

Diversity and foraging activity of pollinators of *Foeniculum vulgare* Miller in Bikaner, India

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ABSTRACT: Fennel, a popular winter rabi spice, relies heavily on pollinators for its reproduction. Periodical surveys conducted in fennel fields at weekly intervals, revealed 31 species of flower visitors/pollinators which included 31 insect species from 17 families and 6 orders with Dipterans and Hymenopterans being the most dominant visitors. Hymenoptera (58.21%) was the most common insect order to visit the fennel flowers in terms of percent abundance. *Apis florea* (19.86%), *Lucilia sericata* (17.73%) and *Polistes olivaceus* (17.73%) were identified as the most frequent pollinators. The highest foraging activity was observed at 11:00 a.m (15.09 bees/10 plants/ 5 minutes). The foraging behaviour of these pollinators varied significantly with *A. florea* spending the maximum time per flower (75 sec). *A. florea* (21.24) and *L. sericata* (23.41) had the highest foraging rates. The study revealed that the foraging activity of these pollinators was significantly correlated with weather parameters. *A. florea* exhibited a substantial negative correlation with relative humidity ($r=-0.7224$) and a significant positive correlation with both maximum and minimum temperatures ($r=0.8100$ and 0.7523 , respectively). *A. florea* and *L. sericata* were found to be more sensitive to temperature change, resulting in more dramatic changes in foraging behaviour with warming.

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KEY WORDS: Fennel, entomophylic, flower visitors, diversity, behaviour, weather parameters, warming

INTRODUCTION

Fennel (*Foeniculum vulgare* Miller), also known as saunf, is a popular winter rabi spice grown in northern India. It thrives in dry, cold climates and hence is grown in Gujarat, Rajasthan, Uttar Pradesh, Madhya Pradesh, Karnataka and Punjab (Pruthi, 1976). Plant-pollinator interactions are highly valued mutualism in agricultural food

production because they provide essential ecological activities that promote world biodiversity. Pollinators are group of animal species that transmit pollen in blooming plants (Ollerton, 2017). Pollination insects mainly belong to three orders namely Lepidoptera, Hymenoptera and Diptera (Mitra and Parui, 2002; Mitra *et al.*, 2008). Insects as pollinators play an important role in cross-pollination of fennel which help to create variation, boost hybrid vigour and

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sustain gene flow in the environment, all of which contribute to the preservation of crop varietal diversity. Fennel blossoms are visited by at least twenty-five insect species belonging to fifteen families and five orders, among seven belonging to the order Lepidoptera, nine in Hymenoptera, five in Diptera, three in Coleoptera and one in Odonata. *Apis florea* F., *A. cerana indica* F., *A. mellifera* L. and *A. dorsata* F. were the most common insect pollinators (Bharti *et al.*, 2015). Pollinator diversity has great impact on agricultural production quality. Higher diversity of insect pollinators is very important in maintaining ecological balance. Biodiversity is calculated by various indices which are used to measure the richness and evenness of different species in population. High diversity index is referred as a key indicator of healthy area (Fedor and Zvarikova, 2019). The degree of pollination mainly depends on foraging speed, foraging rate, strength and diversity of pollinators. Foraging ecology is one of important parameter in successful pollination and is variable from one pollinator species to other, even within the species. To know the influence of weather parameters on pollinator's activity and behaviour in fennel, they were correlated with pollinators foraging activity which were helpful to know the ideal weather conditions for pollinator activity.

MATERIALS AND METHODS

The fennel crops were raised under field conditions at research farm, College of Agriculture, Bikaner during 2021-2022. The field area was first divided into four equal plots of 10m width and 10m length with irrigation channels (2m width). The diversity of insect visitors/pollinators on mustard was observed daily on ten randomly selected plants for five minutes at hourly interval from 06.00 to 18.00h throughout the flowering period to document various insect visitors. The insect visiting flowers were collected with sweep nets, mounted and got identified and the diversity was measured using Shannon-Weiner diversity index.

Abundance of insect visitors is checked on ten randomly selected plants for five minutes at hourly interval from 06.00 to 18.00h, using stopwatch.

Further, rhythmic activities of different insect visitors were recorded at the time of blooming of fennel. These observations were started when 50 per cent of the plants came into bloom. The relative abundance of each species/group to the total insect visitors was calculated by formula proposed by Das and Jha (2018). Different aspects of foraging behaviour of most frequent visitors of fennel crop were recorded. Each of different pollinator species were observed for its foraging behaviour for the collection of nectar and/or pollen. The diurnal variations were recorded for 5 min from 06.00h to 18.00h on fennel for major pollinator species on fennel at hourly interval and their variations in foraging activities at different timings were expressed as mean number of pollinators/ 10 plants/ 5 min. The number of flowers visited by foraging species per five minutes was recorded at peak foraging hour of respective forager species during entire flowering period and average number of flowers visited by pollinator species was expressed as number of flowers visited by a pollinator per 5 minutes.

