Fennel, *Foeniculum vulgare* as banker crop for syrphids to promote aphidophagy and myophily

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A study was conducted to document the pollination index of syrphid flies and to record the natural incidence of syrphid larvae on fennel aphid, *Hyadaphis coriandri*. Five different species of syrphid flies, viz. *Episyrphus balteatus*, *Ischiodon scutellaris*, *Paragus serratus*, *Dideopsis aegrota* and *Betasyrphus linga* were recorded in the flowers of fennel. *E. balteatus* ranked first in the order of pollination index. The natural incidence of larvae of *D. aegrota* was significantly higher in the umbels infested with *H. coriandri*. The results of the study confirmed the possible utility of fennel as a banker crop for the natural proliferation of syrphid predators.

Keywords: Fennel, natural predation, pollination index, syrphid.

FENNEL is an important spice crop belonging to the family Apiaceae and cultivated as '*rabi* crop' in India. The flowers of fennel are small, bright yellow in clusters borne on flat umbels. Fennel is an entomophilous crop that attracts a wide range of beneficial insects and is reported to be recommended as a 'magnet species or framework plant'[1]. Syrphid flies, commonly referred to as flower flies or hover flies, are an important group of Dipteran pollinators gaining particular interest as beneficial species, and alternative managed pollinators[2]. Adult flies visit the flowers of different crops to meet their nutritional needs and have specialized foraging behaviours and a capacity for floral constancy. Syrphid flies can efficiently handle and pollinate smaller-sized flowers that bloom in groups like onion, mustard and several other crop plants. The body of these flies is hairy and can easily pick up the pollen from the flowers and move actively between the flowers resulting in efficient pollen transfer.

On the other hand, larvae of syrphids are efficient predators of aphids infesting many crops[3]. Aphidophagous syrphids are reported to oviposit in relation to aphid density in the crops, and the hatching larvae predate efficiently over the aphid colonies limiting outbreaks in the aphid population. The aphid, *Hyadaphis coriandri* is a major sucking pest infesting fennel causing economic loss to the crop and reducing the seed yield and marketability of the seeds[4]. The nymphs and adults congregate in large numbers in the apical shoots and umbels and suck the sap, resulting in poor and shrivelled seed formation.

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Increasing crop diversity by providing host plants for the natural proliferation of beneficial insects is an emerging concept in insect pest management. As syrphids provide dual benefits, viz. larvae as aphid predators and adults as pollinators, the present study is aimed at understanding the diversity of larvae and adult flies of syrphids in fennel that aids in possible utilization of fennel as a 'banker crop' in cropping systems for the natural proliferation of larvae and adults of syrphids.

The present study was carried out in the ICAR-National Bureau of Agricultural Insect Resources (NBAIR) experimental farm Yelahanka Campus, Bengaluru, India (13.096792N, 77.565976E), from December 2021 to March 2022. The experiment was conducted in a plot size of 15 m × 15 m in fennel (local variety) in an area of 0.25 acres.

The number of syrphid flies visiting the flowers of fennel was recorded during the peak flowering time (February to March 2022) for a period of 10 sunny days. The number of umbels visited by the syrphid flies per 10 min was recorded to determine the foraging rate. The foraging speed, i.e. time spent by the flies per umbel in seconds, was recorded. Five live specimens of each foraging fly species were collected using the sweep nets in the collection vials and brought to the laboratory. The sampled flies were killed using ethyl acetate and mounted using insect pins. The mounted flies were observed under the microscope (Model Olympus SZX7, Japan) for pollen grains in their body parts. The different body parts of the flies where the pollen grains were observed were recorded.

The umbels of fennel infested with *H. coriandri* were observed for the presence of larvae of syrphids at weekly intervals for 30 days. The number of syrphid larvae per umbel was recorded. Ten larvae of each species of syrphid were collected along with the aphid-infested umbels in the collection dish (9 × 4 cm) fitted with mesh and brought to the laboratory. The mean number of *H. coriandri* consumed per day by the different species of larvae of syrphids was recorded. The per cent pupation and adult emergence of different species of syrphids were also recorded.

