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Comparative Analysis of Pollinator Diversity, Abundance, and Foraging Activity Patterns on Fennel (*Foeniculum vulgare*) and Black Cumin (*Nigella sativa*) in the Northern Transitional Zone of Karnataka, India

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ABSTRACT

This study investigated during *rabi*, 2021–22 (October-March) at the University of Agricultural Sciences, Dharwad, Karnataka, India to study the diversity and abundance of insect pollinators on fennel (*Foeniculum vulgare Miller*) and black cumin (*Nigella sativa* L.). Visual counting method revealed that Hymenoptera was the dominant order across both crops, with Apis florea (little bee) being the primary pollinator, constituting 94.8% of total visitors in fennel and 86.02% in black cumin. In fennel, Coleoptera (3.7%) and Diptera (1.1%) represented minor pollinator groups, while black cumin showed limited Coleoptera presence (1.16%). Pollinator activity in fennel peaked during 1300–1400 h, with maximum visitation occurring at 90% flowering stage (40.53 visitors m^{-2} 5 min^{-1}). Contrastingly, black cumin pollinator activity peaked between 1000-1100 h, with highest visitation during peak flowering (10.53 visitors m^{-2} 5 min^{-1}). Biodiversity indices revealed that black cumin supported higher pollinator diversity (Shannon-Wiener Index: 0.44–0.55; Simpson Index: 0.24–0.29) compared to fennel (Shannon-Wiener Index: 0.19–0.28; Simpson Index: 0.07–0.12). The findings highlight the crucial ecological role of *A. florea* in both crops while documenting temporal variations in pollinator activity throughout flowering periods. This baseline information on pollinator communities is essential for developing sustainable pollination management strategies for these economically important seed spices.

KEYWORDS: Black cumin, fennel, diversity, pollinators, foraging activity

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Data Availability Statement: Legal restrictions are imposed on the public sharing of raw data. However, authors have full right to transfer or share the data in raw form upon request subject to either meeting the conditions of the original consents and the original research study. Further, access of data needs to meet whether the user complies with the ethical and legal obligations as data controllers to allow for secondary use of the data outside of the original study.

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1. INTRODUCTION

Fennel (*Foeniculum vulgare Miller*), often referred to as saunf, is among the most significant seed spices for the winter season. It is primarily cultivated in northern India. Fennel thrives in dry and cold weather conditions, which is why it is grown in states like Gujarat, Rajasthan, Uttar Pradesh, Madhya Pradesh, Karnataka, Haryana, and Punjab. Pollination constrains crop yields and plays a crucial role in enhancing agricultural productivity. The pollinator community associated with fennel is highly varied, including different species of bees (*Apis mellifera, Xylocopa* spp.), hoverflies (Syrphidae), beetles (Coleoptera) and butterflies (Lepidoptera) that are drawn to its abundant umbel flower clusters (Chittka and Schurkens, 2001). Rader et al. (2016) found that non-bee insects were responsible for up to 38% of visits to fennel flowers. Factors in the environment, such as the complexity of the landscape and farming practices, greatly affect the structure of the pollinator community and the frequency of their visits to fennel blossoms (Garibaldi et al., 2016; Krimmer et al., 2019).

Black cumin (*Nigella sativa* L.), an important medicinal plant in the Ranunculaceae family, relies on insect pollination for optimal seed production. Despite its agricultural and medicinal significance, the pollinator communities that support this crop have received limited attention. Understanding the diversity and ecology of these pollinators is vital for developing sustainable practices that enhance crop yields and conserve beneficial insects. Research in pollination ecology has consistently shown that a variety of pollinator species contributes to resilience against environmental changes and tends to yield better pollination services than systems with a single species (Garibaldi et al., 2013; Winfree et al., 2018). In the case of black cumin, efficient pollination leads directly to improved seed production, oil content, and profiles of bioactive compounds, all of which influence its market value and therapeutic effectiveness (Ahmad et al., 2013). Climate change, alongside the intensification of agriculture, presents significant challenges to pollinator populations. Altered phenological patterns may disrupt the timing synchronization between flowering periods and pollinator activity (Bartomeus et al., 2011), while the consequences of habitat destruction and pesticide exposure continue to influence the dynamics of pollinator populations (Potts et al., 2016). These issues highlight the necessity of having baseline ecological information to guide conservation efforts tailored to agricultural environments where black cumin is grown. Since very meagre information is available on the insect pollination requirements of fennel and black cumin, therefore the present study was carried out on the diversity and abundance of insect visitors/pollinators.

