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Diversity, abundance of insect pollinators and impact of mode of pollination on yield of carrot (*Daucus carota* L.) in India

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Abstract

Biodiversity of pollinators on carrot cv. Hisar Gairic (*Daucus carota* L.), was studied in Hisar, Haryana, India. Total thirty three insect species belonging to sixteen families of six orders were recorded, in which, eleven belong to order Lepidoptera, twelve Hymenoptera, six Diptera, three Coleoptera, and one belongs to Odonata. Among the insect pollinators, *Apis florea* F., *A. cerana indica* F., *A. mellifera* L. and *A. dorsata* F. were the most frequent pollinators. Among different *Apis* species, *A. florea* spent the maximum time (4.87 sec/umbelet) followed by *A. mellifera* (1.90 sec/umbelet), *A. cerana* (1.16 sec/umbelet) and the least in case of *A. dorsata*, i.e., 0.94 sec. The yield per plant, yield per m² area, test weight and germination per cent in case of open pollination were 11.11 g, 61.38 g, 4.14 g and 80.00%, respectively, whereas, in case of without insect pollination, it was 4.63 g, 25.06 g, 3.17 g and 53.29% and in case of Hand Pollination 8.36 g, 46.29 g, 3.66 g and 66.57%, respectively, which was significantly higher in case of open pollination. Hence, insect pollinators were essential to get good returns in this seed crop.

Keywords: abundance, foraging speed, foraging rate, carrot cv. Hisar gairic, modes of pollination, yield

Introduction

Carrot (*Daucus carota* L.), belonging to the family Umbelliferae, is an important vegetable crop grown in spring-summer and autumn-winter in temperate regions and during winter in tropical and sub-tropical regions. They are consumed either fresh as a salad crop or cooked vegetable. Large quantity of carrot is also processed, either alone or in mixtures with other vegetables, by canning, freezing, or dehydration. The plant is biennial, i.e., it grows vegetatively in the first season and produces seed in the second season. Carrot flowers are generally protoandrous, thus self-pollination is largely absent. The crop as a result depends upon insect pollinators for seed production (Free, 1993) [6]. The major carrot growing states in India are Punjab, Uttar Pradesh, Karnataka, Tamil Nadu and Andhra Pradesh. The total area under carrot in India is over 64,000 ha with an annual production of 1,145,000 tonnes in 2012-13. Although, this root crop has been widely cultivated since long, yet its yield per acre remains very low, and hence, there is considerable scope to increase the production potential of carrot (Anonymous, 2014) [1]. Pollination, one of the limiting factors for crop productivity and is significantly contributing to the agricultural productivity, 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. Insect pollination accounts for 90 per cent of animal pollination Buchmann and Nabhan, (1996) [3]. Since very meagre information is available on the pollination requirements of carrot, therefore the present study was carried out on the diversity and abundance of insect visitors/ pollinators and the effect of different modes of pollination on seed yield of carrot in Hisar, Haryana, India.

Material and Methods

Study sites and climate

The experiment comprises carrot cv. Hisar Gairic crop with three modes of open pollination (OP), hand pollination (HP) and without insect pollination (WIP), was conducted at Research Farm of the Department of Vegetable Science, CCS Haryana Agricultural University, Hisar (India). 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 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 maximum and minimum temperature shows wide

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

Soils status, fertilization and crop husbandry

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 @ 12 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. For raising a healthy crop of carrot cv. Hisar Gairic, 60 kg nitrogen, 30 kg phosphorus and 30 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 15 March to 25 April 2013 in root to seed type carrot crop.

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 15 March to 25 April 2013 in root to seed type carrot crop. 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 carrot cv. Hisar Gairic flowers recorded during the blooming period of the crop. The crop had flowering time from 15 March to 25 April 2013 in root to seed type carrot seed crop. The counts of insect visitors were made on umbelet per square meter area per 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 2:00 hours for 7 days each after the initiation of 10 per cent flowering in the crop, at peak flowering and before the cessation of flowering in carrot crop.

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) [6]. 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) [6]. 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.

Effect of different modes of pollination on seed set

The effect of different modes of pollination on carrot seed crop like yields and quality was investigated using three modes of pollination viz. open pollination (OP), hand pollination (HP) and without insect pollination (WIP). In OP, the field (1m x1m) was exposed to the natural open pollination i.e., crop area was not covered with nylon net. In HP, the field (1m x1m) was enclosed with nylon net before initiation of flowering and pollination done manually at 7.30 to 8.00 a.m. in the morning. In WIP, a selected crop area of 1m x1m was enclosed with nylon net before initiation of flowering in the crop to restrain the entry of flower visitors.

