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Pollinator's diversity and abundance on cumin (*Cuminum cyminum* L.) and their impact on yield enhancement at semi-arid regions

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Abstract
The present investigation was conducted to study pollinator's diversity and abundance on cumin (*Cuminum cyminum* L.) and their impact on yield enhancement under semi-arid regions during 2015-16 and 2016-17 at research farm of ICAR-NRC on Seed Spices, Ajmer (Rajasthan), India. Cumin flowers were visited by 20 species of insects belonging to 11 families from 6 orders. Apoidea (62.4%) and Diptera (27.5%) were the two major groups comprising 89.9% of the total visitors. *Apis florea* was the most dominant species (31.2%) followed by *A. mellifera* (16.9%), *A. dorsata* (13.4%), *Episyrphus balteatus* (13.0%) and *Musca* sp. l (9.6%). *A. mellifera* and *A. dorsata* started foraging early at 8.00 h and *A. florea* at 9.00, peaked from 12.00 to 14.00 hr and declined drastically thereafter. Non-*Apis* pollinators were visited cumin flowers early morning by 6.00 hr with meagre in population and present throughout the day with two peaks between 11.00 to 13.00 hr, while *E. balteatus* reached to its peak at 15.00 hr. Most of floral visitors ceased their population and few were negligible at 18.00 hr. Population dynamics of most abundant pollinators were recorded during fourth week of February. A minimum yield of 364.50 kg/ha was recorded in caged plots without insect pollinators (control). Yields in open and bee pollinated plots were 515.30 and 510.41 kg/ha, with an increase of 41.37 and 40.03% over without insect pollinated plots, respectively but at par with each other. Maximum yield was in plots treated with bee attractant - Jaggery solution 10% (520.83 kg/ha) which was 42.88% higher over control and 1.07 and 2.04% higher over open pollinated and bee pollinated plots. Bee pollination also increased quality of cumin seed over control (WIP).

Keywords: Cumin, insect pollinators, pollination, population dynamics, yield

Introduction
Cumin (*Cuminum cyminum* Linn.) is a traditional, herbaceous plant (chromosome 2n=14) belongs to the family Apiaceae and originated from Mediterranean region [1]. Its growing areas are mainly distributed in India, Iraq, Iran, Syria, Pakistan, Egypt China, Turkey, Israel and Italy [2]. In India, cumin is considered as most important and valuable crop among all seed spices, largely cultivating in Gujarat, Rajasthan and Madhya Pradesh [1]. In the country, it is growing in 8.08 lakh hectare area, producing 5.03 lakh tonnes of seeds with an annual productivity of 623 kg/ha in 2015-16 [3]. India is considering as largest producer, consumer and exporter country over the world. Cumin is largely used for giving Tadka in most of the vegetable cuisines to create unique aroma and flavour [1]. It is also used for flavouring, seasoning and imparting aroma in variety of food items and beverages [1]. Cumin has adequacy in nutritional profile, like protein, carbohydrate, fat and soluble dietary fibres along with vitamins such as riboflavin, thiamine and niacin. It is also a rich source of iron and minerals [4]. Besides food and nutritional significance, it has several medicinal properties used as antioxidant [5], antidiabetic [6], anticarcinogenic [7], stimulant, carminative, stomachic, astringent and constructive in diarrhoea and dyspepsia. The active principles in the cumin may improve gut motility and help in digestion [8]. Dried cumin seeds contain 2.5 to 4.5% volatile oil. Due to oleoresin and cuminaldehyde content, it has more demand in the international market. Cuminaldehyde is good detoxicant which help in the regular removal of toxins from body [4].

Every plant species need pollination and fertilization to set seeds and fruits and pollinators often play a vital role in pollination. Cumin is a cross pollinated crop wherein, a plenty of floral visitors attend the flowers. Its inflorescence is a compound umbel and their tiny flowers are either white or pink [11].

