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Diversity, temporal abundance, foraging behaviour of floral visitors and effect of different modes of pollination on coriander (*Coriandrum sativum* L.)

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Abstract

Studies on spatial distribution, foraging behaviour of pollinators and effect of different modes of pollination on yield of coriander (*Coriandrum sativum)* were undertaken at Karnal (Haryana). Coriander flowers were visited by 34 species of insects belonging to 18 families and 8 orders. Apoidea (35.9%), diptera (47.8%) and other hymenoptera (13.2%) were the three major groups comprising 96.9% of the total visitors. Italian honey bee, *Apis mellifera* was the most prominent species (31.1%) followed by *Episyrphus balteatus* (19.2%) and unidentified Hymenoptera species (10.2%). Honey bees foraged both for nectar and pollen whereas, dipterans and other species for nectar alone. *A. mellifera* started foraging early at 09.05 h, peaked from 11.00 to 16.00 h and declined drastically thereafter. *A. dorsata* peaked at 11.00 h and was not recorded after 14.00 h. *A. cerana* population peaked from 10.00 to 14.00 h and was not recorded after 15.00 h. The syrphid and other dipteran flies were present throughout the day with two peaks, first from 07.00 to 11.00 h and another minor peak late in the afternoon from 15.00 to 18.00 h. *A. cerana* had higher foraging rate (15.2 flower^{-1}) than *A. mellifera* (13.1) and *A. dorsata* (10.6) and likewise visited more number of plants per minute (3.6, 2.7 and 2.1 min^{-1}, respectively). A meagre yield of 6.3 g plant^{-1} was recorded in caged plots without honey bees (control). Yields in open and honey bee pollinated plots were 14.0 g each, with an increase of 122.2% over without insect pollinated plots. Maximum yield was in plots treated with bee attractant Bee-Q (18.1 g plant^{-1}) which was 187.3% higher over without insect pollinated plots and 30.0% higher over open pollinated or bee pollinated plots.

Keywords: coriander, *Coriandrum sativum,* floral visitors, pollination.

Introduction

Coriander (*Coriandrum sativum* L.: Umbelliferae) is a typical xygomorphic, the flower having much reduced five sepals, five petals, five stamens and inferior ovaries consisting of two chambers, each containing one ovule. A fleshy disc (stylopadium) surrounds the ovaries around which nectar is secreted and two short styles emerge from the centre of the disc. Although the flowers are self-fertile the protandrous condition largely prevents self-pollination (McGregor 1976).

Coriander flowers provide both nectar and pollen and are visited by an array of floral visitors. *Apis mellifera* L., *A. cerana* F., *A.*

dorsata F., *A. florea* F. and *Trigona irridipennis* L. are the main pollinators reported in India (Deodikar & Suryanarayana 1977; Shelar & Suryanarayana 1981; Baswana 1984; CCSHAU 2000 & 2001) and *Andrena ovatula* and a hoverfly (*Syrphus corollae)* from Egypt (El-Berry *et al*. 1974). *Prosopis* spp. constituted 46% of the total floral visitors, honey bees 36% and *Andrena* sp. 18% of visitors in Italy (Ricciardelli & Ambrosio 1979). Increase in coriander seed yield in open and bee pollination over caged plots to exclude pollinators have been reported by many researchers (Deodikar & Suryanarayana 1977; Ricciardelli & Ambrosio 1979; Shelar & Suryanarayana 1981; Baswana 1984; Sihag 1986). Barring these studies, no other work on insect pollinators of coriander has been undertaken prompting studies on diversity, temporal abundance and effect of modes of pollination on coriander yield.

Materials and methods

The investigations were undertaken at the Research Farm, Regional Research Station, Karnal (Haryana), of CCS Haryana Agricultural University (29°43′ N latitude, 76^0 58′E longitude, 245 m above MSL) on coriander cultivar DH 5 (a medium bushy variety maturing in 120–130 days) during 1998–99 and 1999–2000. The crop was planted on ridges at a spacing of 30 cm x 20 cm and recommended horticultural practices were undertaken (CCSHAU 1998).