The comparative pollination efficiency of the most abundant flower-visiting syrphid flies was studied in fennel by recording various parameters, viz. the number of loose pollen grains on their body, rate of foraging (number of flowers visited/10 min), foraging speed (time spent per umbel in seconds) and abundance of foraging fly (number of flies/m^2/5 min). The pollen grains on the body of the flies were counted by randomly collecting 10 individuals during their peak activity (morning hours). The collected flies were shaken vigorously in 70% ethanol to remove the entire pollen from the body of the fly. The volume of ethanol was made up to 5 ml and 1 ml of aliquot was taken, and the number of pollen grains was counted using the hemocytometer.

Analysis of variance (GLM in SAS 9.3; SAS Institute, Cary, NC) was used to compare the abundance, foraging rate, foraging speed, number of pollen grains in the body of syrphid adults, number of syrphid larvae/umbel, predation

Table 1. Foraging speed, foraging rate and number of loose pollen grains on the body of five different species of syrphid flies in fennel

Syrphid species	Foraging speed (time spent per umbel in seconds)	Foraging rate (number of umbels visited/10 min) (mean ± SE)	Number of pollen grains on the body of the fly (mean ± SE)
Episyrphus balteatus	3.90 ± 1.08b	6.20 ± 1.64b	279.0 ± 29.09a
Ischiodon scutellaris	5.80 ± 2.28a	9.60 ± 0.55a	267.80 ± 56.70a
Paragus serratus	3.24 ± 0.13bc	4.40 ± 2.88b	135.80 ± 45.00b
Dideopsis agerota	1.40 ± 0.55d	3.40 ± 3.21b	180.68 ± 39.16b
Betasyrphus linga	2.00 ± 1.22cd	4.00 ± 2.74b	281.20 ± 44.77a
F value	8.99	5.74	13.53
P value	$P < 0.001$	$P < 0.001$	$P < 0.001$

Table 2. Pollination index of five different species of syrphid flies foraging in fennel

Syrphid species	Rank assigned on the basis of: Foraging speed (time spent per umbel in seconds)	Foraging rate (number of umbels visited/10 min)	Number of pollen grains on the body of the fly (mean ± SE)	Average score	Relative abundance (syrphids/m^2/5 min)	Pollination index (rank)
E. balteatus	2	2	2	2.00	8.40 ± 1.14a	16.80 (1)
I. scutellaris	1	1	3	1.67	6.20 ± 1.64b	10.35 (2)
P. serratus	3	3	5	3.67	2.00 ± 1.22c	7.34 (4)
D. agerota	5	5	4	4.67	1.60 ± 1.51c	7.47 (3)
B. linga	4	4	1	1.28	2.00 ± 1.58c	2.56 (5)

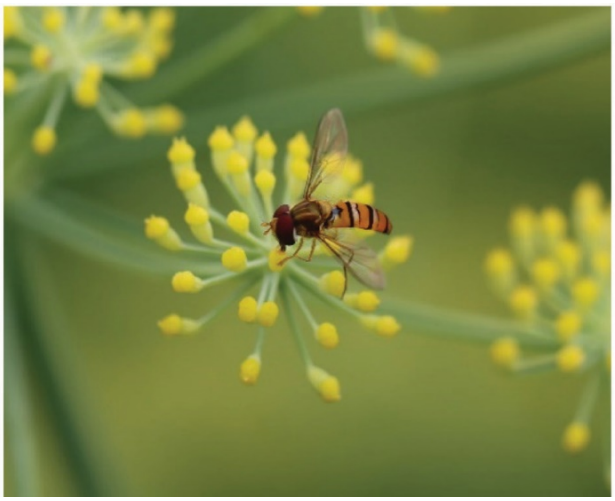

Figure 1. *Episyrphus balteatus* foraging in fennel flowers.

rate of syrphids and per cent pupation of syrphid larvae. Where significant difference was detected, treatment means were separated using Tukey's HSD Test (0.05%). The five species of syrphids were scored with respect to their foraging rate, foraging speed, and number of loose pollen grains in their body and the average score was calculated. The pollination index was worked out by taking the product of the abundance of the syrphid flies with the average score of foraging parameters of the five species of the syrphid flies.

