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Diversity and foraging behaviour of safflower (*Carthamus tinctorius* L.) pollinators

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Abstract
Studies on safflower variety PBNS-86 revealed that the crop was visited by twelve species of insect *viz*., *Apis dorsata*, *A. florea*, *Trigona iridipennis*, *Xylocopa fenestrate*, *Creontiades dilutus*, *Cheilomenes sexmaculata*, *Amata bicincta*, *Papilio demoleus*, *Ischiodon scutellaris*, *Musca domestica*, one unidentified wasp from Hymenoptera and one unidentified Hover fly from Diptera. These insect species belong to five orders *viz*., Hymenoptera, Lepidoptera, Coleoptera, Hemiptera and Diptera. With respect to the preferred visit timings of the pollinators, it was observed that preferred visit time for hymenopteran pollinator was afternoon hours from 12.00 to 14.00 hrs, while the pollinators from Diptera and Hemiptera were more active in morning hours. The members of Lepidoptera order are active in the morning as well as evening hours and the coleopterans are found as only occasional visitors. It is observed that maximum temperature showed significant but negative correlation with *A. florea* population (r = - 0.422*). The *A. dorsata* showed positive significant correlation with rainfall (r = 0.517*) while it was significantly negative with maximum temperature (r = - 0.556*), minimum temperature (r = - 0.686*) and evening relative humidity (r = - 0.451*). The population of *T. iridipennis* showed significant but negative correlation with maximum temperature (r = - 0.679*), minimum temperature (r = - 0.573*) and evening relative humidity (r = - 0.496*). The population of *P. demoleus* showed negative but significant correlation with minimum temperature (r = - 0.410*). Maximum temperature (r = - 0.559*) established negative significant correlation with the population of *C. sexmaculata* visiting safflower. It is evident from the data that only maximum temperature (r = - 0.448*) showed significant but negative correlation with *M. domestica* population.

Keywords: Pollinators, safflower, *Apis florea*, *Apis dorsata*, foraging behaviour, correlation

Introduction
Safflower (*Carthamus tinctorius* L.) is commonly known as Karadayee and is a member of family Compositae. It is important *Rabi* oilseed crop of the country and well adopted to dry region. There are 36 species in the genus *carthamus*, found in many parts of world namely Asia, Africa, Mediterrian region, out of these only (*C. tinctorius* L.) (2n = 24) is cultivated in India. Safflower has been grown in India since immemorial and it is mentioned as kusumba in ancient scriptures. Kumari and Pandey (2005) [11] mentioned that safflower is usually considered as self-pollinating crop, however, cross pollination increases the number of seed setting. They further mentioned that in Bhagalpur area in Bihar, India, the flowering span extend from the middle of February to second week of April and during this period the population of insect pollinators varied remarkably. Boch (1961) [4] reported that safflower is a partially cross-pollinated crop and the safflower plots to which insects had full access produced twice as much seed as plots from which insects were excluded during the blooming period. Safflower has high adaptability to low moisture conditions Javed *et al*., (2013) [7] and hence it is expanding at faster rate to newer areas. Due to this it is essential to generate information on the status of naturally occurring pollinator diversity and abundance, which has direct impact on the yield and quality of seed. Also, the abiotic factors have direct impact on the pollinators, hence, the present study will also be aimed to document insect pollinator diversity, abundance and impact of abiotic factors on safflower pollinators.

Material and Methods
The experimental trial was carried out at the research farm of Department of Agricultural Entomology, College of Agriculture, Latur during *rabi* 2020. The numbers of insect pollinators of each species visiting safflower were recorded at flowering till its complete cessation. Safflower variety PBNS-86 was sown on 9th November, 2020 with 45 x 20 cm^2 row to plant spacing, plot size 10 x 10 m with all recommended agronomic practices except

insecticidal sprays for pest management. The relative abundance of pollinators was studied 10 x 10 m plot was divided into four quadrate and the observations on frequent insect visitors to the safflower from each quadrant was recorded daily on one plant (including all branches) for five minutes at 8:00, 10:00, 12:00, 14:00, 16:00 and 18.00 hours throughout the flowering period. The recorded data was expressed as mean number of pollinators / plant / minutes. The visit timing for different pollinators recorded at every two-hour interval as mentioned above, the preferred visit time for the pollinators was find out. Especially for the honey bees. The population of different pollinators was correlated with the abiotic weather factors and correlations were worked out.