Following parameters were compared in OP, HP and WIP conditions

- Seed yield:** The seed yield per plant and per m² in open, hand and without insect pollinated plants was compared at harvest
- Test weight:** The test weight of 1000 seeds obtained from different modes of pollination was recorded to compare the modes of pollination.
- Seed viability:** A total of 100 seeds obtained from three modes of pollination sown in Petri splates to know the effect of modes of pollination on seed germination/viability.

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 carrot cv. Hisar gairic flowers

Data on diversity of insect visitors/ pollinators on carrot flowers have been presented in Table 1. Total thirty three insect species belonging to sixteen families of six orders were recorded from the carrot flowers, in which, eleven belong to order Lepidoptera, twelve belong to Hymenoptera, six belong to Diptera, three belong to Coleoptera, and one belongs to Odonata. The hymenopterans were the major floral visitors comprising from four families viz., Apidae (*Xylocopa virginica* L., *Xylocopa latipes* Drury, *Apis florea* F., *Apis cerana indica* F., *Apis mellifera* L. and *Apis dorsata* F.), Megachilidae (*Megachile* sp.), Halictidae (*Halictus* sp.) and Vespidae (*Vespa orientalis* L., *Vespa bicolor* F., *Polistes olivaceus* F. and *Eumenes dimidiatipennis* Sauss). They were followed in order of diversity by dipterans from four families viz., Muscidae (*Musca domestica* L.), Calliphoridae (*Chrysomya megacephala* F.), Sarcophagidae (*Sarcophaga* sp.) and Syrphidae (*Eristalinus aeneus* Scopoli, *Eristalinus*

sp. and *Eristalinus tabanoides* Jaennicke), lepidopterans from five families viz., Nymphalidae (*Danaus chrysippus* L., *Hypolimnas misippus* L., *Tirumala* sp. and *Junonia orithya* L.), Pieridae (*Pieris brassicae* L., *Catospilia pomona* F. and *Terias hecabe* L.), Papilionidae (*Papilio demoleus* L.), Lycaenidae (*Lampides boeticus* L.) and Arctiidae (*Utethesia pulchella* L. and *Amata* sp.), coleopteran from one family viz.,

Coccinellidae (*Coccinella septempunctata* L., *Cheilomenes sexmaculata* Chevrolat and *Brumoides suturalis* F.) and one species from one family of Odonata viz., Coenagrionidae (*Ceriagrion coromandelanum* F.)

Among the insect pollinators *A. florea*, *A. cerana indica*, *A. mellifera* and *A. dorsata* were the most frequent pollinators.