2. MATERIALS AND METHODS

The present investigations were carried out during *rabi*, 2021–22 (October-March), in the biodiversity park, University of Agricultural Sciences, Dharwad, Karnataka, India (15°26' North latitude, 75°07' East longitude and at an altitude of 678 meters above mean sea level). The experimental area is located in the Northern Transitional Zone (Zone VIII) of Karnataka, which receives 700–800 mm average annual rainfall. The temperature and relative humidity range from 12–37°C and 40 to 85%, respectively. Locally available varieties of both crops were grown for the study. The experimental plots of 3m x 3m were raised for both crops as per the package of practices, except for the plant protection measures during the flowering period.

2.1. Observations

Visual count was done randomly in both the crops which were grown under open pollination conditions by selecting five spots of one square meter area for 5 min. Observations were recorded during time intervals of 0800–0900 h, 1000–1100 h, 1300–1400 h and 1600–1700 h at different flowering stages throughout the crop flowering period. During the period of observation, Samples collected were placed in a killing jar having ethyl acetate as the killing agent, pinned, preserved and identified by the taxonomical expert of the Division of Entomology, Dr. Yeshwanth, GKVK, Bangalore.

2.2. Relative abundance of insect pollinators

The relative abundance of pollinators was calculated by using the formula given below to know the dominance of species in black cumin and fennel ecosystems.

$$\text{Relative abundance} = \frac{\text{Abundance of the species}}{\text{Total abundance of all species}} \times 100 \quad ..(1)$$

Data collected on species was used to calculate the Simpson index of diversity (1-D) and Shannon-Weiner diversity index (H) using the following procedures.

2.2.1. Shannon-wiener diversity index (H)

The Shannon-Wiener diversity index is calculated by using the following equation:

$$H = -\sum pi \ln pi \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Where, pi=Proportion of the i^{th} species of pollinator ln=Natural log with base e=2.718.

2.2.2. Simpson index of diversity (1-D)

$$D = 1-\sum pi \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Studies on diversity and abundance of insect pollinator fauna of different marginal crops.

3. RESULTS AND DISCUSSION

The taxonomic analysis on fennel pollinators highlights a remarkable dominance of Hymenoptera, with little bees (*Apis florea*) comprising an astounding 94.8% of the total insect population. This single species alone accounts for 95.2% of the relative abundance within the Hymenoptera order, establishing it as the most crucial species in the ecosystem. While Hymenoptera showcases nearly total prevalence, other insect orders exhibit minimal representation. Coleoptera makes up 3.7% of the total population, mainly from two ladybug species: the variegated ladybug (*Hippodamia variegata*) and the Indian wave striped ladybug (*Cheilomenes sexmaculata*). The Diptera order has the lowest presence, with a collective relative abundance of only 1.1%, which includes syrphid flies, tachinid flies, and blow flies (Table 1 and Figure 1). This data underscores the vital ecological role of little bees in this habitat, while other insect groups hold significantly lesser roles within the community structure.