Diversity of floral visitors was studied by sweep-netting the insect visitors throughout the flowering period as per standard protocol. The visitors were identified by comparing with the reference collection maintained at the Apiculture Laboratory of Regional Research Station, Karnal. *A. cerana* were visiting from its natural abodes (from four feral colonies 200 m from the field) whereas, *A. mellifera* were visiting from 20 colonies stationed 100 m from the field. The temporal abundance of insect visitors was studied from 1 m^2 bloom area for a period of 2 min in three replications. Observations were made at 30% to 40% crop flowering at hourly intervals (06.00 to 18.00 h) for 10 calm, clear and sunny days. Foraging rate of the *Apis* foragers under observation was studied by counting the number of umbels visited min^{-1} and in addition, the number of plants visited by the honey bees per min^{-1} was also recorded. Investigations on the impact of different modes of pollination (MOP) on seed yield were made under four modes namely, without insect pollination (WIP), bee pollination (BP) open pollination (OP) and Bee-Q. In WIP, the plants were caged in 16-mesh nylon cages (3.5 m height) and the crop was sprayed with endosulfan 35 EC to eliminate all the insects inside. In BP, a four-frame *A. mellifera* colony was kept inside the net at 10% flowering stage. Plants were exposed to natural pollination in OP. The Bee-Q plots were sprayed with the bee food attractant (manufactured by M/s Custom Chemicides, USA and marketed by Excel Industries Ltd., Mumbai) @ 17 g^{-1} of water. Spraying was done in the morning, at 20% flowering stage using 200 l spray solution and was directed towards the umbels. These treatments were replicated thrice in a plot size of 20 m^2. The yield parameters namely, seed number and weight and 1000-seed weight were recorded.

Results and discussion

Diversity of insect visitors

Coriander flowers were visited by 34 species of insects belonging to 18 families and 8 orders (Table 1). Apoidea (35.9%), Diptera (47.8%) and other Hymenoptera (13.2%) were the three major groups comprising 96.9% of the total visitors. *A. mellifera* was the most dominant species (31.1%) followed by *Episyrphus balteatus* De Geer (19.2%) and unidentified Hymenoptera species 1 (10.2%), *Musca* sp. 1 (9.0%), *Eristalis* sp. 1 (7.7%), *E. arvorum* (4.8%) and *A. cerana* (2.5%). Among the six apoidea species, *A. mellifera* (31.1%) was followed by *A. cerana* (2.5%) and *A. dorsata* (1.9%). Among the other hymenopterans (4 species), unidentified Hymenoptera species 1 (10.2%) was important followed by *Camponotus* sp. (1.4%).

Table 1. Population of insect visitors on coriander

Species	Family	Mean population day^{-1}	Proportion (%) of total visitors
Hymenoptera			
Apoidea			
Apis mellifera L.	Apidae	161.5	31.1
A. dorsata F.	Apidae	10.0	1.9
A. cerana F.	Apidae	13.0	2.5
A. florea F.	Apidae	0.2	0.1
Ceratina sexmaculata Smith	Apidae	0.2	0.1
Trigona irridipennis L.	Meliponeae	2.0	0.4
Total Apoidea		186.8	35.9
Other Hymenoptera			
Unidentified Hymenoptera sp. 1	-	53.0	10.2
Camponotus sp.	Formicidae	7.3	1.4
Polistes hebraceus	Vespidae	2.0	0.4
Unidentified Hymenoptera sp. 2		6.5	1.3
Total other Hymenoptera		68.8	13.2
Total Hymenoptera		255.7	49.2
Diptera			
Episyrphus balteatus De Geer	Syrphidae	105.0	19.2
Episyrphus sp.	Syrphidae	6.5	1.3
Eristalis tenax L.	Syrphidae	6.8	1.3
Eristalis arvorum L.	Syrphidae	24.8	4.8
Eristalis sp. 1	Syrphidae	40.2	7.7
Eristalis sp. 2	Syrphidae	0.5	0.1
Eristalis sp. 3	Syrphidae	1.0	0.2
Eristalis sp. 4	Syrphidae	3.3	0.6
Musca sp. 1	Muscidae	46.7	9.0
Musca sp. 2	Muscidae	3.7	0.7
Musca sp. 3	Muscidae	0.5	0.1
Musca sp. 4	Muscidae	4.8	0.9
Chrysomyia bezziana Vill.	Muscidae	1.8	0.4
Unidentified	Muscidae	0.2	0.1
Bombus sp.	Bombylidae	3.0	0.6
Total Diptera		248.7	47.8
Coleoptera			
Coccinella septumpunctata L.	Coccinellidae	10.7	2.1
Raphilopalpa foevicollis	Chrysomelidae	0.5	0.1
Heteroptera			
Leptocoris augar	Coreidae	1.7	0.3
Lepidoptera			
Lampides boeticus L.	Lycaenidae	0.5	0.1
Pieris brassicae L.	Pieridae	0.2	0.1
Danais chrysippus L.	Danaidae	0.2	0.1
Zygoptera			
Unidentified		0.3	0.1
Spider		0.5	0.1
Unidentified		1.0	0.2
Total others		15.5	3.0
Grand total		519.9	