The abundance of syrphid flies, foraging rate (number of umbels visited by the flies/5 min), foraging speed (number of umbels visited/5 min), and number of loose pollen grains carried by the foraging fly in its body were recorded (Table 1). Five different species of hoverflies, viz. *Ischiodon scutellaris*, *Episyrphus balteatus*, *Dideopsis aegrota*, *Betasyrphus linga* and *Paragus serratus* visited the umbels of fennel during the period of observation. A significant difference was observed in the foraging rate between these five species of syrphid flies, i.e. F value = 5.74; $P < 0.001$. The number of umbels visited per 10 min by the five species of syrphids, *I. scutellaris*, *E. balteatus*, *D. aegrota*, *B. linga* and *P. serratus* were 9.60 ± 0.55, 6.20 ± 1.64, 3.40 ± 3.21, 4.00 ± 2.74 and 4.40 ± 2.88 respectively. A significant difference (F value = 8.99; $P < 0.001$) in the foraging speed of these five species was observed. The foraging speed in terms of time spent in each flower in seconds by *I. scutellaris*, *E. balteatus*, *D. aegrota*, *B. linga* and *P. serratus* was 5.80 ± 2.28, 3.90 ± 1.08, 1.40 ± 0.55, 2.00 ± 1.22 and 3.24 ± 0.43 respectively. The foraging flies were observed to carry the pollen grains on their different body parts, viz. mouth parts, legs and abdomen. The number of loose pollen grains adhering to the foraging syrphid flies differed significantly between the species (F value = 13.53; $P < 0.001$). The mean number of loose pollen grains on the body was significantly higher in the adult *B. linga* (281.20), which was statistically at par with *E. balteatus* (279.00) and *I. scutellaris* (267.80). The number of pollen grains on the body of *D. aegrota* (180.68) and *P. serratus* (135.80) was statistically at par.

The most abundant syrphid fly visitor was *E. balteatus* (8.40 ± 1.14/m^2/5 min), followed by *I. scutellaris* (6.20 ± 1.64/m^2/5 min) (Table 2). The relative abundance of adult foraging flies of *B. linga* (2.00 ± 1.58/m^2/5 min), *P. serratus* (2.00 ± 1.22/m^2/5 min) and *D. aegrota* (1.60 ± 1.51/m^2/5 min) were statistically at par with each other. The pollination index of *E. balteatus*, *I. scutellaris*, *P. serratus*, *D. aegrota* and *B. linga* was 16.80, 10.35, 7.34, 7.47 and 2.56

Table 3. Natural occurrence of syrphid predator in fennel inflorescence infested with *Hydadaphis coriandri*

Syrphid species	Number of larvae observed per infested umbel	Mean number of *H. coriandri* preyed per day	Percent pupation
E. balteatus	1.90 ± 0.74b	74.20 ± 12.61bc	92.00a
I. scutellaris	2.20 ± 1.03b	62.40 ± 9.38c	90.00a
P. serratus	1.80 ± 0.63b	44.40 ± 13.93d	66.21b
D. agerota	4.30 ± 1.42a	80.60 ± 9.13b	96.10a
B. linga	1.40 ± 0.51c	97.40 ± 4.33a	100.00a
F value	15.83	18.14	13.95
P value	$P < 0.001$	$P < 0.001$	$P < 0.001$

Figure 2. Larva of *Betasyrphus linga* feeding on *Hyadaphis coriandri.*

respectively. The descending order of the pollination index of the five species of syrphid flies in fennel was *E. balteatus* > *I. scutellaris* > *D. aegrota* > *P. serratus* > *B. linga* (Figure 1).

