata* visited maximum number of umbelets (20.27 umbelets/min) followed by *A. mellifera* (14.71 umbelets/min) and *A. cerana* (11.99 umbelets/min). *A. florea* visited least number of umbelets, i.e., 7.34 umbelets/min. Irrespective of different bee species, the maximum number of umbelets was visited during 1100-1300 hrs of the day (19.74 umbelets/min) followed by 1300-1500 hrs (18.45 umbelets/min), 0900-1100 hrs (16.94 umbelets/min), 1500-1700 hrs (16.00 umbelets/min), and 0700-0900 hrs (5.87 umbelets/min). The least number of umbelets/minute was visited during 1700-1900 hrs of the day, i.e., 4.47 umbelets/min. The mean foraging rate (umbelet visited/minute) in case of *A. dorsata* varied from 14.96 to 29.68 umbelets during different hours of the day and no population of *A. dorsata* was observed at 0700-0900 hrs of the day. It was 2.06 to 20.62 umbelets in case of *A. mellifera*, 16.46 to 20.36 umbelets in case of *A. cerana* and no population of *A. cerana* was observed at 0700-0900 and 1700-1900 hrs of the day, whereas, 6.22 to 8.28 umbelets/min were recorded in case of *A. florea*.

Number of loose pollen grains sticking to the body of a bee: The number of loose pollen grains sticking to the body of bees while foraging on fennel flowers has been presented in Table 6. Significant differences were found among the number of loose pollen grains sticking to the body of different foragers of four *Apis* species. *A. dorsata*: entrapped the highest number of loose pollen grains on their body (avg. 3,03,000 pollen grains) followed by *A. mellifera* (avg. 2,60,000 pollen grains) and *A. cerana* (avg. 2,56,000 pollen grains) and it was lowest in case of *A. florea* (avg. 2,05,000 pollen grains).

Pollination efficiency: The pollination efficiency of different bee species foraging on fennel flowers presented in Table 7 depict that *A. dorsata* entrapped the maximum number of pollen grains (avg. 3,03,000 pollen gains) followed by *A. mellifera* (avg. 2,60,000 pollen grains), *A. cerana* (avg. 2,56,000 pollen grains) and *A. florea* (avg. 2,05,000 pollen grains). The abun-

Table 7. Pollination efficiency of different bee species on fennel cv. HF-143 flowers.

Bee species	Abundance (bees/m ² /5 min)	Foraging rate (number of flowers visited/min)	Loose pollen grains sticking on the body of bees	Pollination index (abundance x foraging rate x loose pollen grains)	Pollination efficiency (Rank)
<i>A. mellifera</i>	3.62	14.71	260,000	13845052	3 rd
<i>A. cerana</i>	1.82	11.99	256,000	5586381	4 th
<i>A. dorsata</i>	3.21	20.27	303,000	19715210	1 st
<i>A. florea</i>	9.23	7.34	205,000	13888381	2 nd

Table 8. Correlation coefficient between different abiotic factors and bee species population on fennel cv. HF-143.

Bee species	BSS	Temp ^r (°C)	RH
<i>A. mellifera</i>	0.833*	0.900*	-0.906*
<i>A. cerana</i>	0.894*	0.881*	-0.964**
<i>A. dorsata</i>	0.888*	0.970*	-0.939*
<i>A. florea</i>	0.905*	0.922*	-0.920*

*Significant at 5%; ** at 1%; BSS means bright sunshine hours; temp means temperature; RH means relative humidity.

dance of *A. florea* (9.23 bees/m²/5 min) was highest followed by *A. mellifera* (3.62 bees/m²/5 min) and *A. dorsata* (3.21 bees/m²/5 min), while the abundance of *A. cerana* was least (1.82 bees/m²/5 min). The foraging rate of *A. dorsata* (20.27 umbelets/min) was highest followed by *A. mellifera* (14.71 umbelets/min) and *A. cerana* (11.99 umbelets/min) while in case of *A. florea*, it was least (7.34 umbelets/min). The pollination index of *A. dorsata* was highest (19715210) followed by *A. florea* (13888381), *A. mellifera* (13845052) and *A. cerana* (5586381). Hence, it was observed that *A. dorsata* was the most efficient pollinator followed by *A. florea*, *A. mellifera* and *A. cerana* on fennel cv. HF-143 flowers under agro-ecological conditions of Hisar (Haryana).