Diptera was the most diverse group of floral visitors with 15 species contributing 47.8% of the total floral visitors. Eight species of the syrphid flies constituted 35.2% of the total floral visitors and *E. balteatus* was the most dominant (19.2%) among them. Muscidae with six species contributed 11.2% of the visitors and *Musca* sp. 1 was the most important with 9.0% of population.

Coriander flowers were also visited by other insects like *Coccinella septumpunctata* L. (2.1%), spiders and some other unidentified insects with little or no pollination value and the bug *Leptocoris augar* (0.3%) that are in fact injurious to the plants but their proportion was too little to be of significance.

A. mellifera as the most dominant floral visitor of coriander has also been reported earlier from Italy and Haryana (Ricciardelli & Ambrosio 1979; CCSHAU 2000; 2001, respectively) whereas, abundance of *A. cerana, A. dorsata, A. florea* and *Trigona irridipennis* was recorded by Deodikar & Suryanarayana (1977), Shelar & Suryanarayana (1981) and Baswana (1984) from India. The abundance of syrphid flies and wild bees in the present study is supported by the reports of El-Berry *et al*. (1974) from Egypt and Ricciardelli & Ambrosio (1979) from Italy.

Temporal abundance of floral visitors

Data pertaining to most numerically abundant and important nine floral visitors were considered for this study (Table 2). *A. mellifera* was the most abundant floral visitor (12.1 bees $m^{-2}h^{-1}$) over time and space followed by *E. balteatus* (7.8) and unidentified Hymenoptera sp. 1 (4.1). *A. mellifera* started foraging at 09.00 h (3.8 bees m^{-2}), its population increasing exponentially and peaked from 11.00 to 15.00 h (21.2–23.8 bees m^{-2}), declined gradually afterwards to cease completely at 18.00 h. The population of *A. cerana* was at low levels (0.2 bees m^{-2}) at 09.00 h and peaked from 11.00 to 13.00 h (2.0-3.3 bees m^{-2}), declining gradually later and was not recorded after 17.00 h. *A. dorsata* also started foraging at 9.00 h with a peak from 10.00 to 11.00 h (2.7-3.5 bees m^{-2}) declining

