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Study of foraging behaviour of syrphids *viz. Episyrphus balteatus* (De Geer) *and Eupeodes frequens* (Matsmura) (Diptera: Syrphidae) on mustard bloom (*Brassica juncea* L.: Cruciferae) under mid hill conditions

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Abstract
The present study was carried out in the Farm of Department of Entomology, UHF Nauni, Solan (India) on Indian mustad (*Brassica juncea* L.). Hoverflies are important pollinators and play an important role in cross pollination in mustard. To determine the pollination efficiency of syrphids *viz. Episyrphus balteatus* (De Geer) and *Eupeodes frequency* (Matsmura), different parameters *viz.* foraging rate, foraging speed, relative abundance and loose pollen grains adhering to the body of forager were recorded under open field conditions on Indian mustard bloom (*Brassica juncea* L.). Foraging rate, foraging speed, relative abundance loose pollen grains was recorded as 8.26 flowers/min, 6.45 sec/flower, 5.21 syrphids/ m^{2}/5min and 475.60 pollens per forager, respectively for *E. balteatus* and these for *E. frequens* was 11.20 flower/min, 4.68 sec/flower, 3.51 syrphids/m^2/5min and 305.40 pollens/forager, respectively. *E. balteatus* showed a higher pollination index (6.93) than *E. frequens* (5.83), hence, *E. balteatus* ranked higher than *E. frequens* in study of comparative pollination efficiency.

Keywords: Syrphids, hoverflies, *Episyrphus balteatus*, *Eupeodes frequens*, Indian mustard, *Brassica juncea*, pollination efficiency, foraging rate, foraging speed, relative abundance, loose pollen grains

1. Introduction
Among the various aphidophagous syrphid flies, *Episyrphus balteatus* (De Geer) and *Eupeodes frequens* (Matsmura) are most common and predominant species worldwide in the agriculture ecosystem (Sadeghi) [18]. As identification marks, *E. balteatus* adults are bright colored, normally orange-yellow abdomen with black strips on body and *E. frequens* adults black colored abdomen with bright yellow bands (Beeraganni *et al.*) [3]. Honeydew of cabbage aphids enhances the survival of the adult hover flies, and can be an important food source when the syrphids are searching within the crop for oviposition sites (Paul *et al.*) [15].
In mid hill region of Himachal Pradesh *E. frequens* has been found to predate upon *B. brassicae* infesting cauliflower (Sharma *et al.*) [23]. *E. frequens* also has ability to forage for aphid colonies and it is one of the few species which is capable of crushing pollen grains for feed.
The hoverfly *E. balteatus* (Family: Syrphidae) is one of the most common insect in south Asia and other parts of the world. The larvae of the species are predators of more than 100 aphid species worldwide (Sadeghi and Gilbert) [18]. Thus it has predatory potential and plays an important role in the biological control of aphids in the natural agro ecosystem.
The rising global food demand and reports on decline in managed and wild pollinators is a significant threat to the production of insect-dependent crops. Over the last fifty years, globally the proportion of agricultural land subjected to the pollinator dependent crops has increased (Aizen *et al.*) [1]. *B. juncea* is a self-incompatible crop due to which flowers cannot utilize their own pollen and need biological agents like different insect species for transfer of the pollen from male flowers to the female flowers (Roy *et al.*) [17]. Hence, insect pollinators are very important source of pollination for producing seeds and to get optimum yield (Devi *et al.*) [7]. Adults of syrphid species cross pollinate oil seed crops and the plants pollinated by *E. balteatus* and *Eupeodes* sp. produce significantly higher number of seeds per siliqua and yield per plot (Jauker and Wolters) [13].

Thus, the adults of *E. balteatus* and *E. frequens* have strong ability to forage for aphid colonies, pollens and nectar. They are capable of crushing the pollen grains for feed and have proved themselves as efficient pollinators (Veen) [26].

2. Materials and methods

2.1 Pollination Efficiency of Syrphids on mustard

Pollination efficiency of *E. balteatus* and *E. frequens* was worked out on the basis of following parameters:

Note: all the parameters were recorded under open field conditions on mustard bloom during sunny days.

2.2 Foraging rate

Foraging rate of syrphids was recorded in terms of the number of flowers visited per minute by one individual, for each observation one syrphid fly was followed for one minute using stopwatch and number of flowers visited by that particular individual were recorded. These observations were taken at different hours of the day *viz.* 0900 -1000, 1200-1300, 1500-1600 hour intervals for 7 sunny days (5 replications) on mustard bloom.

2.3 Foraging speed

Foraging speed of syrphids was recorded in terms of time (seconds) spent by individual fly on each flower with the help of stop watch, 20 observations were taken for each syrphid fly at different hours of the day *viz.* 0900 -1000, 1200-1300, 1500-1600 hour intervals up to 7 sunny days (5 replications) on mustard bloom.