The data of mean activity of pollinators in fennel during different flowering periods was concised and depicted in Table 2. Primary insect pollinators considered during the study were grouped as *A. florea*, coccinellids and others. At 50, 75 and 90% flowering, the mean number of pollinators

Table 1: Relative abundance of insect pollinator fauna of fennel

Sl. No.	Common name	Scientific name	Family	Order	Species abundance (%)	Relative abundance % (order)
1.	Little bee	*Apis florea*	Apidae		94.8	95.2
2.	Stingless bee	*Tetragonula sp.*		Hymenoptera	0.4	
3.	Syrphid	*Sphaerophoria macrogaster*	Syrphidae	Diptera	0.31	1.1
4.	Tachinid fly	*Tachinid sp.*	Tachinidae		0.57	
5.	Blow fly	*Chrysomya bezziana*	Calliphoridae		0.22	
6.	Variegated ladybug	*Hippodamia variegata*	Coccinellidae	Coleoptera	}	3.7
7.	Indian wave striped ladybug	*Cheilomenes sexmaculata*				

Apis florea

Tachinid sp.

Chrysomya bezziana

Sphaerophoria macrogaster

Tetragonula sp.

Hippodamia variegata

Figure 1: Pollinators recorded on fennel

Table 2: Diurnal variation in activity of insect pollinator fauna at different flowering stages in fennel

50% Flowering						
	Number of visitors m^{-2} 5 $minutes^{-1}$					
Species	08.00–09.00 h	10.00–11.00 h	13.00–14.00 h	16.00–17.00 h	Total	Mean
Apis florea	11.8	24.6	28.8	16.0	81.2	20.3±7.77
Coccinellids	0.2	0.8	1.0	0.4	2.4	0.6±0.36
Others	0	0.4	0.2	0.2	0.8	0.2±0.16
Total	12	25.8	30	16.6	84.4	21.1±8.25
Mean	4	8.6	10	5.53	28.13	7.03±2.75
75% Flowering						
	Number of visitors m^{-2} 5 $minutes^{-1}$					
Species	08.00–09.00 h	10.00–11.00 h	13.00–14.00 h	16.00–17.00 h	Total	Mean
Apis florea	15.8	26.4	33.2	20.0	95.4	23.85±7.61
Coccinellids	0.4	1.2	1.6	0.8	4	1±0.52
Others	0	0.4	0.2	0	0.6	0.15±0.19
Total	16.2	28	35	20.8	100	25±8.25
Mean	5.4	9.33	11.6	6.93	33.33	9.1±2.72
90% Flowering						
	Number of visitors m^{-2} 5 $minutes^{-1}$					
Species	08.00–09.00 h	10.00–11.00 h	13.00–14.00 h	16.00–17.00 h	Total	Mean
Apis florea	18.6	30.2	38.8	25.8	113.4	28.35±8.45
Coccinellids	1.0	1.8	2.2	1.6	6.6	1.65±0.5
Others	0.2	0.2	0.4	0.8	1.6	0.4±0.28
Total	19.8	32.2	41.4	29.2	121.6	30.4±8.90
Mean	6.6	10.73	13.8	9.73	40.53	10.13±2.97

m^{-2} 5 $minutes^{-1}$ visiting the fennel ecosystem were 28.13, 33.33 and 40.53, respectively. Irrespective of the flowering stage, A. florea was found to be significantly dominant with mean of 20.33, 23.85 and 28.35 at 50, 75 and 90% flowering correspondingly. The activity of pollinators peaked during 1300–1400 h of the day regardless of the flowering stage with the means of 10, 11.6 and 13.8 visitors m^{-2} 5 min^{-1}. Similarly, the second peak activity was observed at 10.00-11.00 h with the means of 8.6, 9.33 and 10.73 at 50, 75 and 90% flowering, respectively. At 1600–1700 h, a decline in the mean activity of pollinators was witnessed with 5.53, 6.93 and 9.73 (visitors m^{-2} 5 min^{-1}) at 50, 75 and 90% flowering, respectively. While the mean activity was found to be comparatively low at 0800–0900 h. A similar trend was observed in the case of the major pollinator (A. florea) whose peak activity was observed during 1300–1400 h with a mean activity of 28.8, 33.2 and 38.8 visitors m^{-2} 5 min^{-1} at 50, 75 and 90% flowering respectively.