Table 2. Temporal abundance of insect visitors on coriander

Insect visitor	Mean population of insect visitors m^{-2} during different hours												
	06.00	07.00	08.00	09.00	10.00	11.00	12.00	13.00	14.00	15.00	16.00	17.00	18.00	Mean
Apis mellifera L.	0.0	0.0	0.0	3.8	14.3	21.2	23	23.2	23.8	22.3	15.8	7.5	2.0	12.1
A. dorsata F.	0.0	0.0	0.0	0.5	2.7	3.5	2.0	0.8	0.5	0.0	0.0	0.0	0.0	0.8
A. cerana F.	0.0	0.0	0.0	0.2	1.8	3.3	3.2	2.0	1.0	0.5	1.0	0.0	0.0	1.0
Unidentified Hymenoptera sp. 1	0.5	1.7	2.3	10.5	11.7	8.5	5.0	4.0	2.8	1.7	2.2	1.2	1.0	4.1
Episyrphus balteatus De Geer	0.2	6.8	11.5	17.8	17.8	7.8	4.0	4.5	4.7	7.3	5.7	8.0	5.8	7.8
Eristalis tenax L.	1.2	1.7	1.2	0.0	0.0	0.2	0.2	0.2	1.2	0.8	0.0	0.2	0.2	0.5
E. arvorum L.	0.0	0.5	1.5	1.7	2.8	2.8	2.3	2.0	1.7	3.5	3.2	2.2	0.7	1.9
Eristalis sp. 1	0.3	12.5	7.5	4.8	2.3	1.0	1.3	2.5	0.8	2.0	2.3	1.5	1.2	3.1
Musca sp. 1	2.2	11.3	8.3	7.5	3.8	0.2	0.3	0.3	1.7	1.8	2.8	3.3	3.5	3.6
Mean	0.4	3.5	3.2	4.7	5.7	4.9	4.2	4.0	2.3	4.0	3.3	2.4	1.4	
SD	0.7	4.9	4.2	5.8	6.4	6.5	6.8	6.9	7.1	6.8	4.7	3.0	1.9	

Table 3. Effect of Bee-Q application on population of insect pollinators on coriander

Species	Mean population observation period^{-1}		Increase (%) in Bee-Q over OP
	OP	Bee-Q	
Apis mellifera L.	18.2	24	31.9
A. dorsata F.	1.2	2.2	83.3
A. cerana F.	1.4	3.3	135.7
Unidentified Hymenoptera sp. 1	1.8	2.4	33.3
Mean of Hymenopterans	5.7	8.0	41.2
Episyrphus balteatus De Geer	11.9	10.9	-8.4
Eristalis tenax L.	0.5	0.3	-40
Eristalis arvorum L.	3.0	3.5	16.7
Eristalis sp. 1	2.7	2.8	3.7
Musca sp. 1	2.1	2.4	14.3
Mean of dipterans	4.0	3.9	-1.5
Overall mean	4.3	5.2	20.7
CD (P=0.05)	0.8	2.4	

OP=Open pollination

later and was absent after 14.00 h.

E. balteatus was present throughout the day, though with low population at 06.00 h (0.2 flies m^{-2}), increasing substantially later and had two peaks, first from 08.00 to 10.00 h (11.5–17.8 flies m^{-2}) followed by a minor peak from 15.00 h onwards. Unidentified Hymenoptera sp. 1 was present throughout the day with peaks from 09.00 to 11.00 h (8.5–11.7 m^{-2}) with a declining trend afterwards.

Temporal presence of honey bees point toward a well-reported phenomenon governed by thermoregulation of honey bee colonies coupled with their peculiar foraging behaviour that is governed by many factors like the time of opening of flower, daily pollen presentation and nectar secretory rhythms, which are species specific (Synge 1947; Percival 1950; 1955). The honey bees during the observation period (winter months of north India) started foraging late only after reaching a temperature threshold at about 09.00 h. The dipterans and other hymenopterans on the other hand are solitary living and were present throughout the day and might also be using coriander plants as nesting sites.

A. mellifera had maximum foraging frequency from 11.00 to 15.00 h whereas for *A. cerana*, it was shorter by 2 hours from 11.00 to 13.00 h only, but strangely it was not recorded after 16.00 h. *A. dorsata* peaked from 10.00 to 12.00 h, but was not recorded after 14.00 h. Different honey bees species are reported to specialize in resource partitioning over time and space and peak their activity with peak amount and concentration of sugars in the nectar and are also guided by resource presentation by plant species concerned as reported by Synage (1947) and Percival (1950; 1955).

The dipterans and other hymenopterans feeding on nectar, only for their body requirement, were present throughout the day and had two peaks, first in the morning hours of 07.00 to 09.00 h and minor peaks late in the afternoon.