Table 1: List of insect visitors/pollinators of carrot flowers

S. No.	Scientific name	Family	Order	Working behaviour
1.	<i>Danaus chrysippus</i> L.	Nymphalidae	Lepidoptera	Top and Side
2.	<i>Pieris brassicae</i> L.	Pieridae	Lepidoptera	Top and Side
3.	<i>Papilio demoleus</i> L.	Papilionidae	Lepidoptera	Top and Side
4.	<i>Terias hecabe</i> L.	Pieridae	Lepidoptera	Top and Side
5.	<i>Hypolimnas misippus</i> L.	Nymphalidae	Lepidoptera	Top and Side
6.	<i>Tirumala</i> sp.	Nymphalidae	Lepidoptera	Top and Side
7.	<i>Catospilia pomona</i> F.	Pieridae	Lepidoptera	Top and Side
8.	<i>Junonia orithya</i> L.	Nymphalidae	Lepidoptera	Top and Side
9.	<i>Lampides boeticus</i> L.	Lycaenidae	Lepidoptera	Top and Side
10.	<i>Utethesia pulchella</i> L.	Arctiidae	Lepidoptera	Top and Side
11.	<i>Amata</i> sp.	Arctiidae	Lepidoptera	Top and Side
12.	<i>Apis florea</i> F.	Apidae	Hymenoptera	Top
13.	<i>Apis cerana indica</i> F.	Apidae	Hymenoptera	Top
14.	<i>Xylocopa latipes</i> Drury	Apidae	Hymenoptera	Top
15.	<i>Xylocopa virginica</i> L.	Apidae	Hymenoptera	Top
16.	<i>Apis mellifera</i> L.	Apidae	Hymenoptera	Top
17.	<i>Apis dorsata</i> F.	Apidae	Hymenoptera	Top
18.	<i>Vespa orientalis</i> L.	Vespidae	Hymenoptera	Top
19.	<i>Polistes olivaceus</i> F.	Vespidae	Hymenoptera	Top
20.	<i>Eumenes dimidiatipennis</i> Sauss	Vespidae	Hymenoptera	Top
21.	<i>Vespa bicolor</i> F.	Vespidae	Hymenoptera	Top
22.	<i>Megachile</i> sp.	Megachilidae	Hymenoptera	Top
23.	<i>Halictus</i> sp.	Halictidae	Hymenoptera	Top
24.	<i>Musca domestica</i> L.	Muscidae	Diptera	Top
25.	<i>Chrysomya megacephala</i> F.	Calliphoridae	Diptera	Top
26.	<i>Sarcophaga</i> sp.	Sarcophagidae	Diptera	Top
27.	<i>Eristalinus aeneus</i> Scopoli	Syrphidae	Diptera	Top
28.	<i>Eristalinus tabanoides</i> Jaennicke	Syrphidae	Diptera	Top
29.	<i>Eristalinus</i> sp.	Syrphidae	Diptera	Top
30.	<i>Coccinella septempunctata</i> L.	Coccinellidae	Coleoptera	Top
31.	<i>Cheilomenes sexmaculata</i> Chevrolat	Coccinellidae	Coleoptera	Top
32.	<i>Brumoides suturalis</i> F.	Coccinellidae	Coleoptera	Top
33.	<i>Ceriagrion coromandelanum</i> F.	Coenagrionidae	Odonata	Top and Side

Abundance

Abundance of different bee species at initiation of flowering stage of carrot cv. Hisar Gairic seed crop

The data on abundance of major insect pollinators at initiation of the flowering stage of carrot cv. Hisar Gairic seed crop flowers at different hours of the day have been presented in Table 2. Variations in abundance were recorded over time and space. Among different bee species the maximum mean population was observed in case of *Apis florea* (5.33 bees/m²/5 min) followed by *A. mellifera* (3.83 bees/m²/5 min) and *A. dorsata* (2.41 bees/m²/5 min), whereas, the least abundance was observed in case of *A. cerana indica*, i.e., 1.83 bees/m²/5 min. Irrespective of different bee species, the maximum population was observed during 1100-1300 h of the day (7.11 bees/m²/5 min) followed by 0900-1100 h (4.61 bees/m²/5 min), 1300-1500 h (4.39 bees/m²/5 min), 1500-1700 h (2.54 bees/m²/5 min) and 0700-0900 h (0.82 bees/m²/5 min) of the day. The lowest population was recorded during 1700-1900 h, i.e., 0.64 bees/m²/5 min. The mean bee species population over different day hours on carrot cv. Hisar Gairic flowers ranged from 1.83 bees/m²/5 min in case of *A. cerana* to 5.33 bees/m²/5 min in case of *A. florea*. For *A. florea*, the maximum bee population was observed at 1100-1300 h (10.14 bees/m²/5 min), followed by 1300-1500 h (8.00

bees/m²/5 min) of the day, and 0900-1100 h (5.71 bees/m²/5 min) of the day. The least population of *A. florea* was observed during 0700-0900 h, i.e., 1.57 bees/m²/5 min. For *A. mellifera*, the maximum bee population was observed at 1100-1300 h (8.71 bees/m²/5 min), followed by 0900-1100 h (5.86 bees/m²/5 min) of the day, 1300-1500 h (4.86 bees/m²/5 min) of the day. The least population of *A. mellifera* was observed during 0700-0900 h of the day, i.e., 0.43 bees/m²/5 min. For *A. cerana*, the maximum bee population was observed at 1100-1300 h (4.43 bees/m²/5 min), followed by 0900-1100 h (3.00 bees/m²/5 min) and 1300-1500 h (2.14 bees/m²/5 min) of the day. There was no population of *A. cerana* observed during 0700-0900 h and 1700-1900 h of the day. For *A. dorsata*, the maximum bee population was observed at 1100-1300 h (5.14 bees/m²/5 min), followed by 0900-1100 h (3.86 bees/m²/5 min) and 1300-1500 h (2.57 bees/m²/5 min) of the day. There was no population of *A. dorsata* observed during 1700-1900 h of the day. The cumulative mean abundance of important bee species reveal that *A. florea* was the most abundant visitor with a mean population of 5.33 bees/m²/5 min followed by *A. mellifera* (3.83 bees/m²/5 min) and *A. dorsata* (2.41 bees/m²/5 min) and *A. cerana* was the least frequent (1.83 bees/m²/5 min) visitor of carrot cv. Hisar Gairic flowers in the present investigations.