The overwhelming dominance of *Apis florea* (94.8% of total population) in the fennel ecosystem is a significant finding that indicates the specialized nature of the plant-pollinator relationship in this crop. This finding aligns with research by Meena et al. (2015) who reported that fennel (*Foeniculum vulgare* Mill.) is highly (80–90%) cross-pollinated, with

Table 3: Relative abundance of insect pollinator fauna of black cumin

Sl. No.	Common name	Scientific name	Family	Order	Species abundance (%)	Relative abundance % (order)
1.	Little bee	*A. florea*	Apidae		86.02	
2.	Stingless bee	*Tetragonula* sp.		Hymenoptera	12.40	98.84
3.	Rock bee	*Apis dorsata*			0.42	
4.	Red pumpkin beetle	*Aulacophora foveicollis*	Chrysomelidae	Coleoptera	1.16	1.16

A. florea comprising 81% of the total visitors. The slightly higher percentage observed in our study (94.8% versus 81%) may be attributed to variations in local conditions, but the overall pattern of *A. florea* dominance remains consistent. The representation of various insect orders (Hymenoptera, Coleoptera, and Diptera) in our study, although with different abundances, aligns with findings from other regions of India. Layek and Karmakar (2022) documented various insect species visiting fennel in West Bengal, India, with Hymenoptera being the most prevalent order, followed by Diptera, Coleoptera, Lepidoptera, and Hemiptera. Similarly, Bharti et al. (2015) and Shilpa et al. (2014) established the dominance of Hymenoptera within the spectrum of visitors to fennel in other Indian states, and Skaldina (2020) reported similar patterns in other countries. The presence of ladybug species (*Hippodamia variegata* and *Cheilomenes sexmaculata*) as the main representatives of Coleoptera in our study highlights the ecological complexity of the fennel agroecosystem, where these predatory insects may serve dual roles as occasional pollinators and biological control agents. The limited presence of Diptera (1.1%) in our study contrasts somewhat with findings of Layek and Karmakar (2022), where Diptera was the second most abundant order, suggesting potential regional variations in insect community composition.

The results of the study of insect pollinators of black cumin revealed 3 species belonging to 2 families under 2 orders. Among the total insect pollinators visited black cumin, the abundance of the order Hymenoptera was highest, with 98.84%, and Coleoptera had the least abundance (1.16%). Among the hymenopterans, the species abundance of *A. florea* was maximum (86.04%) followed by *Tetragonula* sp. (12.80%). From the order of Coleoptera, a species of Chrysomelidae (*Aulacophora foveicollis*) was recorded (Table 3 and Figure 2). The activity of major pollinators visiting the flowers of black cumin (Table 4) differed significantly during different hours of the day throughout the blooming period of the crop. During the blooms, a mean number of visitors m^{-2} 5 min^{-1} of 6.73 was observed at the initiation of flowering, which was raised to 10.53 at peak flowering period and then declined to 5.73 at the cessation of flowering. Adding to that, the number of insect visitors m^{-2} 5 min^{-1} increased from 0800-0900 h (1.13 at initiation and cessation and 1.66 at the peak of flowering) onwards and reached a maximum between 1000–1100 h (2.66, 4.53 and 2.2 at initiation, peak and cessation of flowering respectively) of the day. But the number of pollinators decreased after 1300–1400 h (1.8, 2.86 and 1.4 at initiation, peak and cessation of flowering correspondingly) to the end of the day at 1600–1700 h (1.13, 1.46 and 1.00 at initiation, peak and cessation of flowering sequentially) during the study period. *A. florea* being a weighty pollinator compared to others,

Table 4: Diurnal variation in activity of pollinators during different stages of flowering in black cumin