Results and Discussion

Diversity of safflower pollinators

The data presented in Table 1 showed that safflower PBNS-86 variety was visited by twelve species belonging to five orders *viz*., Hymenoptera, Lepidoptera, Coleoptera, Hemiptera and Diptera. Five species *viz*., *A. dorsata*, *A. florea*, *T. iridipennis*, *X. fenestrate* from Apidae and one unidentified wasp spp. from Vespidae were recorded under Hymenoptera. Three species *viz*., *I. scutellaris*, *M. domestica* and one unidentified Hover fly from family Syrphidae (*I. scutellaris*), Muscidae (*M. domestica*) under Diptera were recorded. Lepidopteran foragers belonged to four families *viz*., Papilionidae and Erebidae among which, one species each of families Erebidae (*A. bicincta*) and Papilionidae (*P. demoleus*) were recorded on safflower plant. One Hemiptera species *C. dilutus* (Mirid bug) belonging to the family Miridae was recorded. One Coleopteran species *C. sexmaculata* belonging to the family Coccinelidae was recorded. Percentagewise Hymenoptera (41.66%) was found as the dominating insect order followed by Diptera (25%) and Lepidoptera (16.66%).

Table 1: Diversity of pollinators in safflower

Sr. No.	Order	Family	Common Name	Scientific Name
1	Hymenoptera	Apidae	Rock bee	*Apis dorsata*
2		Apidae	Little honey bee	*Apis florae*
3		Apidae	Stingless bee	*Trigona iridipennis*
4		Apidae	Carpenter bee	*Xylocopa fenestrate*
5		Vespidae	Wasp	Unidentified
6	Lepidoptera	Papilionidae	Lemon butterfly	*Papilio demoleus*
7		Erebidae	Handmaiden moth	*Amata bicincta*
8	Coleoptera	Coccinellidae	Lady bird beetle	*Cheilomenes sexmaculata*
9	Hemiptera	Miridae	Mirid bug	*Creontiades dilutes*
10	Diptera	Muscidae	Housefly	*Musca domestica*
11		Syrphidae	Hover fly	*Ischiodon scutellaris*
12		Syrphidae	Hover fly	Unidentified

Present finding is in line with finding of Khalil *et al*., (1986) [10] who reported 19 insect species of 5 orders (Hemiptera, Lepidoptera, Coleoptera, Diptera and Hymenoptera) as visitors to safflower in bloom. Navatha, (2012) [11] reported 20 insect species from eleven families of six orders *viz*., 10 hymenopterans, six lepidopterans and one species each from Diptera, Coleoptera, Odonata and Orthoptera were recorded on safflower. Also, Tale, (2016) [15] reported as many as 20 species of pollinators on safflower. Out of these, 8 species belong to order Hymenoptera, 5 species from Lepidoptera, 4 species from Diptera and 2 species from Coleoptera. Similar results were observed in the present study and dominance of hymenopteran pollinators (41.66%) was observed.

Thus, the research work carried out on pollinator study by many earlier workers on safflower crop indicated that Hymenoptera is the important insect order followed by Diptera and Lepidoptera. Insects from order Coleoptera are also reported but as an occasional visitor. The findings of present study indicated similar trend underlining the importance of order Hymenoptera, Diptera and Lepidoptera in the pollination activity in the flowering crops like safflower contributing significantly in the yield.

Preferred visit timing for different pollinators

Foraging behaviour of safflower pollinators was observed and presented in Tables 2 to 4. Their preferred visit timing to safflower was observed to be in the afternoon from 12.00 hrs to 14.00 hrs. Significantly more visits of *A. florea* (1.52 / plant / minute) were recorded at 12.00 hrs followed by at 14.00 hrs (1.04 / plant / minute) and at 10.00 hrs (0.46 / plant / minute). However, no significant differences were observed with respect to their number visiting safflower at 16.00 hrs, 18.00 hrs and 8.00 hr.