Pollination studies on *C. cyminum* are not available in India and abroad so far. Hymenopterans particularly honeybees are of great economic importance in term of increased yield and quality of seed spices. Honeybees in cumin (*C. cyminum*) not only increased the production but also produce honey which is viscous, contain higher quantity of iron and unsaturated sugar with attractive aroma [9]. *Apis florea* contributes 36.79% of total pollinators in pollination of *Nigella sativa* at Dera Ismail Khan [10]. Despite its great importance, a very little attention has been made to know the occurrence of insect pollinators, diversity and abundance on cumin flowers in semi-arid regions. The objective of the present study was to identify the insect pollinators and their occurrence and abundance on cumin at semi-arid regions. Knowledge of potential insect pollinators of cumin crop is the way to find out the impact on enhancement of yield and quality.

Materials and methods

The current study was undertaken at research farm, ICAR-National Research Centre on Seed Spices, Ajmer (a semi-arid region of Rajasthan) for two consecutive years 2015-16 and 2016-17 to ascertain the diversity of insect pollinators, their occurrence and abundance on cumin crop in *Rabi* season. The experimental site is located at latitude of 26° 27' 0" N and 74° 38' 0" E longitude having 460 meter msl altitude. The experimental location is surrounded by Aravalli hills, receives annual average rainfall 300-550 mm, temperature 2-5° C in January and 42-45° C in May-June and 60-80% relative humidity during the period of study. Field trials were conducted in randomized block design, replicated four times. Seeds of cumin variety GC-4 were sown in plot sized of 5 x 4 meter (20 m^2 area) under the specified crop geometry (25 x 10 cm row to row and plant to plant distance). Five treatments (mode of pollination) *viz*., Control- without insect pollination (WIP)-caged, open pollination (OP), bee pollination (BP)-caged, bee attractant sugar solution (10%) and jaggery solution (10%) were applied. In WIP and BP, the plants were caged in 16-mesh nylon nets framed with GI pipes in 2.5 m height but in control plots, crop sprayed with azadirachtin 0.03% EC @ 5ml/lit., to eliminate all the insects inside. In BP, a four-frame *A. mellifera* colony was kept inside the net at 10-20% flowering stage. Plants were exposed to natural pollination in open pollination. All required agricultural practices were followed as per package of practices adopted for cumin crop at the institute.

Data collection

Diversity of floral visitors was studied by sweep-netting the insect visitors, initiated at 30% flowering and continued till end of flowering. The specimens of floral visitors were collected, preserved and identified with the help of literature available at NRCSS. All floral visitors were occurred on cumin crop from their natural habitat, whereas, *Apis mellifera* were visiting the crop from the colonies stationed 200 meter from the experiment. The temporal abundance of floral visitors was studied from 1 m^2 bloom area for a period of 5 minute in four replications. The visual observations on insect pollinators of cumin flowers were recorded at full blooming stage of the crop at hourly intervals from morning to evening by 6.00 to 18.00 h. These observations were recorded for 10 calm, clear and sunny days. Per plot yield data were recorded on harvest and converted into yield kg per hectare. The replicated data were statistically analyzed using OPSTAT software developed by CCSHAU, Hisar (India).

Results and Discussion

The data on various parameters of pollination studies in cumin were recorded and presented as under given headings.