Initiation of flowering						
	Number of visitors m^{-2} 5 $minutes^{-1}$					
Species	08.00–09.00 h	10.00–11.00 h	13.00–14.00 h	16.00–17.00 h	Total	Mean
A. florea	2.8	6.4	4.6	3.0	16.8	4.2±1.67
A. cerana indica	0.4	1.2	0.8	0.2	2.6	0.65±0.44
A. dorsata	0.2	0.4	0	0.2	0.8	0.2±0.16
Total	3.4	8	5.4	3.4	20.2	5.05±2.18
Mean	1.13	2.66	1.8	1.13	6.73	1.68±0.72
Peak flowering						
A. florea	4.2	10.4	7.6	4.0	26.2	6.55±3.05
A. cerana indica	0.6	2.2	1.0	0.2	4	1±0.86
A. dorsata	0.2	1.0	0	0.2	1.4	0.35±0.44
Total	5	13.6	8.6	4.4	31.6	7.9±4.23
Mean	1.66	4.53	2.86	1.46	10.53	2.63±1.41
Cessation of flowering						
A. florea	3.0	5.4	3.6	2.8	14.8	3.7±1.18
A. cerana indica	0.4	1.0	0.6	0.2	2.2	0.55±0.34
A. dorsata	0	0.2	0	0	0.2	0.05±0.1
Total	3.4	6.6	4.2	3	17.2	4.3±1.61
Mean	1.13	2.2	1.4	1	5.73	1.43±0.54

Apis florea *Tetragonula sp.* *Aulacophora foveicollis*

Figure 2: Pollinators recorded on black cumin

recorded an activity of 4.2, 6.55 and 3.7 visitors m^{-2} 5 min^{-1} at initiation, peak and cessation of flowering sequentially. The activity of *A. florea* varied during different hours of the day throughout the blooming period. The peak activity was recorded at 1000–1100 h (6.4, 10.4, 5.4 at initiation, peak and cessation of flowering respectively) and the least activity at 800-900 h (2.8 at initiation, 4.2 at peak and 3.0 at cessation of flowering). Whereas a second peak in the activity was observed at 1300–1400 h. (4.6, 7.6 and 3.6 at initiation, peak and cessation of flowering sequentially). The activity of *Tetragonula* (0.65, 1.00 and 0.55 at initiation, peak and cessation of flowering respectively) and other pollinators (0.2, 0.35 and 0.05 at initiation, peak and cessation of flowering correspondingly) was significantly lower than *A. florea* (Table 4). Our findings on pollinator diversity in black cumin align with several previous studies. Similarly, Kanth et al., 2023 and Rajani et al., 2014 identified bees as the primary pollinators of black cumin, with *A. florea* being the most numerous and active honey bee species visiting various seed spice crops. Their observation that maximum foraging occurred between 10:00 and 11:00 am corroborates our findings of peak pollinator activity during the same period. The dominance of Hymenoptera as the major order of pollinators visiting black cumin flowers (98.84%) in our study is consistent with observations by Joshi et al., 2024; Snehalatha and Jha, 2024 and Sikdar et al. (2019) who also reported that the majority of pollinators visiting black cumin blooms belonged to the order Hymenoptera. Additionally, our identification of both Hymenoptera and Coleoptera as the main orders of insect visitors is in agreement with Abd-El-Wahab and Ebadah (2011), who confirmed that most insect visitors to black cumin (*Nigella sativa*) belong to these two orders, with Hymenoptera members being more abundant.

Table 5: Diversity indices of pollinators at different flowering stages in marginal crops

Flowering stage	Shannon-wiener index (H)	Simpson index of diversity (1-D)
Black cumin		
Initiation	0.54	0.29
Peak	0.55	0.29
Cessation	0.44	0.24
Fennel		
50%	0.19	0.07
75%	0.25	0.10
90%	0.28	0.12

4. CONCLUSION

The variations in species composition and relative abundance between our study and previous research may be attributed to differences in study location, season, and prevailing weather conditions. Consistent dominance of *A. florea*, across multiple studies suggests their critical importance for black cumin pollination. Our findings indicated that black cumin exhibited relatively higher biodiversity indices during its flowering phases compared to fennel. In contrast, fennel displayed a gradual increase in biodiversity indices as the flowering progressed from 50% to 90%.

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