Major pollinators were observed for documenting the time spent by each visitor on flower of fennel at peak activity. The time spent to insert the proboscis and suck up the nectar or brushing/collecting pollen were considered as the time spent per flower, which were recorded with the help of a stopwatch. Pollinators foraging activity was correlated with various weather parameters *viz.*, temperature, rainfall, wind direction and relative humidity to know the activity of different pollinators in relation to various changes in these parameters in fennel. The data collected were statistically analysed by using the one way of ANOVA and and by using the SPSS computer program (IBM SPSS Statistics for Windows, Version 20.0. Armonk, NY: IBM Corp.).

RESULTS AND DISCUSSION

Diversity of insect visitors/pollinators: Insect visitors of fennel crop revealed that a total of 31 species belonging to 17 families of six orders were recorded from the fennel flowers. The hymenopterans and dipterans were the major and

dominant floral visitors comprising of 10 species each observed from four and five families respectively, followed by floral visitors of two families from Coleoptera (5), three families from Lepidoptera, two from Hemiptera (2) and the least diversified one is the Neuroptera with only one species (Table 1). Earlier, Hymenopterans and dipterans were noticed as dominant among pollinators in mustard bloom by Das and Jha (2018) in Nadia, West Bengal, India and similar records were also provided by Thakur *et al.* (2022) in spice in Pusa and Dholi locations of Bihar, India.

Abundance of insect visitors/pollinators in fennel: The per cent abundance of insect orders visiting the fennel flowers were dominated by Hymenoptera (58.21%) followed by Diptera (32.61%) and the least by Neuroptera (0.72%) (Table 1). Sharma and Meena (2019) and Paikara and Painkra (2020) observed maximum abundance of pollinators from Hymenoptera in spice in Rajasthan (53.05%) and Chhattisgarh (88.17%). Of the total insect visitor population, the family Apidae displayed maximum (28.42%) abundance succeeded by Calliphoridae (24.82%). Ali *et al.* (2024) explained that the honey bee colonies were not only abundant pollinators, but they also increased the number of seeds per umbel, seed size and fruit weight. Muscidae (2.13%) was reported as the minimum pollinators. Among the different insect species *A. florea* (19.86%) was the predominant species visiting the flowers followed by species such as *Lucilia sericata* (17.73%) and *Polistes olivaceus* (17.73%). Vandhi *et al.* (2022) recorded *A. florea* as the most abundant pollinator among all the floral visitors in coriander in Madurai, Tamil Nadu. Four species were observed as least (0.70%) visitors viz., *Uthesia pulcella* L., *Episyrphus balteatus* (De Geer), *Lampides boeticus* L. and *Coccinella transversalis* Fab.

Shannon-Weiner diversity index displayed that *A. florea* as the higher abundance in population (-0.3210) followed by *L. sericata* (-0.3067) and *P. olivaceus* (-0.3067). Shannon biodiversity index of 2.6401 was observed in fennel umbels. A higher Shannon index indicated a greater diversity of species in the ecosystem; if the index is zero, the

community is home to just one species. Similar results of *Apis* sp. dominance were reported by Ranjitha *et al.* (2019) and Thakur *et al.* (2022). It was further observed that, the pollinator population increased with flowering and gradually declined after peak period of flowering. It started with 1.41 insects m⁻² on 24th December, which gradually increased in subsequent weeks to reach its peak on 20th January (3.70 insects m⁻²) synchronising the peak period of flowering. It again decreased towards cessation of the flowering i.e., 6th week onwards (2.39 insects m⁻²) and minimum abundance was observed on 2nd February (0.42 insects m⁻²). The average number of insects recorded during the blooming period was 2.36 m⁻².