2.4 Loose pollen grains

The number of loose pollen grains adhering to the body of syrphid flies were determined by capturing the syrphids foraging over the mustard bloom with the help of forcep to avoid shaking of body and killed immediately in measured quantity (2ml) of 70 percent alcohol in a glass vial and shaken well to wash out the loose pollen grains out from its body into the liquid. Now syrphid was removed from the vial and the liquid containing pollen gains was observed under microscope over counting dish and number of pollen grains were counted.

2.5 Relative abundance

Relative abundance of syrphid flies was determined in the terms of number of syrphids visiting per meter square area per 5 minutes. These observations were made on 5 randomly selected bloom areas, the marked area was observed visually for 5 minutes (each replication) and number of syrphids visited that area, were recorded. These observations were taken on mustard bloom under open field conditions during different day hours *viz.* 0900 -1000, 1200-1300, 1500-1600 hour intervals up to 7 sunny days (5 replications) on mustard bloom.

Pollination efficiency was assessed on the basis of their relative abundance and foraging behaviour *viz.*, foraging speed, foraging rate and number of loose pollen grains adhering to their body. In order to have fair assessment, rating was assigned and calculated by following way:

- The minimum time spent per flower was given the highest rank and vice-versa.
- The maximum flowers visited per minute was given the highest rank and vice-versa.
- The syrphid species carrying the maximum number of loose pollen grains was given the highest rank and lowest rank was assigned to syrphid species with the least number of loose pollen grains adhering to the body.

Average efficiency rating thus obtained was multiplied by the mean population of each pollinator in order to obtain the pollination index. (Bohart and Ney; Bakshi) [6, 2]

2.6 Data analysis

The data recorded on various parameter was analysed statistically using suitable transformation (where needed) in Randomized block design (RBD). Analysis of variance for the experiment was done as per the model suggested by Panse and Sukhatme [14]. The data to be recorded was analysed using MS-Excel, OPSTAT and SPSS 16.0.

3. Results

The pollination efficiency of syrphids was recorded on mustard under field conditions. It was worked out by recording different parameters as under:

3.1 Foraging rate of *Episyrphus balteatus* and *Eupeodes frequens* on mustard bloom during different day hours

The data on foraging rates (number of flowers visited/min) by *E. balteatus* and *E. frequens* on mustard bloom is presented in Table 1 *E. frequens* visited more number of flowers (11.20 flowers/min) than *E. balteatus* 8.26 (flowers/min).

Among the species statistically maximum flowers visited per minute were for *E. frequens* (13.40 flowers/min) at 1200-1300hr followed by (10.86 flowers/min) at 1500-1600hr by same species followed by *E. balteatus* (9.94 flowers/min)) at 1200-1300hr. Whereas, statistically minimum foraging rate (6.37 flowers/min) was observed for *E. balteatus* at 0900-1000hr followed by *E. balteatus* (8.49 flowers/min) at 1500-1600hr which is statistically similar to *E. frequens* (9.34 flowers/min) at 0900-1000hr.

Irrespective of species, the statistically maximum foraging rate was recorded at 1200-1300hr (11.67 flowers/min) followed by (9.67 flowers/min) at 1500-1600hr and (7.86 flowers/min) at 0900-1000hr.

Table 1: Foraging rate of *Episyrphus balteatus* and *Eupeodes frequens* on mustard bloom during different day hours

Day hours	Number of flowers visited per minute		Mean
	E. balteatus	*Eupeodes frequens*	
0900-1000	6.37	9.34	7.86
1200-1300	9.94	13.40	11.67
1500-1600	8.49	10.86	9.67
Mean	8.26	11.20	
$CD_{0.05}$ Species = 0.27, Day hours = 0.33, Species x Day hours = 0.47			

3.2 Foraging speed of *Episyrphus balteatus* and *Eupeodes frequens* on mustard bloom during different day hours

The data presented in Table 2 reveals that the time spent per flower by two syrphid species differed significantly. *E. balteatus* spent significantly more time (6.45 sec/flower) than (4.68 sec/flower) by *E. frequens.*

The interaction effect of species and day hours indicated that *E. balteatus* spent statistically maximum time of (8.77 sec/flower) at 0900-1000hr followed by (6.02 sec/flower) at 1500-1600hr by the same species which was statistically at par with *E. frequens* (5.77 sec/flower) at 0900-1000hr, whereas, statistically minimum time spent per flower (3.71 sec/flower) was observed for *E. frequens* at 1200-1300hr

followed by (4.56 sec/min) and (4.55 sec/min) for *E. balteatus* and *E frequens* at 1200-1300hr and 1500-1600hr, respectively.

Irrespective of syrphid species, statistically maximum time spent per flower was recorded at 0900-1000hr (7.27 sec/flower) followed by (5.29 sec/flower) at 1500-1600hr and (4.13 sec/flower) at 1200-1300hr.