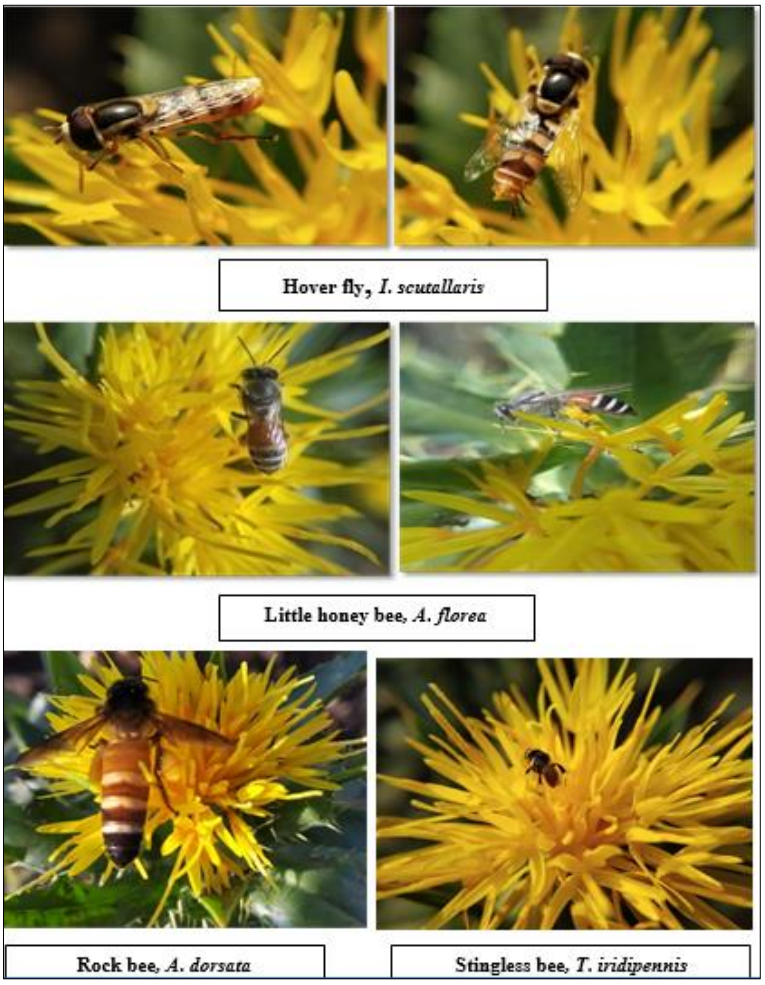

Plate 1: Diversity of safflower pollinators

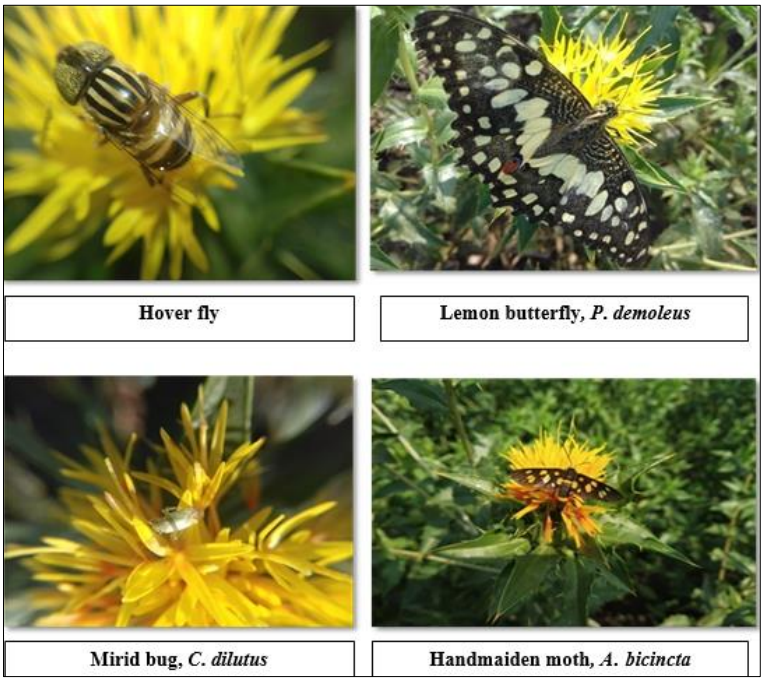

Plate 2: Diversity of safflower pollinators

In all the pollinators which visited safflower during the investigation period, *A. dorsata* were found in highest numbers. With respect to *A. dorsata*, more or less similar trend was observed and their maximum visits (1.74 / plant / minute) were recorded at 14.00 hrs, however, this visit number is statistically at par with the visit numbers recorded at 12.00 hrs (1.56 / plant / minute). At 10.00 hrs their number reduced to some extent and 1.08 *A. dorsata* / plant / minute were recorded. However, their visits at 08.00 hrs, 16.00 hrs and 18.00 hrs were very less and reported only 0.01, 0.28 and

0.02 per plant per minute, respectively. *T. iridipennis* were found more active during morning hours as reflected from their visits to the safflower heads. Maximum 0.27 *T. iridipennis* visiting safflower heads were observed at 12.00 hrs and this visit number is at par with the visits at 10.00 hrs and 08.00 hrs which were 0.20 and 0.16 *T. iridipennis* / plant / minute. Their visit number in the afternoon hours is reduced very much and reported ony 0.10, 0.14 and 0.03 / plant / minute at 14.00, 16.00 and 18.00 hrs, respectively. The X. fenestrate showed somewhat similar visit timing trend to that of *T. iridipennis* on safflower heads.

Table 2: Relative abundance of pollinators from Hymenoptera on safflower at different time of the day