Table 2: Abundance of different bee species at initiation of the flowering on carrot cv. Hisar Gairic at different hours of the day

Bee species	Number of bees/ m ² /5min during different day hours						Mean
	0700-0900	0900-1100	1100-1300	1300-1500	1500-1700	1700-1900	
<i>A. mellifera</i>	0.43(1.18)	5.86(2.60)	8.71(3.11)	4.86(2.41)	2.43(1.82)	0.71(1.27)	3.83(2.06)
<i>A. cerana</i>	0(1.00)	3.00(1.98)	4.43(2.31)	2.14(1.76)	1.43(1.53)	0(1.00)	1.83(1.60)
<i>A. dorsata</i>	1.29(1.51)	3.86(2.19)	5.14(2.47)	2.57(1.86)	1.57(1.59)	0(1.00)	2.41(1.77)
<i>A. florea</i>	1.57(1.59)	5.71(2.58)	10.14(3.33)	8.00(3.00)	4.71(2.38)	1.86(1.67)	5.33(2.43)
Mean	0.82(1.32)	4.61(2.34)	7.11(2.81)	4.39(2.26)	2.54(1.83)	0.64(1.24)	

- Each value represents mean of 7 observations.
 - Figures in parentheses are $\sqrt{(x+1)}$ transformed values.
- | Factors | SE(m) | C.D. (p= 0.05) |
|-------------------------|-------|----------------|
| Bee species | 0.04 | 0.11 |
| Day hours | 0.05 | 0.13 |
| Bee species x Day hours | 0.09 | 0.26 |

Abundance of major insect pollinators at peak flowering stage of carrot cv. Hisar Gairic seed crop

The data on abundance of major insect pollinators at peak of the flowering stage of carrot cv. Hisar Gairic seed crop flowers at different hours of the day have been presented in Table 3. Variations in abundance were recorded over time and space. Among different bee species, the maximum mean population was observed in case of *Apis florea* (5.83 bees/m²/5 min) followed by *A. mellifera* (4.36 bees/m²/5 min) and *A. dorsata* (2.74 bees/m²/5 min), whereas, the least abundance was observed in case of *A. cerana*, i.e., 2.21 bees/m²/5 min. Irrespective of different bee species, the maximum population was observed during 1100-1300 h of the day (7.68 bees/m²/5 min) followed by 1300-1500 h (5.07 bees/m²/5 min), 0900-1100 h (5.00 bees/m²/5 min), 1500-1700 h (2.96 bees/m²/5 min) and 0700-0900 h (1.11 bees/m²/5 min) of the day. The lowest population was recorded during 1700-1900 h (0.89 bees/m²/5 min) of the day. The mean bee species population over different day hours on carrot cv. Hisar Gairic flowers ranged from 2.21 bees/m²/5 min in case of *A. cerana* to 5.83 bees/m²/5 min in case of *A. florea*. For *A. florea*, the maximum bee population was observed at 1100-1300 h (10.71 bees/m²/5 min), followed by 1300-1500 h (8.57 bees/m²/5 min) and 0900-1100 h (6.29 bees/m²/5 min) of the