Diversity of insect pollinators

Diversity of various floral visitors associated with cumin (*Cuminum cyminum* L.) was confirmed that the cumin flowers were visited by 20 species of insects belonging to 11 families from 6 orders during entire flowering period (Table 1). Among these floral visitors, maximum insect species were noticed from Hymenoptera (7 species) followed by Diptera (5 species), Lepidoptera (3 species), Hemiptera (2 species), Coleoptera (2 species) and Neuroptera (1 species) on the crop. Apoidea (62.4%) and Diptera (27.5%) were the two major groups comprising 89.9% of the total visitors. *Apis florea* was the most dominant species (31.2%) followed by *A. mellifera* (16.9%), *A. dorsata* (13.4%), *Episyrphus balteatus* De Geer (13.0%) and *Musca* sp. l (9.6%). No such work was carried out by earlier researchers on pollinators diversity particularly on cumin crop, hence, results could not be compared and discussed. However, honeybees species *Apis florea* [12], *A. cerana, A. mellifera* and syrphid flies [13] & [14] reported the most common and potential pollinators of fennel support to the present study. Chaudhary and Singh [15] reported the *A. mellifera*, a most diversed floral visitor of coriander in Karnal (Haryana) and Apoidea contributed as most prominent group of pollinators, get support the present findings. Among other floral visitors, *Coccinella septempunctata* L. (3.9%) was recorded in higher proportion followed by *Episyrphus* sp. (2.4%), *Menochilus sexmaculatus* (1.8%), *Eristalis* sp., (1.6%) and unidentified hymenoptera sp. 1 (1.5%). The remaining cumin floral visitors *viz*., *Trigona irridipennis* L., *Eristalis* sp., *Musca* sp. 2, *Hellula undalis* F., *Chrysoperla carnea* and others were found less important (<1 per cent) in their population proportion during flowering period also play some role in pollination. Similar observations were recorded by Deodikar and Suryanarayana [16], Shelar and Suryanarayana [17], Baswana [18] and Meena *et al*. [9] are close conformity to present study.

Table 1: Diversity of floral visitors on cumin flowers at semi-arid region

Species	Family	Mean population (/m^2area/5minutes)	Proportion (%) of total visitors
Hymenoptera			
Apis florea F.	Apidae	16.8	31.2
Apis mellifera L.	Apidae	9.1	16.9
Apis dorsata F.	Apidae	7.2	13.4
Trigona irridipennis L.	Meliponeae	0.5	0.9
Total Apoidea		33.6	62.4
Other Hymenoptera			
Xylocopa sp.	Xylocopinae	0.2	0.3
Unidentified hymenoptera sp. 1		0.8	1.5

Unidentified hymenoptera sp. 2		0.3	0.5
Total Hymenoptera		34.9	64.8
Diptera			
Episyrphus balteatus De Geer	Syrphidae	7.0	13.0
Episyrphus sp.	Syrphidae	1.3	2.4
Eristalis sp.	Syrphidae	0.9	1.6
Musca sp. 1	Muscidae	5.2	9.6
Musca sp. 2	Muscidae	0.4	0.7
Total Diptera		14.8	27.5
Coleoptera			
Menochilus sexmaculatus F.	Coccinellidae	1.0	1.8
Coccinella septempunctata L.	Coccinellidae	2.1	3.9
Hemiptera			
Dysdercus koenighii F.	Pyrrhocoridae	0.2	0.4
Oxycarenus laetus Kirby	Lygaeidae	0.1	0.2
Lepidoptera			
Spodoptera litura F.	Noctuidae	0.2	0.4
Helicoverpa armigera (Hub.)	Noctuidae	0.1	0.2
Hellula undalis F.	Pyralidae	0.3	0.5
Neuroptera			
Chrysoperla carnea	Chrysopidae	0.1	0.2
Total others		4.1	7.6
G. total of floral visitors		53.8	