Timing	Number of visiting pollinators (Per plant per minute)				
	A. florea	***A. dorsata***	***T. iridipennis***	***X. fenestrate***	**Wasp**
8.00	0.05 (0.74)	0.01 (0.71)	0.16 (0.81)	0.02 (0.72)	0.00 (0.70)#
10.00	0.46 (0.97)	1.08 (1.25)	0.20 (0.83)	0.08 (0.76)	0.01 (0.71)
12.00	1.52 (1.42)	1.56 (1.43)	0.27 (0.87)	0.17 (0.81)	0.09 (0.77)
14.00	1.04 (1.23)	1.74 (1.48)	0.10 (0.77)	0.02 (0.72)	0.18 (0.82)
16.00	0.14 (0.79)	0.28 (0.86)	0.14 (0.79)	0.06 (0.74)	0.01 (0.71)
18.00	0.06 (0.74)	0.02 (0.72)	0.03 (0.72)	0.02 (0.72)	0.02 (0.72)
SE ±	0.03	0.06	0.02	0.02	0.01
CD at 5%	0.11	0.18	0.07	0.07	0.03
CV (%)	8.07	1.16	8.09	6.71	2.93

* Average of 24 observations. # Figures in parentheses are x + 0.5 transformed values.

At 12.00 hrs maximum (0.17 / plant / minute) visits of *X. fenestrate* were recorded however, no statistical differences were observed in the visiting *X. fenestrate* numbers at 10.00 hrs (0.08 / plant / minute) and at 16.00 hrs (0.06 / plant / minute). At 08.00 hrs, 14.00 hrs and 18.00 hrs only 0.02 *X. fenestrate* were found visiting safflower heads per plant. Wasps are found more active during afternoon hours than in the morning and evening and a maximum of 0.18 wasps / plant / minute were found visiting safflower heads at14.00 hrs. Slightly reduced number of wasp visits (0.09 / plant / minute) was observed at 12.00 hrs. No significant differences were observed in the wasp numbers visiting safflower heads at 08.00 hrs, 10.00 hrs, 16.00 hrs and 18.00 hrs as they recorded 0.00, 0.01, 0.01 and 0.02 visits per plant per minute, respectively.