Five different species of larvae of the syrphids, *I. scutellaris*, *E. balteatus*, *D. aegrota*, *B. linga* and *P. serratus* were observed to feed on the colonies of *H. coriandri* (Table 3). A significant difference was observed between the number of larvae of syrphids recorded in the colonies of *H. coriandri* (F value = 15.83; $P < 0.0001$). The mean number of larvae of *I. scutellaris*, *E. balteatus*, *D. aegrota*, *B. linga* and *P. serratus* observed per umbel was 1.90 ± 0.74, 2.20 ± 1.03, 1.80 ± 0.63, 4.30 ± 1.42 and 1.40 ± 0.52 respectively.

The mean number of *H. coriandri* consumed per day by different species of syrphids differed significantly (F value = 18.14; $P < 0.0001$) (Table 3). The larvae of *B. linga* (97.40 ± 4.33 aphids/day) (Figure 2) consumed a significantly greater number of *H. coriandri* followed by *D. aegrota* (80.60 ± 9.13 aphids/day), *E. balteatus* (74.20 ± 12.61 aphids/day), *I. scutellaris* (62.40 ± 9.38 aphids/day) and *P. serratus* (44.40 ± 13.93 aphids/day). There was a significant difference in the percent pupation of the larvae of these syrphids species reared on *H. coriandri* (F value = 13.95; $P < 0.0001$). The mean percent pupation was observed to be the highest in *B. linga* (100%), followed by *D. aegrota* (96.17%), *E. balteatus* (92.10%), *I. scutellaris* (90%) and *P. serratus* (66.21%).

The flowers of fennel were visited by five different species of adult syrphid flies. The bright yellow-coloured flowers of the fennel might also be a reason that attracted a greater number of hoverflies. Among the five different species, *E. balteatus* was observed to be the most abundant, followed by *I. scutellaris*. Marked foraging preference of *E. balteatus* towards the yellow-coloured flowers was well reported[5]. Plants belonging to the family Apiaceae possess flat umbels with coloured flowers and were reported to be visited by insects from numerous taxa, predominantly by flies. In Apiaceae crops, viz. *Carum carvi* L. and *Coriandrum sativum* L., about 224 specimens of syrphid flies were reported, among which *E. balteatus* (Deg.), *Sphaerophoria sciripta* (L.), *Syrphus vitripennis* Meig. and *Eupeodes corollae* (Fab.) were predominant[6]. *E. balteatus* was the most predominant species of syrphids in fennel, followed by *Eristalis tenax* and *E. arvorrum*[7].

The quantum of loose pollen grains carried by the adult foraging hoverfly, *B. linga* was the highest, followed by *E. balteatus*, and *P. serratus* carried the lowest number of loose pollen grains in its body. The reason could be attributed to the smaller size of *P. serratus* compared to all other species of syrphids. The pollen load carried by the insects may vary with their body size. Intercropping carrots with other Apiaceae plants like *Coriandrum sativum* and *Satureja hortensis* harboured a large number of syrphid flies that decreased the incidence of pest insects in carrots[8]. In the current study, the pollination index of *E. balteatus* was higher, followed by *I. scutellaris,* compared to other species of syrphids. Though the number of loose pollen grains carried by *E. balteatus* was significantly lesser than *B. linga*, the abundance and higher foraging rate and foraging speed might have accounted for the higher pollination index of *E. balteatus*. *E. balteatus* stood first in the pollination index, followed by *Eupeodes frequens* in mustard[9]. Our results suggested that fennel could be used as a 'cover crop or banker crop' for increasing the abundance of adult syrphid flies in crops where myophily is the mode of pollination.