Abundance of floral visitors

The data pertaining to most abundant and important seven species of floral visitors were considered for this study (Table 2). Honeybee species, *Apis florea* was recorded as most abundant pollinator on cumin along with their maximum population of 16.8 bee/m^2 bloom area/5 minute followed by followed by *A. mellifera* (9.6 bee/m^2 bloom area/5 minute), *A. dorsata* (7.2 bee/m^2 bloom area/5 minute), *Episyrphus balteatus* De Geer (6.6 flies/m^2 bloom area/5 minute), and *Musca* sp. 1 (5.2 flies/m^2 bloom area/5 minutes), *Episyrphus* sp. (3.2 flies/m^2 bloom area/5 minute) and *C. septempunctata* (2.1 beetles/m^2 bloom area/5 minute). Data on foraging behaviour of various floral visitors presented in Table 2 revealed that, there were no activities of honeybee species recorded at 6.00 hr, however, *A. mellifera* and *A. dorsata* started foraging at 7.0 hr while *A. florea* by 8.0 hr with lower population. Subsequently, their activity increased with the advancement of temperature and sunlight and reached to its peak between 12.00 to 14.00 hr. After that their population declined gradually and became negligible at 18.00 hr. The maximum mean population was recorded for *A. florea* (6.67 bees) over time and space followed by *A. mellifera* (3.98 bees) and *A. dorsata* (3.39 bees). Maximum activities of honeybees on fennel were also recorded between 12.00-14.00 hr [12, 19] are similar to the present result.

Foraging of non-*Apis* floral visitors started by 6.00 hr with low population ranged between 0.1 to 0.6 insect/m^2 bloom area. *Episyrphus balteatus* De Geer was recorded as most abundant floral visitor started foraging by 6.00 hr (0.2 flies/m^2), its population increasing exponentially and peaked at 11.00 hr (5.8 flies/m^2) and 15.00 hr (6.6 flies/m^2), declined gradually afterwards to cease completely at 18.00 h. The population of *Musca* sp. 1 was in low level (0.6 flies/m^2) at 06.00 hr and then increased to peak from 12.00 to 14.00 hr (4.2-5.2 flies/m^2), declining gradually later and was recorded negligible after 17.00 hr. *Episyrphus* sp. also started foraging at 6.00 hr with a peak from 11.00 to 12.00 hr (3.2 flies/m^2) and then declining gradually afterwards to cease completely at 18.00 hr. *C. septempunctata* also started foraging at 6.00 hr with a peak at 11.00 hr and 13.00-14.00 hr (2.2 flies/m^2) and then declining gradually afterwards to reduce to 0.4 beetles/m^2 at 18.00 h. The maximum mean population of non-*Apis* pollinators was recorded for *Episyrphus balteatus* De Geer (2.43 bees) over the time and space followed by *Musca* sp. 1 (2.34 flies/m^2), *Episyrphus* sp. (1.21 flies/m^2) and *C. septempunctata* with 1.12 beetles/m^2 (Table 2). Abundance of Syrphid flies and wild bees in present finding is also supported by earlier workers El-Berry *et al.* [20] on medicinal plants from Egypt and Ricciardelli and Ambrosio [21] on coriander from Italy.

Table 2: Abundance of floral visitors on cumin

Insect visitor	Mean population of insect visitors m^{-2} bloom area during different hours													
	6.00	**7.00**	**8.00**	**9.00**	**10.00**	**11.00**	**12.00**	**13.00**	**14.00**	**15.00**	**16.00**	**17.00**	**18.00**	**Mean**
Apis mellifera L.	0.0	0.6	1.0	2.4	3.6	6.0	6.6	8.2	9.6	5.8	4.6	3.4	0.0	3.98
A. florea F.	0.0	0.0	3.4	5.6	7.2	9.0	10.7	14.0	16.8	12.6	5.7	1.8	0.0	6.67
A. dorsata F.	0.0	0.4	1.2	2.0	2.6	6.7	7.0	7.2	7.2	4.2	4.2	1.2	0.2	3.39
Episyrphus balteatus De Geer	0.2	0.4	0.6	1.2	2.2	5.8	3.6	3.6	3.2	6.6	3.2	1.0	0.0	2.43
Episyrphus sp.	0.2	0.4	0.2	0.4	2.0	3.2	3.2	1.8	1.3	1.2	0.8	1.0	0.0	1.21
Musca sp. 1	0.6	0.6	1.0	3.0	3.2	4.0	4.2	5.2	4.4	2.2	1.2	0.4	0.4	2.34
C. septempunctata	0.1	0.2	0.2	1.0	1.2	2.0	2.0	2.1	2.0	1.6	1.2	0.4	0.4	1.12
Mean	0.2	0.4	1.1	2.2	3.1	5.2	5.3	6.0	6.4	4.9	3.0	1.3	0.1	
SD	0.2	0.2	1.1	1.7	1.9	2.4	2.9	4.3	5.5	4.0	1.9	1.0	0.2	