From Lepidoptera, *A. bicincta* and *P. demoleus* were the two pollinators found visiting the safflower heads. Evening and morning hours were found more suitable for the visits of *A. bicincta*. At 18.00 hrs significantly more number (0.30 / plant / minute) of *A. bicincta* were found visiting safflower heads. Slightly reduced number of visits (0.16 / plant / minute) was observed at 16.000 hrs and this visit number was at par with the visits at 10.00 hrs (0.15 / plant / minute), 08.00 hrs and 14.00 hrs (0.14 / plant / minute each), respectively. At 12.00 hrs in the afternoon only 0.01 *A. bicincta* were found visiting safflower heads. Maximum visits of *P. demoleus* (0.11 / plant / minute) were recorded at 18.00 hrs, however, this visit number was statistically at par with the visit numbers recorded at 12.00 hrs (0.05 / plant / minute). During rest of the day timings no statistical differences were observed in their visits to the safflower heads. However, no statistical differences were observed in the visiting *P. demoleus* numbers at 10.00, 14.00, 08.00 and 16.00 hrs 0.03, 0.02, 0.01 and 0.01 *P. demoleus* / plant / minute were found visiting safflower heads.

Table 3: Relative abundance of pollinators from Lepidoptera, Coleoptera and Hemiptera on safflower at different time of the day

Timing	Number of visiting pollinators (Per plant per minute)			
	Lepidoptera		**Coleoptera**	**Hemiptera**
	A. bicincta	***P. demoleus***	***C. sexmaculata***	***C. dilutes***
8.00	0.14 (0.79)	0.01 (0.71)	0.02 (0.72)	0.21 (0.83)#
10.00	0.15 (0.80)	0.03 (0.72)	0.01 (0.71)	0.10 (0.77)
12.00	0.01 (0.71)	0.05 (0.74)	0.04 (0.73)	0.07 (0.75)
14.00	0.14 (0.79)	0.02 (0.72)	0.04 (0.73)	0.02 (0.72)
16.00	0.16 (0.81)	0.01 (0.71)	0.06 (0.74)	0.05 (0.74)
18.00	0.30 (0.89)	0.11 (0.78)	0.09 (0.77)	0.01 (0.71)
SE ±	0.02	0.01	0.01	0.02
CD at 5%	0.07	0.05	0.04	0.08
CV (%)	6.40	5.38	4.21	7.51

* Average of 24 observations. # Figures in parentheses are x + 0.5 transformed values

From Coleoptera, only *C. sexmaculata* was found visiting the safflower heads. More visits of *C. sexmaculata* (0.09 / plant / minute) were recorded at 18.00 hrs and this visit number is at par with the visits at 16.00 hrs, 12.00 hrs and 14.00 hrs which were 0.06, 0.04 and 0.04 *C. sexmaculata* / plant / minute, respectively. Their visit number in the morning hours was reduced very much and reported only 0.02 and 0.01 / plant / minute at 08.00 and 10:00 hrs, respectively.

From Hemiptera order, *C. dilutes* were found more active during morning hours as reflected from their visits to the safflower heads. Maximum 0.21 *C. dilutes* bugs visited safflower heads at 08.00 hrs and this visit number was at par with the visits at 10.00 hrs and 12.00 hrs which was 0.10 and 0.07 bugs / plant / minute, respectively. Their visit number in the afternoon hours was reduced very much and reported only 0.02, 0.05 and 0.01 bugs / plant / minute at 14.00, 16.00 and 18:00 hrs, respectively.

In the present investigation, Diptera was found as the second dominant order after Hymenoptera with respect to the pollinator visits to safflower heads. Significantly more visits

of *I. scutellaris* (0.16 / plant / minute) were recorded at 08.00 hrs followed by at 12.00 hrs (0.08 / plant / minute) and at 10.00 hrs (0.05 / plant / minute). In the afternoon hours, their number reduced remarkably and only 0.02 and 0.01 *I. scutellaris* per plant per minute were observed. At 14.00 hours no visits were reported.

Table 4: Relative abundance of pollinators from Diptera on safflower at different time of the day

Timing	Number of visiting pollinators (Per plant per minute)		
	I. scutellaris	***M. domestica***	**Hover fly**
8.00	0.16 (0.81)	0.08 (0.76)	0.09 (0.76)#
10.00	0.05 (0.74)	0.02 (0.72)	0.04 (0.73)
12.00	0.08 (0.76)	0.05 (0.74)	0.06 (0.75)
14.00	0.00 (0.70)	0.03 (0.72)	0.01 (0.71)
16.00	0.01 (0.71)	0.02 (0.72)	0.03 (0.72)
18.00	0.02 (0.72)	0.06 (0.74)	0.04 (0.73)
SE ±	0.01	0.02	0.01
CD at 5%	0.03	NS	0.04
CV (%)	3.27	5.98	3.65