Foraging behaviour of frequent insect pollinator in fennel: The foraging behaviour of three species viz., *A. florea*, *L. sericata* and *P. olivaceus* done on fennel flowers at different hours of the day, showed variations in activity over time (Fig 1). *A. florea* started the foraging activity at 9.00h of the day and its mean number showed an increasing trend up to 11.00h and thereafter declined with maximum foraging activity at 11.00h (15.09 bees/10 plants/ 5 minutes). The study revealed that *L. sericata* started the foraging activity at 9.00h of the day and its mean number showed an increasing trend up to 12.00h and thereafter declined with maximum foraging activity at 12.00h (15.09 insect visitors/ 10 plants/ 5 minutes). However, no bee activity was observed in the morning and after 17.00h. Also, the study revealed that *P. olivaceus* started the foraging activity at 11.00h of the day and its mean number showed an increasing trend up to 14.00h and thereafter declined with maximum foraging activity at 14.00h (9.09 insect visitors/ 10 plants/ 5 minutes). Moderate foraging activity was observed at 12.00h and 13.00h, with 3.73 visitors/ 10 plants and 5.64 visitors/ 10 plants, respectively. However, no bee activity was observed on morning and after 15.00h onwards. The activity of *P. olivaceus* was observed during the midday only. Saha *et al.* (2022) documented that the foraging of *A. florea* was high at 11.00h and low at early morning and late evening. Less activity was observed at morning and evening hours ranging from 4.64 to 1.91 bees per ten plants per five minutes.

Table 1. List and relative abundance of insect visitors / pollinators on fennel during *Rabi*

Order and its abundance (%)	Family and its abundance (%)	Species	Shannon-Weiner index	Species abundance (%)
Hymenoptera (58.21)	Apidae (24.82)	<i>Apis florea</i> Fab.	-0.3210	19.86
		<i>Apis cerana indica</i> Fab.	-0.0604	1.43
		<i>Apis dorsata</i> Fab.	-0.0604	1.43
		<i>Xylocopa auripennis</i> L.	-0.0604	1.43
		<i>Xylocopa fenestrata</i> Fab.	-0.0604	1.43
		<i>Xylocopa aestuans</i> (L.)	-0.1011	2.84
	Halictidae (5.67)	<i>Halictus</i> sp.	-0.1628	5.67
	Megachilidae (2.84)	<i>Megachile</i> sp.	-0.1011	2.84
	Vespidae (21.28)	<i>Polistes olivaceus</i> (DeGeer)	-0.3067	17.73
		<i>Vespa orientalis</i> L.	-0.1184	3.55
Coleoptera (2.85)	Coccinellidae (2.84)	<i>Coccinella septumpunctata</i> L.	-0.0351	0.72
		<i>Coccinella transversalis</i> Fab.	-0.0351	0.70
		<i>Cheilomenes sexmaculata</i> Fab.	-0.0351	0.71
		<i>Epilachna</i> sp.	-0.0351	0.71
	Meloidae (1.42)	<i>Mylabris pustulata</i> Thunberg	-0.0604	1.42
Diptera (32.61)	Calliphoridae (28.42)	<i>Chrysomya megacephala</i> Fab.	-0.1877	7.09
		<i>Lucilia sericata</i> (Meigen)	-0.3067	17.73
	Muscidae (2.13)	<i>Musca</i> sp.	-0.0604	1.42
	Syrphidae (3.07)	<i>Musca domestica</i> L.	-0.0351	0.71
		<i>Eristalis</i> sp.	-0.0604	1.43
	Sarcophagidae (0.70)	<i>Episyrphus balteatus</i> (De Geer)	-0.0351	0.70
		<i>Eupeodes</i> sp.	-0.0351	0.70
		<i>Metasyrphus corollae</i> Fab.	-0.0604	1.42
		<i>Sarcophaga</i> sp.	-0.0351	0.70
	Dolichopodidae (0.70)	<i>Dolichopus</i> sp.	-0.0351	0.70
Hemiptera (2.14)	Pyrrhocoridae (1.43)	<i>Dysdercus cingulatus</i> Fab.	-0.0604	1.43
	Pentatomidae (0.70)	<i>Halyomorpha halys</i>	-0.0351	0.70
Lepidoptera (2.12)	Lycaenidae (0.70)	<i>Lampides boeticus</i> L.	-0.0351	0.70
	Nymphalidae (0.71)	<i>Danaus chrysippus</i> L.	-0.0351	0.71
	Erebidae (0.70)	<i>Uthesia pulcella</i> L.	-0.0351	0.70
Neuroptera (0.72)	Chrysopidae (0.72)	<i>Chrysoperla carnea</i> (Stephens)	-0.0351	0.72
			H'=2.6401	