The abundance of larvae of *B. linga* in the colonies of *H. coriandri* was significantly higher compared to other species of syrphids. Conversely, the abundance and foraging rate of adult flies of *B. linga* in the flowers of fennel was

significantly lower compared to other species of syrphids. Adult flies of *B. linga* were observed to hover around the colonies of *H. coriandri* compared to flowers that might have resulted in greater oviposition which is evident from a significantly higher number of *B. linga* larvae amidst the colonies of *H. coriandri*. Indeed, the larvae of *E. balteatus* and *D. aegrota* were also observed in several species of weeds infested with aphids bordering the fennel crop. The authors also noticed similar observations of a significantly greater number of *B. linga* larvae compared to the larvae of *I. scutellaris*/*E. balteatus* in the mustard crop infested with aphids (Amala *et al*. unpublished data).

The mean number of *H. coriandri* consumed by *B. linga* was significantly higher compared to other species of aphids. Interestingly, the larvae of *B. linga* were observed in umbels fully infested with *H. coriandri* compared to other species of syrphid larvae, i.e. *E. balteatus*, *I. scutellaris*, *D. aegrota* and *P. serratus* which were observed in umbels with a moderate infestation of *H. coriandri*. The occurrence of a significantly greater number of *B. linga* larvae in the highly aphid-infested umbels of fennel indicated the food selection attribute of the adult syrphid fly that ensures an enhanced rate of survival with ample food (aphid) source. Oviposition of adult insects near suitable ample food sources increase the fitness attribute of predators. Co-occurrence of egg mass of coccinellids with the larvae of syrphids (*E. balteatus*, *I. scutellaris*, *D. aegrota* and *P. serratus*) was observed in the umbels of fennel with less to a moderate infestation of *H. coriandri*. The percent pupation was lowest in *P. serratus,* which could be directly correlated with the lowest amount of prey (*H. coriandri*) intake by *P. serratus* compared to other species of syrphids. The prey quantity intake directly impacting the per cent pupation of coccinellid predator *Coccinella transversalis* F. was reported where aphid prey consumed by the coccinellid in scarce and optimum quantity recorded a per cent pupation of 65% and 79% respectively[10]. The observations clearly suggested that fennel supports the natural multiplication of coccinellid beetles in addition to predatory syrphids.

The coexistence of both ladybird beetles and syrphids in aphid colonies and larvae of both predators strongly interact with each other during the circumstances of low food sources. The ovipositing females of syrphid flies were reported to locate even smaller colonies of aphids. The hatching larvae of the syrphids were voracious feeders of aphids with a brief prey handling time and higher rates of reproduction. The umbels infested with the colonies of *H. coriandri* had copious honeydew secreted by the aphids. Honeydew as a source of sugar in the infested umbels of fennel might be the reason that attracted the adult syrphids for feeding. Honeydew is a vital food source for the host searching syrphids during oviposition. Fennel predominantly was reported to attract coccinellids and syrphids and hence recommended for beneficial flower strips in the Czech Republic[11]. The natural abundance of larvae of syrphids in fennel indicated that the crop could be used as a 'banker plant' for the natural proliferation of syrphids in the crops prone to aphid infestation.

The results of the present study indicated that syrphid flies provide a dual advantage to fennel crop, with adult flies as pollinators and larvae as predators of *H. coriandri*. Fennel could also be used as a 'banker plant' providing supplementary food for beneficial insects in a biocontrol pest management programme in certain crops like pulses and cole crops where aphids cause economic damage. Also, fennel helps conserve and proliferate aphidophagous syrphids in cropping systems.

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ACKNOWLEDGEMENT. We acknowledge the financial support received under the DST-SERB Core Research Grant: CRG/2021/006479 for carrying out the research work.

Received 10 January 2023; revised accepted 22 March 2023

doi: 10.18520/cs/v124/i12/1469-1472