Effect of abiotic factors on insect pollinator activity: The effects of different abiotic factors on the activity of different bee species have been presented in Table 8. The data depicted that the activity of different bee species on fennel varied with different abiotic factors and had significantly positive correlation with bright sunshine hours (BSS) and temperature (TEMP) in different hours of the day during foraging but had negative correlation with relative humidity (RH). When the period of bright sunshine was longer, the total bee population was also more, and the total bee population also decreased significantly with the decrease in bright sunshine hours. In *Rabi* season, the warmer temperature had been favourable for the activities of bees, which increased with the increase in day temperature from morning to noon and it reached to a peak at favourable temperature and decreased with decreasing temperature. The activity of bees increased with the decrease in humidity. The relative humidity in morning and evening hours remained more as compared to afternoon. Thus, the activities of bees were more in noon hours. It was observed that the effect of wind velocity on foraging of different bee species was not significant.

DISCUSSION

In the present study twenty five: insect species belonging to fifteen families of five orders were recorded from fennel flowers, in which, seven belong to order Lepidoptera, nine to Hymenoptera, five to Diptera, three to Coleoptera and one to Odonata. Chaudhary (2006) reported that the floral visitors on fennel included 39 species belonging to 20 families and 7 orders. Earlier studies indicated that *A. florea* (Sagar, 1981; Baswana, 1984) and *A. mellifera* were the chief floral visitors of fennel (Youngken, 1950). Hanh

et al. (2014) reported that twenty-four insect species on cucumber at agro-climatic region of hisar. Among different bee species, the maximum mean population observed in case of *Apis florea* (9.23 bees/m²/5 min) followed by *A. mellifera* (3.62 bees/m²/5 min) and *A. dorsata* (3.21 bees/m²/5 min), whereas, the least abundance was observed in case of *A. cerana indica*, i.e., 1.82 bees/m²/5 min. Irrespective of different bee species, the maximum population was observed during 1100-1300 hrs of the day (7.80 bees/m²/5 min) followed by 1300-1500 hrs (6.08 bees/m²/5 min), 0900-1100 hrs (5.88 bees/m²/5 min), 1500-1700 hrs (4.28 bees/m²/5 min) and 1700-1900 hrs (1.63 bees/m²/5 min). The lowest population was recorded during 0700-0900 hrs, i.e., 1.15 bees/m²/5 min. : Among different *Apis* species, *A. florea* spent maximum time (4.49 sec/umbelet) followed by *A. mellifera* (1.71 sec/umbelet) and *A. cerana* (1.21 sec/umbelet). The least time per umbelet was recorded in case of *A. dorsata*, i.e., 1.11 seconds. Among different bees, *A. dorsata* visited maximum number of umbelets (20.27 umbelets/min) followed by *A. mellifera* (14.71 umbelets/min) and *A. cerana* (11.99 umbelets/min). *A. florea* visited least number of umbelets/minute (7.34 umbelets/min). Mishra et al. (1988) reported that the peak foraging activity of *A. mellifera*, *Eristalis* sp. and other dipterans were observed between 1200 and 1300 hrs, whereas, *A. cerana indica* and syrphids were observed between 1300 and 1400 hrs on mustard flower at Solan (Himachal Pradesh), India. Kapil and Brar (1971) observed that *A. dorsata*, *A. florea*, and *A. cerana indica* began foraging at 0700 to 1000 hrs on rapeseed and mustard, and the peak foraging activity was recorded between 1230 and 1400 hrs and ceased by 1700 h. Temperature and relative humidity have inverse relationship with each other (Sihag and Abrol, 1986). At high temperature (>40°C) and low humidity, the honeybees (*A. mellifera*) stop foraging for nectar and/or pollens and engage in water collection (Sihag, 1990). Sunshine influences the atmospheric temperature as well as the intensity of light, both of which play an important role in flying/foraging activities of honey and other bees (Lengler and Link, 1984).