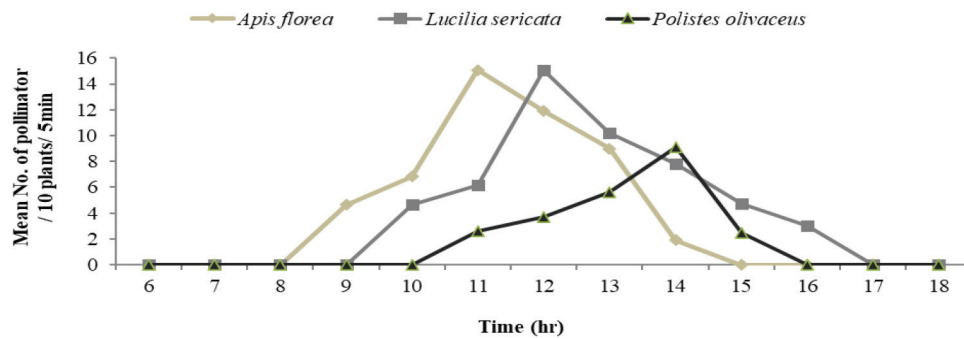


Fig 1. Temporal variations in activity of major insect visitors/pollinators on fennel

However, no bee activity was observed on early morning and after 15.00 h onwards. This is justified with the results of Thakur *et al.* (2022) who observed peak foraging activity during morning hours when the flowers are partially open under favourable weather conditions.

Foraging rate: Foraging rate was different from one insect visitor to other in fennel umbels. The maximum number of umbels were visited by *L. sericata* (23.41) followed by *A. florea* (21.24) and *P. olivaceus* (11.25). The peak foraging hour for these pollinator species with maximum numbers of pollinators were 12.0, 11.0 and 14.0. For all the three insect visitors the peak foraging activity was observed at different hours. The mean number of insect visitors was observed as 15.09, 15.09, 9.09 insect visitors per ten plants per five minutes for *A. florea*, *L. sericata*, *P. olivaceus* respectively. In fennel, *L. sericata*, and *A. florea* made higher visits to flowers. Kumar and Rai (2020) reported that in Bihar, India, among the *Apis* species, *A. florea* recorded the highest foraging rate in Fennel.

Foraging speed: The data showed that *A. florea* spent maximum time (75 sec) with mean foraging

activity of 21.24 sec per flower among the three major insect visitors/pollinators on fennel flowers. This was followed by *L. sericata* which spent maximum time of 48 sec and minimum of 6 sec with mean foraging time 23.41 sec. *P. olivaceus* spent maximum time of 45 sec and minimum time of 8 sec with mean foraging time of 11.25 sec. This was recorded during the peak foraging hour of all the three-insect visitor or pollinator species.

Correlation between foraging activity with weather factors: The data revealed that *A. florea* showed significant positive association with maximum temperature ($r=0.8100$) and minimum temperature ($r=0.7523$), and significant negative association with relative humidity ($r=-0.7224$) and non-significant negative association with wind speed ($r=-0.1327$). According to the report of Thakur *et al.* (2022), the same weather correlation trend was observed with *A. mellifera* in at Pusa and Dholi locations of India. *L. sericata* showed significant positive association with maximum temperature ($r=0.6022$) and minimum temperature ($r=0.7250$) and it showed non-significant negative correlation with relative humidity ($r=-0.4229$) and non-significant positive association with wind speed

Table 2. Correlation between foraging activity of major pollinators and weather parameters in fennel

Pollinators	Temperature - max	Temperature - min	RH (%)	Wind speed (km h ⁻¹)
<i>Apis florea</i>	0.8100*	0.7523*	-0.7224*	-0.1327
<i>Lucilia sericata</i>	0.6022*	0.7250*	-0.4229	0.1165
<i>Polistes olivaceus</i>	0.8712*	0.8388*	-0.5961*	-0.0900

*Significant at 0.05 level

($r = 0.1165$). *P. olivaceus* showed significant positive association with maximum temperature and minimum temperature ($r = 0.8712$ and $r = 0.8388$) and significant negative association with relative humidity ($r = -0.5961$) (Table 2).

Regression models for foraging activity of *A. florea* in relation to weather parameters:

The significant weather factors correlated with activity of insect visitors were taken and regressed to quantify the extent of variability/dependability of insect visitors on these factors. The foraging activity and maximum temperature were regressed to know the variability in *A. florea* foraging activity due to maximum temperature which could be explained by different models. Various models show variability to a extent of 65.6 to 68.9 per cent. The Power model ($y = 2.96x^{1.139}$) variation was 68.9. The variation in linear ($y = 4.569x - 4.773$) was of 65.6, followed by Logarithmic ($y = 36.68\ln(x) - 44.31$) and Polynomial ($y = -0.098x^2 + 6.155x - 11.13$) models. The activity of *A. florea* depends on maximum temperature up to the extent of 68.9 per cent (Table 3a).