Foraging rate of Apis *species*

The mean foraging rate (the number of umbels visited by foragers min^{-1}) was higher in *A. cerana* (15.2) than *A. mellifera* (13.1) and was lowest in *A. dorsata* (10.6). Likewise, *A. cerana* visited more number of flowers min^{-1} (3.7) compared to *A. mellifera* (2.7) and *A. dorsata* (2.1). Shelar & Suryanarayana (1981) also recorded higher foraging rate and plants visited min^{-1} for *A. cerana* (14.5 and 3.2, respectively), but their studies did not include

Table 4. Effect of different modes of pollination on yield of coriander

Treatment	Mean seed weight (g plant^{-1})	Per cent change over			No. of seeds plant^{-1}	Per cent change over			1000-Seed weight (g)
		WIP	OP	BP		WIP	OP	BP	
WIP (Control)	6.3	-	122.2	122.2	459.1	-	105.6	112.3	13.8
OP	14.0	122.2	-	0.0	943.9	105.6	-	112.3	14.9
BP	14.0	122.2	0.0	-	974.5	112.3	-3.2	-	14.1
Bee-Q	18.1	187.3	29.3	29.3	1345.9	193.2	42.6	38.1	13.4
C D (P=0.05)	3.9	-	-	-	279.4	-	-	-	NS

Values are means of 3 replications, 10 plants^{-1} replication; WIP=Without insect pollination; OP=Open pollination; BP=Bee pollination

A. mellifera.

Effect of Bee-Q on floral visitors population

Application of bee attractant Bee-Q resulted in increased orientation of floral visitors towards the coriander bloom (Table 3). The number of total floral visitors increased by 20.7% in Bee-Q plots (5.2 visitors observation periods^{-1}) compared to that under natural conditions or open pollination (4.3 visitors). This increased response however, was group specific for the observed honey bee species but was species specific in dipterans. Bee-Q application was primarily directed to attract the honey bees to the flowers and resulted in their higher proportion (by 41.8%) in Bee-Q (8.0 honey bees observation period^{-1}) over open pollinated plots (5.7 honey bees). Among the different honey bee species, the proportion of *A. mellifera* increased by 31.9% whereas that of *A. cerana* by 135.7%. *A. dorsata* population too increased by 83.3%. It was surprising to record greater increase in less abundant *Apis* species than the most abundant *A. mellifera* which increased by 31.9%. The overall dipteran's population was lower (-1/5%) in Bee-Q treated plots (3.9 visitors observation period^{-1}) than open pollinated plots (4.0 visitors). *E. balteaus* and *E. tenax* registered negative trend (8.4 and 4.0% reduction) in Bee-Q plots whereas, in the rest, the increase was marginal (3.7 to 16.7%).

Yield

The overwhelming contribution of insect pollinators on seed yield of coriander was clear from the study (Table 4). Lowest yield of 6.3 g plant^{-1} was recorded in WIP plots with no input of flower visitors. The yields in plots exposed to natural pollination (OP) and those caged with honey bee colony (BP) were statistically at par with each other (14.0 g plant^{-1} each), and an increase of 122.2% over WIP was observed. The maximum yield was however, recorded in plots sprayed with Bee-Q (18.1 g plant^{-1}), an increase of 187.3% over WIP and 29.3% over OP and BP. The number of seeds per plant^{-1} too recorded a similar trend with the least number of seeds in WIP

(459.1 plant^{-1}), which increased to 943.9 in OP and to 974.5 in BP (increase of 105.6% and 112.3%, respectively over WIP). Maximum number of seeds, however, were recorded in Bee-Q plots (1345.9 plant^{-1}), an increase of 193.2%, 42.6% and 38.1% over WIP, OP and BP, respectively. The differences in 1000-seed weight due to insect pollination were, however, non-significant. The present study finds the support of Shelar & Suryanarayana (1981), Sihag (1986) and Lafreniere (1997) who also reported yield increase in OP and BP over WIP. The 1000-seed weight in the present study was comparable in different treatments, whereas, Sihag (1986) reported heavier seed in caged plots (15.8 g) compared to OP (12.8 g).

The study clearly established the contribution of insect pollinators in increasing the seed yield of coriander and the application of bee attractant Bee-Q resulted in additional increment of 29.3% over open pollination. *A. mellifera* being the most abundant pollinator and in most cases the only manageable pollinator, is therefore recommended to be used as an input to increase productivity in coriander.

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