Conclusion

Biodiversity of insect pollinators on fennel cv. HF-143 (*Foeniculum vulgare* Miller), was studied in Hisar, Haryana, India. Twenty-five insect species belonging to fifteen families of five orders were recorded from fennel flowers, in which, seven belong to order Lepidoptera, nine to Hymenoptera, five to Diptera, three to Coleoptera and one to Odonata. Among the insect pollinators, *Apis florea* F., *A. cerana indica* F., *A. mellifera* L. and *A. dorsata* F. were the most frequent visitors. It was observed that *A. dorsata* was the most efficient pollinator followed by *A. florea*, *A. mellifera* and *A. cerana* on fennel cv. HF-143 flowers under agro-ecological conditions of Hisar (Haryana). The activity of different bee species on fennel varied with different abiotic factors and had significantly positive correlation with bright sunshine hours (BSS) and tem-

perature (TEMP) in different hours of the day during foraging but had negative correlation with relative humidity (RH). Thus, the impact of abiotic environmental factors would decide the foraging activity of different insect pollinators.

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REFERENCES

- Baswana, K.S. (1984). Role of insect pollination on seed production in coriander and fennel. *South Indian Horticulture*, 32: 117-118.
- Buchmann, L.S. and Nabhan, P.G. (1996). *The Forgotten Pollinators*. Island Press, Washington DC, USA, pp 292.
- Chaudhary, O.P. (2006). Diversity, foraging behaviour of floral visitors and pollination ecology of fennel (*Foeniculum vulgare* Mill.). *Journal of Spices and Aromatic Crops*, 15(1): 34-41.
- Free, J.B. (1993). *Insect Pollination of Crops* (2nd edn.). Academic Press, London, UK, 544 p.
- Hanh, Tran.Thi.My., Sharma, S.K. and Rana, M.K. (2014). Pollination efficiency of native bee pollinators of cucumber (*Cucumis sativus* L.) in India. *Journal of Apiculture*, 29(3): 199- 205.
- Kapil, R.P. and Brar, H.S. (1971). Foraging behaviour of *Apis florea* F. in relation to *Brassica campestris* var. toria. In: *Proceedings XXII International Apiculture Congress*, Moscow, 335p.
- Kumar, S. (1990). Studies on insect pollination in ber (*Ziziphus mauritiana* Lamk.). M.Sc. Thesis, Haryana Agricultural University, Hisar, Haryana, India.
- Lengler, S. and Link, D. (1984). Effects of insolation and solar radiation on the flight activity of some races of honeybees. *Revista do centro de ciencias rurais*, 14(2): 147-151.
- Mishra, R.C., Kumar, J. and Gupta, J. K., 1988. The effect of mode of pollination on yield and oil potential of *Brassica campestris* L. Var. sarson with observations on insect pollinators. *Journal of Apicultural Research*, 27 (2): 186-189.
- Pruthi, J.S. (1976). *Spices and Condiments*. National Book Trust, New Delhi, India.
- Richards, A.J. (1986). *Plant Breeding Systems*. Chapman and Hall, New York, USA, pp. 135-188.
- Sagar, P. (1981). Role of insects in crop pollination of fennel crop at Ludhiana. *PAU Journal of Research*, 18(4): 88-92.
- Sihag, R.C. and Abrol, D.P. (1986). Correlation and path-coefficient analysis environmental factors influencing flight activity of *Apis florea* F. *Journal of Apicultural Research*, 25(4): 202-208.
- Sihag, R.C. (1990). Ecology of European honeybee, *Apis mellifera* L in semi-arid sub-tropical climates. I. Melliferous flora and over- seasoning of the colonies. *Korean Journal of Apiculture*, 5(1): 31-43.
- Tewari, G.N. and Singh, K. (1983). Role of pollinators in vegetable seed production. *Indian Bee Journal*, 45: 51.
- Youngken, H.W.Jr. (1950). Drug plant gardens and apiculture. *Iowa State Apiarist Report 1949*, pp. 115-122.