* Average of 24 observations. # Figures in parentheses are x + 0.5 transformed values

M. domestica was another dipteran found visiting safflower heads. However, different day timings had no impact on their visits to the safflower heads and differences in their visit numbers at different time interval were found non-significant. Maximum visits (0.08 / plant / minute) were recorded at 08.00 hrs followed by 0.06 / plant / minute at 18.00 hrs, 0.05 /plant /minute at 12.00 hrs and 0.03 / plant / minute at 14.00 hrs while only 0.02 / plant / minute were reported at 10.00 hrs and 16.00 hrs each.

Hover fly were found more active during morning hours as reflected from their visits to the safflower heads. Maximum 0.09 Hover fly visiting safflower heads were observed at 08.00 hrs and this visit number is at par with the visits at 12.00 hrs, 10.00 hrs, 18.00 hrs and 16.00 hrs which were 0.06, 0.04, 0.04 and 0.03 Hover fly / plants / minute, respectively. Significantly lowest of 0.01 Hover fly / plant / minute were found visiting safflower heads at 14.00 hrs.

The present findings are in conformity with the findings of Abrol. (2010) [1] who reported that *A. florea* visited fever flowers during the early and late part of the day, the most being visited between 12.00 and 14.00 h. Also, Roy *et al*. (2014) [13] pointed out that the peak activity of the insect visitors in mustard was mainly observed at the middle of the day i.e., from 12 noon to 2 pm. Similar results were reported by Hussain (2015) [6] wherein peak densities of all honeybee species were recorded at 12.00 pm and 02:00 pm while minimum densities were recorded at 08:00 am and 04:00 pm. Further, Tale (2016) [15] found that the intensity of *A. indica*, *A. florea*, *A. mellifera*, *A. dorsata*, *Trigona spp*. and other pollinators were reached at its peak during 10.00 - 12.00 hrs, supporting the findings of present study. In sesame, Kamel *et al*. (2013) [9] observed that the insect pollinators are mostly abundant on flowers between 11.00-1.00 pm and 1.00-3.00 pm. Thus, the findings of all above workers supported the present finding of hymenopteran pollinators preferred visit timing was in between 12.00 to 14.00 hrs. Further, Bhowmik and Bhadra (2015) [3] recorded insect visitors / pollinators were at time periods from 07.00 hrs to 18.00 hrs. They observed that peak foraging activity of the members of Hymenoptera, Diptera, Coleoptera, Hemiptera and Lepidoptera was observed to be around 10:00 am., 11:30 am., 1:30 pm., 11:00 am. and 8:30 am., respectively supporting the findings of present study.

Abiotic factors on pollinators

Correlation between different pollinators and abiotic factors were worked out and presented in Tables 5 to 7. *A. florea* showed negative but significant correlation with maximum temperature (°C) (- 0.422*). *A. dorsata* showed negative significant correlation with maximum temperature (°C) (- 0.556*), minimum temperature (°C) (- 0.686*), evening relative humidity (%) (- 0.451*) while positive and significant correlation with rainfall (mm) (0.517*). *T. iridipennis* showed negative but significant correlation with maximum temperature (°C) (- 0.679*) minimum temperature (°C) (- 0.573*) evening relative humidity (%) (- 0.496*).

P. demoleus showed negative but significant correlation with minimum temperature (°C) (- 0.410*) also *C. sexmaculata* and *M. domestica* showed negative but significant correlation with maximum temperature (°C) (- 0.559*) and (- 0.448*), respectively.