Population dynamics of insect pollinators

The data on average population day^{-1} of insect pollinators of cumin are presented the fig. 1 shows that the occurrence of various floral visitors' *viz*., *A. florea, A. mellifera, A. dorsata,*

Episyrphus balteatus De Geer, *Episyrphus* sp., *Musca* sp. 1 and *C. septempunctata* was started from 25th January with the initiation of flowering. In the beginning, its population was low which ranged 0.2 to 2.6 insects/m^2 bloom area. With the advancement in flowering of cumin, pollinators' population gradually increased and reached to its peak during fourth week of February, where maximum population (10.4 bees/m^2 bloom area) was recorded for *Apis florea* followed by *A. mellifera* (7.6 bees/m^2 bloom area) and *A. dorsata* (4.6 bees/m^2 bloom area). Population trend declined on 1st March and reached to lowest level on 8th March. *Episyrphus balteatus* De Geer and *Episyrphus* sp. reached to highest level during third week 15th February and then declined gradually to lowest by 8th March. *Apis florea, A. dorsata* and *Episyrphus balteatus*' population recorded maximum on 21st February on black cumin [10] are accordance with present findings.

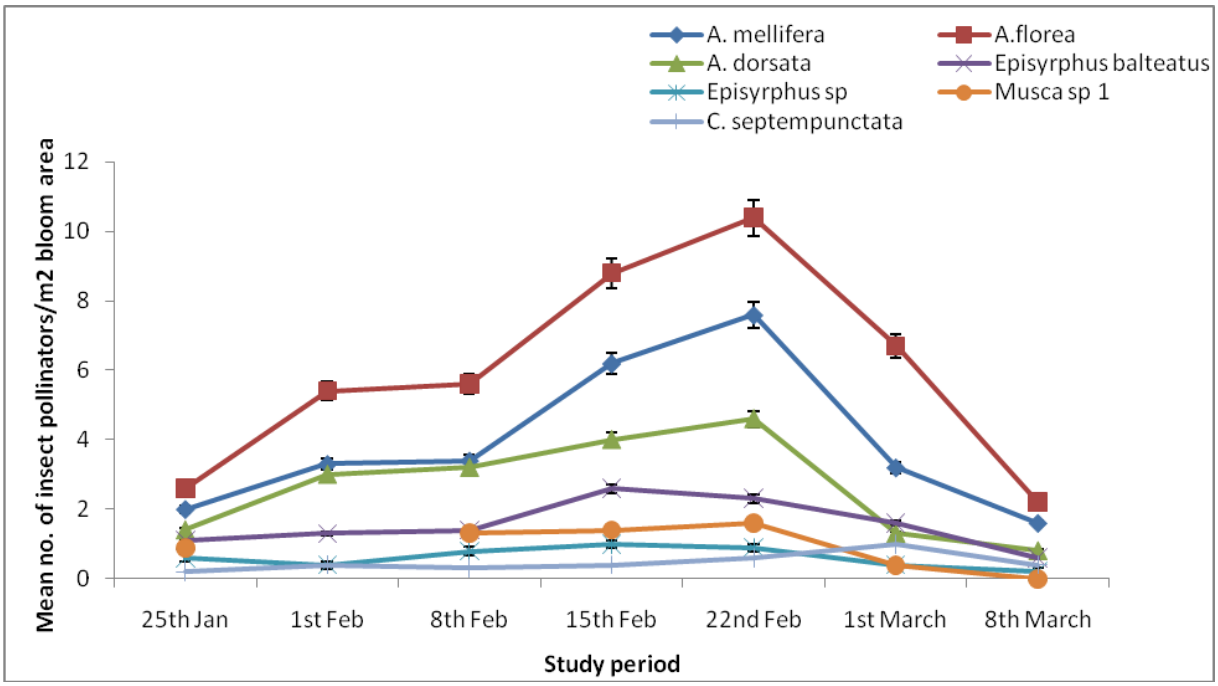

Fig 1: Population dynamics of insect pollinators of cumin

Yield and quality

The irresistible input of insect pollinators on seed yield of cumin was studied and presented in Table 3. Lowest yield of 364.50 kg/ha was recorded in WIP plots (caged) with no input of flower visitors, which was significantly inferior to all mode of pollination. The yield 515.30 kg/ha was obtained in plots exposed to natural pollination or open pollination (OP) and 510.41 kg/ha in bee pollination (BP) caged and installed honey bee colony of *Apis mellifera* were statistically at par with each other. Both the treatments (Bee pollination as well as open pollination) enhanced the yield of cumin by 40.03 and 41.37 per cent, respectively over WIP-without insect pollination (control). The maximum yield 520.83 kg/ha was however, recorded in plots sprayed with Bee-attractant (jaggery solution 10%), an increase of 42.88% over WIP and 1.07% and 2.04% over OP and BP, respectively. Yield recorded in plots sprayed with bee attractant was slightly higher than open and bee pollinated plots but statistically at par with each others. The number of seeds per $plant^{-1}$ too recorded