day. The least population of *A. florea* was observed during 0700-0900 h of the day, i.e., 2.00 bees/ m²/5 min. For *A. mellifera*, the maximum bee population was observed at 1100-1300 h (9.14 bees/m²/5 min), followed by 0900-1100 h (6.29 bees/m²/5 min) and 1300-1500 h (5.86 bees/m²/5 min) of the day. The least population of *A. mellifera* was observed during 0700-0900 h of the day i.e., 0.57 bees/ m²/5 min. For *A. cerana*, the maximum bee population was observed at 1100-1300 h (5.29 bees/m²/5 min) of the day, followed by 0900-1100 h (3.43 bees/m²/5 min) and 1300-1500 h (2.86 bees/m²/5 min) of the day. There was no population of *A. cerana* observed during 0700-0900 and 1700-1900 h of the day. For *A. dorsata*, the maximum bee population was observed at 1100-1300 h (5.57 bees/m²/5 min), followed by 0900-1100 h (4.00 bees/m²/5 min) and 1300-1500 h (3.00 bees/m²/5 min) of the day. There was no population of *A. dorsata* was observed during 1700-1900 h of the day. The cumulative mean abundance of important bee species reveals that *A. florea* was the most abundant visitor with a mean population of 5.83 bees/m²/5 min followed by *A. mellifera* (4.36 bees/m²/5 min) and *A. dorsata* (2.74 bees/m²/5 min) and *A. cerana* was least frequent (2.21 bees/m²/5 min) visitor of carrot cv. Hisar Gairic flowers in the present investigations.

Table 3: Abundance of different bee species at peak flowering of carrot cv. Hisar Gairic at different hours of the day

Bee species	Number of bees/ m ² /5 min						Mean
	0700-0900	0900-1100	1100-1300	1300-1500	1500-1700	1700-1900	
<i>A. mellifera</i>	0.57(1.24)	6.29(2.65)	9.14(3.16)	5.86(2.56)	3.00(1.98)	1.29(1.47)	4.36(2.18)
<i>A. cerana</i>	0.00(1.00)	3.43(2.09)	5.29(2.50)	2.86(1.95)	1.71(1.61)	0.00(1.00)	2.21(1.69)
<i>A. dorsata</i>	1.86(1.68)	4.00(2.22)	5.57(2.56)	3.00(1.98)	2.00(1.72)	0.00(1.00)	2.74(1.86)
<i>A. florea</i>	2.00(1.71)	6.29(2.69)	10.71(3.41)	8.57(3.07)	5.14(2.47)	2.29(1.78)	5.83(2.52)
Mean	1.11(1.41)	5.00(2.41)	7.68(2.91)	5.07(2.39)	2.96(1.95)	0.89(1.31)	

- Each value represents mean of 7 observations
 - Figures in parentheses are $\sqrt{(x+1)}$ transformed values
- | Factors | SE(m) | C.D. (p= 0.05) |
|-------------------------|-------|----------------|
| Bee species | 0.05 | 0.13 |
| Day hours | 0.06 | 0.16 |
| Bee species x Day hours | 0.11 | 0.31 |

Abundance of different bee species at cessation of flowering of carrot cv. Hisar Gairic seed crop

The data on abundance of major insect pollinators at cessation of the flowering stage of carrot cv. Hisar Gairic seed crop flowers at different hours of the day have been presented in Table 4. Variations in abundance were recorded over time and space. Among different bee species, the maximum mean population was observed in case of *Apis florea* (5.69 bees/m²/5 min) followed by *A. mellifera* (4.31 bees/m²/5 min) and *A. dorsata* (2.57 bees/m²/5 min), whereas, the least abundance was observed in case of *A. cerana*, i.e., 1.98

bees/m²/5 min. Irrespective of different bee species, the maximum population was observed during 1100-1300 h of the day (7.21 bees/m²/5 min) followed by 1300-1500 h (5.04 bees/m²/5 min), 0900-1100 h (4.79 bees/m²/5 min), 1500-1700 h (2.89 bees/m²/5 min) and 0700-0900 h (1.11 bees/m²/5 min) of the day. The lowest population was recorded during 1700-1900 h of the day, i.e., 0.79 bees/m²/5 min. The mean bee species population over different day hours on carrot cv. Hisar Gairic flowers ranged from 1.98 bees/m²/5 min in case of *A. cerana* to 5.69 bees/m²/5 min in case of *A. florea*. For *A. florea*, the maximum bee population was observed at 1100-