These results are in conformity with the findings of Abrol (2010) [1] who reported that bee abundance followed air temperature, light intensity, solar radiation and fluctuations in nectar-sugar concentration, but was inversely related to relative humidity. A Correlation Matrix between bee activity and different environmental factors indicated a highly significant and negative association of bee activity with relative humidity, with the other environmental variables highly significant and positive. Solangi *et al*. (2011) [14] noted non-significant but negative correlation between temperature and honey bee population. In present study also all the three species of honey bees showed negative correlation with maximum as well as minimum temperature but the correlation was found to be significant except *A. florae* and minimum temperature. Thus, the present results are partially supported by the findings of Solangi *et al*. (2011) [14]. Bukero *et al*. (2015) [5] found that in safflower, the temperature has negative and humidity have positive correlation with floral activity of pollinators at different visiting times, partially supporting the findings of present study. Bajiya and Abrol (2017) [3] found that the foraging population of *A. mellifera* in mustard was negatively correlated with relative humidity in the morning and evening but was non-significant with rainfall and wind speed. Similarly, population of *A. dorsata* was significant and positively correlated with maximum and minimum temperature and sunshine hours, wind speed and negatively with relative humidity in the morning but was non-significant with relative humidity in the evening, rainfall. Same trend was observed for other pollinator. In case of *X. fenestrata*, the population was significant and positively correlated with minimum temperature and wind speed. Whereas non-significant with maximum temperature, relative humidity in the morning and evening, rainfall and sunshine

hours. In the present study honey bee species *viz*., *A. florae*, *A. dorsata* and *T. iridipennis* showed negative correlation with maximum temperature, minimum temperature, morning and evening relative humidity but it showed positive correlation with rainfall and wind speed (except *A. florae*) while wasp sowed positive non-significant correlation with all the parameters except evening relative humidity which indicated that all the species of honeybees and other pollinators varied in their response to climatic conditions prevailing at a unit time.

Table 5: Correlation of abiotic factors with pollinators

Weather parameter	Correlation coefficient ('r' values)				
	A. florea	***A. dorsata***	***T. iridipennis***	***X. fenestrate***	**Wasp**
Rainfall (mm)	0.066	0.517*	0.373	0.071	0.153
Maximum Temperature (°C)	- 0.422*	- 0.556*	- 0.679*	- 0.208	0.027
Minimum temperature (°C)	- 0.329	- 0.686*	- 0.573*	- 0.175	0.076
Morning relative humidity (%)	- 0.131	- 0.064	- 0.229	- 0.006	0.094
Evening relative humidity (%)	- 0.255	- 0.451*	- 0.496*	- 0.234	- 0.151
Wind speed (Km/h)	- 0.245	0.064	0.043	0.030	0.268

N = 2, *Significant at 5%

Table 6: Correlation of abiotic factors with pollinators

Weather parameter	Correlation coefficient ('r' values)			
	A. bicincta	***P. demoleus***	***C. sexmaculata***	***C. dilutes***
Rainfall (mm)	- 0.268	- 0.096	0.110	- 0.144
Maximum Temperature (°C)	- 0.125	- 0.334	- 0.559*	- 0.060
Minimum temperature (°C)	- 0.242	- 0.410*	- 0.388	0.136
Morning relative humidity (%)	- 0.243	- 0.327	0.081	- 0.057
Evening relative humidity (%)	- 0.327	- 0.348	- 0.055	0.062
Wind speed (km/h)	- 0.007	0.088	- 0.268	- 0.239

N = 2, *Significant at 5%

Table 7: Correlation of abiotic factors with pollinators

Weather parameter	Correlation coefficient ('r' values)		
	I. scutellaris	***M. domestica***	**Hover fly**
Rainfall (mm)	0.199	- 0.025	0.041
Maximum Temperature (°C)	- 0.099	- 0.448*	- 0.392
Minimum temperature (°C)	- 0.060	- 0.380	- 0.160
Morning relative humidity (%)	0.181	- 0.345	- 0.105
Evening relative humidity (%)	0.059	- 0.225	0.024
Wind speed (km/h)	- 0.315	- 0.419	- 0.163

N = 24, *Significant at 5%

Conclusion

The study on pollinator diversity percentagewise Hymenoptera (41.66%) was found as the dominating insect order followed by Diptera (25%) and Lepidoptera (16.66%). Previously, the findings of present study indicated similar trend underlining the importance of order Hymenoptera, Diptera and Lepidoptera in the pollination activity in the flowering crops like safflower contributing significantly in the yield. Visit timings of different pollinators revealed that preferred visit time for hymenopteran pollinator was afternoon hours from 12.00 to 14.00 hrs, while the pollinators from Diptera and Hemiptera were more active in morning hours. The members of Lepidoptera order are active in the morning as well as evening hours and the coleopterans are found as only occasional visitors.

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