a similar trend with the least number of seeds in WIP. The honey bees in cumin (*Cuminum cyminum*) not only increased the production but also produce honey which is viscous, contain higher quantity of iron and unsaturated sugar with attractive aroma [9]. In India, plants of *C. cyminum* caged to exclude insects and plants not caged, yielded 209 and 501 seeds per plant, 0.92 and 1.82 g seeds per plant, respectively [22] are giving similar trend to present work.

The data on test weight (weight of 1000 seeds) of cumin variety GC-4 was also recorded and showed that the average test weight (2.12g) and 2.00 per cent essential oil were recorded in the treatment of bee pollination, wherein plants caged with insect proof nylon net for bee pollination with *A. mellifera* and which was significantly higher than the treatment of without insect pollination-WIP, wherein test weight was 1.78 g and essential oil was 1.46 per cent. It was found that bee pollination also increased the quality of cumin in comparison without insect pollination plots.

Table 3: Effect of insect pollinators on seed yield and quality of cumin under different mode of pollination

Treatment	Seed yield (kg/ha)	Percent change over			Test weight (g)	Essential oil (%)
		WIP	OP	BP		
Control (WIP)-caged	364.50	-	-29.26	-28.58	1.78	1.46
Open pollination (OP)	515.30	41.37	-	-0.96	2.12	2.00
Bee pollination (BP)-caged	510.41	40.03	-0.94	-	2.12	2.00
Bee attractant (Sugar solution 10%)	439.58	19.77	-14.63	-13.87	2.00	1.96
Bee attractant (Jaggery solution 10%)	520.83	42.88	1.07	2.04	2.15	2.02
C D (p= 0.05%)	66.63	-	-	-	0.22	0.38

Conclusion

The study clearly established the contribution of insect pollinators in increasing the seed yield and quality of cumin as cross pollinated crop. Honeybees are the most abundant pollinators and bee pollination the yield of cumin by 40.03% over without insect pollination (control). The maximum foraging activities of pollinators specially honeybees performed between 11.00 to 13.00 hr and farmers apply pesticide during this period and causes of honeybee mortality due to pesticide poisoning is one of the major reason of yield reduction. *A. mellifera* is also one of the most abundant pollinator and it can be considered as manageable pollinator, hence it is recommended to use as an input to increase the productivity in cumin.

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