1300 h (10.43 bees/m²/5 min) of the day, followed by 1300-1500 h (8.43 bees/m²/5 min), 0900-1100 h (6.00 bees/m²/5 min) of the day. The least population of *A. florea* was observed during 1700-1900 h of the day *i.e.*, 2.00 bees/m²/5 min. For *A. mellifera*, the maximum bee population was observed at 1100-1300 h of the day (8.86 bees/m²/5 min), followed by 0900-1100 h (6.29 bees/m²/5 min) and 1300-1500 h (6.14 bees/m²/5 min) of the day. The least population of *A. mellifera* was observed during 0700-0900 h of the day *i.e.*, 0.71 bees/m²/5 min. For *A. cerana*, the maximum bee population was observed at 1100-1300 h (4.29 bees/m²/5 min) of the day, followed by 0900-1100 h (3.29 bees/m²/5 min) and 1300-1500 h of the day (2.71 bees/m²/5 min). There was no

population of *A. cerana* observed during 0700-0900 and 1700-1900 h of the day. For *A. dorsata*, the maximum bee population was observed at 1100-1300 h of the day (5.29 bees/m²/5 min), followed by 0900-1100 h (3.57 bees/m²/5 min) and 1300-1500 h (2.86 bees/m²/5 min) of the day. There was no population of *A. dorsata* observed during 1700-1900 h of the day. The cumulative mean abundance of important bee species reveals that *A. florea* was the most abundant visitor with a mean population of 5.69 bees/m²/5 min followed by *A. mellifera* (4.31 bees/m²/5 min) and *A. dorsata* (2.57 bees/m²/5 min), and *A. cerana* was least frequent (1.98 bees/m²/5 min) visitor of carrot cv. Hisar Gairic flowers in the present investigations.

Table 4: Abundance of different bee species at cessation of flowering of carrot cv. Hisar Gairic at different hours of the day

Bee species	Number of bees/ m ² /5 min						
	0700-0900	0900-1100	1100-1300	1300-1500	1500-1700	1700-1900	Mean
<i>A. mellifera</i>	0.71(1.27)	6.29(2.69)	8.86(3.13)	6.14(2.66)	2.71(1.92)	1.14(1.45)	4.31(2.19)
<i>A. cerana</i>	0.00(1.00)	3.29(2.06)	4.29(2.28)	2.71(1.92)	1.57(1.57)	0.00(1.00)	1.98(1.64)
<i>A. dorsata</i>	1.43(1.51)	3.57(2.13)	5.29(2.49)	2.86(1.94)	2.29(1.79)	0.00(1.00)	2.57(1.81)
<i>A. florea</i>	2.29(1.78)	6.00(2.64)	10.43(3.37)	8.43(3.06)	5.00(2.45)	2.00(1.72)	5.69(2.50)
Mean	1.11(1.39)	4.79(2.38)	7.21(2.82)	5.04(2.40)	2.89(1.93)	0.79(1.29)	

▪ Each value represents mean of 7 observations

▪ Figures in parentheses are $\sqrt{(x+1)}$ transformed values

Factors	SE(m)	C.D. (p= 0.05)
Bee species	0.04	0.12
Day hours	0.05	0.14
Bee species x Day hours	0.10	0.28

Foraging speed

The data on foraging speed, *i.e.*, time spent by different bee species on carrot cv. Hisar Gairic flower during March-April 2013 have been narrated in Table 5. Among different *Apis* species, *A. florea* spent the maximum time (4.87 sec/umbelet) followed by *A. mellifera* (1.90 sec/umbelet) and *A. cerana* (1.16 sec/umbelet). the least time per umbelet was recorded in case of *A. dorsata*, *i.e.*, 0.94 sec. The time spent per umbelet by different bee species differed significantly. The mean foraging speed [time spent (sec)/umbelet] varied from 4.67 to 5.07 seconds in case of *A. florea* during different hours of the day, while in case of *A. mellifera*, it was 0.80 to 2.52 sec and 1.61 to 1.88 seconds in case of *A. cerana*, and *A. cerana*

population was absent during 0700-0900 and 1700-1900 h of the day. In case of *A. dorsata*, it varied from 0.93 to 1.36 seconds, whereas, *A. dorsata* population was absent during 1700-1900 h 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 (2.71 sec/umbelet) was significantly higher than the mean time spent by four bee species during 0700-0900 h (1.77 sec/umbelet), 0900-1100 h (2.58 sec/umbelet), 1300-1500 h (2.52 sec/umbelet), 1500-1700 h (2.37 sec/umbelet) and 1700-1900 h (1.37 sec/umbelet) of the day.