The foraging activity and relative humidity were regressed to know the variability in *A. florea* foraging activity due to relative humidity which could be explained by different models. In the linear model ($y = -9.123x + 125.1$) it could be explained to the extent of 52.1 per cent. The polynomial model ($y = 1.775x^2 - 37.87x + 240.4$) was found to be the best fit, as it could explain variability in *A. florea* foraging activity to the extent of 53.5 per cent due to relative humidity in fennel. Logarithmic model ($y = -73.8\ln(x) + 205.3$) explain variability to the extent of 52.9 per cent. The present studies revealed that the foraging activity of *A. florea* depends on relative humidity to the extent of 53.5 per cent in fennel (Table 3b).

Bee activity was strongly positively and negatively correlated with air temperature and humidity. With an Akaike information criterion (AICc) of 586.17, the most economical minimum model only needed four meteorological variables—air temperature, humidity, rainfall, and wind speed—plus solar elevation. The mean increase in bee activity was 0.046 for every 1°C increase in air temperature.

Although the 95per cent CIs were quite big at high rainfall levels, rainfall was significantly inversely correlated with bee activity. This is mainly because rain falls in heavy, brief summer showers rather than continuously over extended periods of time. Sanderson *et al.* (2015) reported overall bee activity decreased at increasing wind speeds, indicating a lesser but still significant ($P = 0.0007$) detrimental influence of wind speed.

Table 3 a. Different regression models for *Apis florea* foraging activity in relation to maximum temperature

Model	Regression equation	R ²	CD
Linear	$y = 4.569x - 4.773$	0.656	65.6
Logarithmic	$y = 36.68\ln(x) - 44.31$	0.656	65.6
Polynomial	$y = -0.098x^2 + 6.155x - 11.13$	0.656	65.6
Power	$y = 2.96x^{1.139}$	0.689	68.9
Exponential	$y = 10.16e^{0.141x}$	0.684	68.4

R² = Regression Coefficient; CD = Coefficient of Determination

Table 3 b. Different regression models for *Apis florea* foraging activity in relation to relative humidity

Model	Regression equation	R ²	CD
Linear	$y = -9.123x + 125.1$	0.521	52.1
Logarithmic	$y = -73.8\ln(x) + 205.3$	0.529	52.9
Polynomial	$y = 1.775x^2 - 37.87x + 240.4$	0.535	53.5
Power	$y = 992.4x^{-1.43}$	0.489	48.9
Exponential	$y = 211.6e^{-0.17x}$	0.486	48.6

R² = Regression Coefficient; CD = Coefficient of Determination

Regression models for foraging activity of *L. sericata* in relation to weather parameters:

The weather factors in relation to *L. sericata* foraging activity regressed using various linear and nonlinear models to quantify the extent of variability in foraging activity, revealed its impact on the foraging activity.

The *L. sericata* foraging activity and maximum temperature when regressed, the linear model ($y = 4.562x - 0.834$) explained to the extent of 36.2 per cent. The Polynomial model ($y = 3.537x^2 - 50.20x$

Table 3 c. Different Regression models between *Lucilia sericata* foraging activity in relation to maximum temperature

Type of model	Regression equation	R ²	CD
Linear	$y = 4.562x - 0.834$	0.362	36.2
Logarithmic	$y = 33.94\ln(x) - 34.90$	0.339	33.9
Polynomial	$y = 3.537x^2 - 50.20x + 209.4$	0.489	48.9
Power	$y = 5.064x^{0.932}$	0.279	27.9
Exponential	$y = 12.86e^{0.125x}$	0.3	30.0

R² = Regression Coefficient; CD = Coefficient of Determination

+ 209.4) was found to be the best fit, as it could explain variability to the extent of 48.9 per cent due to maximum temperature in fennel. The present studies revealed that the foraging activity of *L. sericata* depends on maximum temperature to the extent of 49 per cent in fennel (Table 3c).

The influence of temperature on foraging likelihood differs significantly among pollinator species, according to logistic regression, which showed that the interaction between species identity and temperature was significant ($X^2 = 13.054$, $df = 3$, $P = 0.005$). *L. sericata*'s foraging likelihood response to temperature, in particular, demonstrated a moderate decline in anticipated probability from high to low temperatures. Devenish (2023) reported that *L. sericata*'s likelihood at high temperatures (0.933) was in the middle of the other three species. Forager activity was positively linked to air temperature and solar elevation, and negatively associated with rainfall, humidity and wind-speed. The effects of increased variability in meteorological conditions are considered by Sanderson *et al.* (2015). From the results, *A. florea* and *L. sericata* were found to be more sensitive to temperature change, resulting in more dramatic changes in foraging behaviour with warming.

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