Table 5: Time spent by different bee species on carrot cv. Hisar Gairic flowers at different hours of the day

Bee species	Time spent (sec.)/ flowers						
	0700-0900	0900-1100	1100-1300	1300-1500	1500-1700	1700-1900	Mean
<i>A. mellifera</i>	1.42(1.52)	2.35(1.83)	2.52(1.88)	2.21(1.79)	2.08(1.75)	0.80(1.29)	1.90(1.68)
<i>A. cerana</i>	0.00(1.00)	1.71(1.65)	1.88(1.70)	1.78(1.67)	1.61(1.62)	0.00(1.00)	1.16(1.44)
<i>A. dorsata</i>	0.93(1.39)	1.24(1.50)	1.36(1.54)	1.15(1.47)	0.94(1.39)	0.00(1.00)	0.94(1.38)
<i>A. florea</i>	4.73(2.39)	5.00(2.45)	5.07(2.46)	4.92(2.43)	4.83(2.41)	4.67(2.38)	4.87(2.42)
Mean	1.77(1.58)	2.58(1.86)	2.71(1.89)	2.52(1.84)	2.37(1.79)	1.37(1.42)	

▪ Each value represents mean of 10 observations at each sampling time

▪ Figures in parentheses are $\sqrt{(x+1)}$ transformed values

Factors	SE(m)	C.D. (p= 0.05)
Bee species	0.01	0.04
Day hours	0.02	0.05
Bee species x Day hours	0.04	0.10

Foraging rate

The data on flowers visited per minute by different bee species on carrot cv. Hisar Gairic flowers have been presented in Table 6. The number of flowers visited by four bee species differed significantly. Among different bee species *A. dorsata* visited the highest number of umbelets (19.17 umbelets/min) followed by *A. mellifera* (15.32 umbelets/min) and *A. cerana* (10.07 umbelets/min). *Apis florea* visited least number of

umbelets/min (7.89 umbelets/min). Irrespective of different bee species, the maximum umbelets were visited during 1100-1300 h of the day (17.38 umbelets/min) followed by 0900-1100 h (16.88 umbelets/min), 1300-1500 h (15.92 umbelets/min), 1500-1700 h (14.57 umbelets/min) and 0700-0900 h (10.50 umbelets/min) of the day. The least number of umbelets/min was visited during 1700-1900 h of the day, *i.e.*, 3.45 umbelets/min. The mean foraging rate (umbelet visited

per minute) in case of *A. dorsata* varied from 21.40 to 24.50 umbelets during different hours of the day, whereas, *A. dorsata* population was absent during 1700-1900 h of the day. It was 7.20 to 19.00 umbelets in case of *A. mellifera* and

12.30 to 17.00 umbelets in case of *A. cerana*, whereas, *A. cerana* population was absent during 0700-0900 and 1700-1900 h of the day and in case of *A. florea*, the umbelets visited/min was 6.60 to 9.00.

Table 6: Flowers visited by different bee species on Carrot cv. Hisar Gairic flower 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>	10.70 (3.00)	18.90(4.46)	19.00(4.47)	18.66(4.43)	17.47(4.30)	7.20(2.34)	15.32(3.83)
<i>A. cerana</i>	0(1.00)	15.71(4.09)	17.00(4.24)	15.41(4.05)	12.30(3.44)	0(1.00)	10.07(2.97)
<i>A. dorsata</i>	22.92(4.89)	24.00(5.00)	24.50(5.05)	22.20(4.82)	21.40(4.73)	0(1.00)	19.17(4.25)
<i>A. florea</i>	8.36(3.06)	8.90(3.15)	9.00(3.16)	7.40(2.89)	7.10(2.84)	6.60(2.75)	7.89(2.97)
Mean	10.50(2.99)	16.88(4.17)	17.38(4.23)	15.92(4.05)	14.57(3.83)	3.45(1.77)	

▪ Each value represents mean of 10 observations.

▪ Figures in parentheses are $\sqrt{(x+1)}$ transformed values.

Factors	SE(m)	C.D. (p= 0.05)
Bee species	0.08	0.21
Day hours	0.09	0.26
Bee species x Day hours	0.18	0.51

Effects of different Modes of pollination on yield parameters Effects of different Modes of pollination on yield parameter of carrot cv. Hisar Gairic

The Table 7 containing data on yield parameters of carrot cv. Hisar Gairic, depicts that the yield per plant, yield per m² area, test weight and germination per cent in case of open pollination were 11.11 g, 61.38 g, 4.14 g and 80.00%, respectively, whereas, in case of without insect pollination, it

was 4.63 g, 25.06 g, 3.17 g and 53.29% and in case of Hand Pollination 8.36 g, 46.29 g, 3.66 g and 66.57%, respectively, which was significantly higher in case of open pollination. The data presented in Table 13 reveal that the per cent increase in open pollination over without insect pollination was 58.33, 59.17, 23.43 and 33.39, respectively, whereas, the per cent increase in open pollination over hand pollination was 24.75, 24.58, 11.59 and 16.79, respectively.

Table 7: Effect of different Modes of pollination on yield and germination (%) of carrot cv. Hisar Gairic

Modes of pollination	Open pollination (OP)	Without insect pollination (WIP)	Hand pollination (HP)	Per cent increase in open pollination over WIP	Per cent increase in open pollination over HP
Yield /plant (g)	11.11	4.63	8.36	58.33	24.75
Yield /m ² (g)	61.38	25.06	46.29	59.17	24.58
Test weight (g)	4.14	3.17	3.66	23.43	11.59
Germination (%)	80.00	53.29	66.57	33.39	16.79
C.D. (p= 0.05)	1.268	5.451	0.22	3.38	
SE(m)	0.407	1.75	0.07	1.09	

Discussion

In present study thirty three insect species belonging to sixteen families of six orders were recorded from the carrot flowers, in which, eleven belong to order Lepidoptera, twelve belong to Hymenoptera, six belong to Diptera, three belong to Coleoptera, and one belongs to Odonata. Chaudhary (2006) [4] reported that the floral visitors on fennel included 39 species belonging to 20 families and 7 orders. Singh *et al.*, (2010) [9] reported five families, *i.e.*, Hymenopterans with *Apis dorsata* and *A. florea*, Dipterans (Muscidae, Syrphidae), Lepidopterans, Hemipterans and Coleopterans on coriander flowers. Hanh *et al.*, (2014) [7] reported that twenty-four insect species on cucumber at agro-climatic region of hisar. At initiation of the flowering stage of carrot cv. Hisar Gairic seed crop flowers, the maximum mean population was observed in case of *Apis florea* (5.33 bees/m²/5 min) followed by *A. mellifera* (3.83 bees/m²/5 min) and *A. dorsata* (2.41 bees/m²/5 min), whereas, the least abundance was observed in case of *A. cerana*, *i.e.*, 1.83 bees/m²/5 min. At peak of the flowering stage of carrot cv. Hisar Gairic seed crop flowers, the maximum mean population was observed in case of *Apis florea* (5.83 bees/m²/5 min) followed by *A. mellifera* (4.36 bees/m²/5 min) and *A. dorsata* (2.74 bees/m²/5 min), whereas, the least abundance was observed in case of *A. cerana*, *i.e.*, 2.21 bees/m²/5 min. At cessation of the flowering stage of carrot cv. Hisar Gairic seed crop flowers, the maximum mean population was observed in case of *Apis florea* (5.69

bees/m²/5 min) followed by *A. mellifera* (4.31 bees/m²/5 min) and *A. dorsata* (2.57 bees/m²/5 min), whereas, the least abundance was observed in case of *A. cerana*, *i.e.*, 1.98 bees/m²/5 min. Among different *Apis* species, *A. florea* spent the maximum time (4.87 sec/umbelet) followed by *A. mellifera* (1.90 sec/umbelet) and *A. cerana* (1.16 sec/umbelet). The least time per umbelet was recorded in case of *A. dorsata*, *i.e.*, 0.94 sec. Among different bees *Apis dorsata* visited highest number of umbelets (19.17 umbelets/min) followed by *A. mellifera* (15.32 umbelets/min) and *A. cerana* (10.07 umbelets/min). *Apis florea* visited least number of umbelets/min (7.89 umbelets/min). Bharti Vikas (2015) [2] in fennel reported that 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 under agro climatic region of Hisar, Haryana. The yield per plant, yield per m², test weight and germination percentage in case of open pollination were 11.11 g, 61.38 g, 4.14 g and 80.00%, whereas, in case of without insect pollination, it was 4.63 g, 25.06 g, 3.17 g and 53.29%, and in case of Hand Pollination 8.36 g, 46.29 g, 3.66 g, 66.57%, respectively, which is significantly higher in case of open pollination. Kumar and Jaiswal (2012) [8] on coriander reported that the plots open to all insect pollinators yielded highest *i.e.* 15.50 q/ha. Chaudhary and Singh (2007) [5] reported that the lowest yield of coriander 6.3 g/plant was

recorded in without insect pollination plots.

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