Table 2: Foraging speed of *Episyrphus balteatus* and *Eupeodes frequens* on mustard bloom during different day hours

Day hours	Time spent per flower (seconds)		Mean
	E. balteatus	*E. frequens*	
0900-1000	8.77	5.77	7.27
1200-1300	4.56	3.71	4.13
1500-1600	6.02	4.55	5.29
Mean	6.45	4.68	
CD $_{0.05}$ Species = 0.22, Day hours = 0.28, Species x Day hours = 0.39			

3.3 Relative abundance of *Episyrphus balteatus* and *Eupeodes frequens* on mustard bloom during different day hours

The results on abundance of *E. balteatus* and *E. frequens* during different day hours on mustard bloom is presented in Table 3 *E. balteatus* was found significantly most abundant visitor with a mean population of (5.21 syrphids/m^2/5min) than *E. frequens* (3.51 syrphids/m^2/5min).

The interaction effect of syrphid species and day hours revealed that the statistically maximum abundance of 7.08 syrphids/m^2/5min was observed for *E. balteatus* at 0900-1000hr followed by 5.05 syrphids/m^2/5min at 1500-1600hr for the same species and 4.62 syrphids/m^2/$5m^2$ for *E. frequens*. Whereas, statistically minimum abundance (2.31 syrphids/m^2/5min) was recorded at 1200-1300hr for *E. frequens* followed by *E. balteatus* (3.51 syrphids/m^2/5min) at 1200-1300hr which was statistically at par with *E. frequens* (3.60 syrphids/m^2/5min) at 1500-1600hr.

Irrespective of species, maximum number of syrphid visits were observed during 0900-1000hr with mean population (5.85 syrphids/m^2/5min) followed by (4.32 syrphids/m^2/5min) at 1500-1600hr and (2.91 syrphids/m^2/5min) at 1200-1300hr.

Table 3: Relative abundance of *Episyrphus balteatus* and *Eupeodes frequens* on mustard bloom during different day hours

Day hours	Number of syrphids/m^2/5min		Mean
	E. balteatus	*E. frequens*	
0900-1000	7.08	4.62	5.85
1200-1300	3.51	2.31	2.91
1500-1600	5.05	3.60	4.32
Mean	5.21	3.51	
CD $_{0.05}$ Species = 0.23, Day hours = 0.29, Species x Day hours = 0.41			

3.4 Number of loose pollen grains adhering to the body of syrphids foraging on mustard bloom

The data on the number of loose pollen grains sticking to the body of syrphids is presented in Table 4 The number of loose pollen grains sticking to the body of *E. balteatus* varied from 430-520 pollens grains, whereas, for *E. frequens* it varied from 290-340 pollens grains. *E. balteatus* had more average number of loose pollen grains (475.5 pollen grains) on their body than *E. frequens* (305.4 pollen grains).

Table 4: Number of loose pollen grains adhering to the body of syrphids foraging on mustard bloom

Specimen	Number of loose pollen grains/forager	
	E. balteatus	*E. frequens*
1	430	312
2	470	340
3	520	305
4	508	280
5	450	290
Mean± SE	475.6±17.3	305.4±10.5

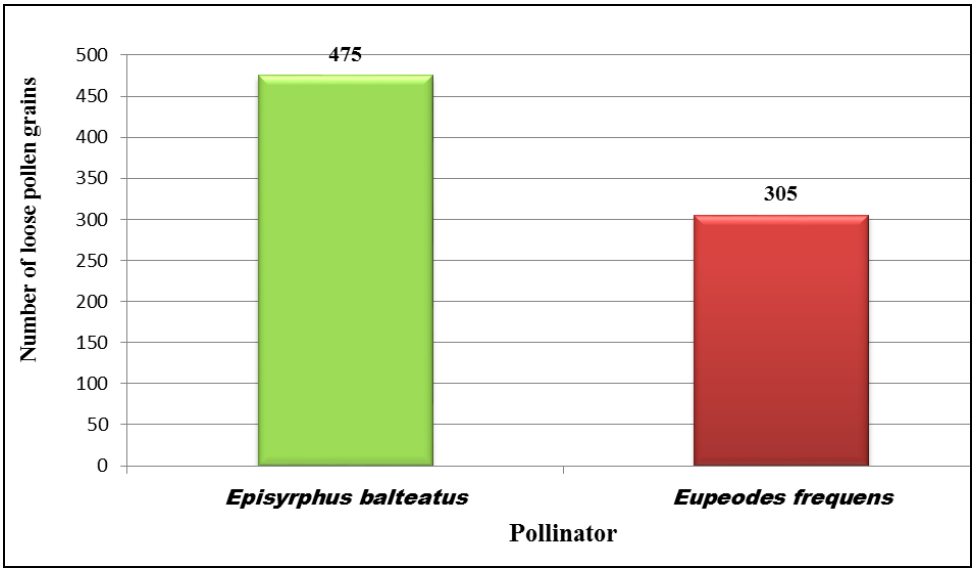

Fig 1: Number of loose pollen grains adhering to the body of syrphids foraging on mustard bloom

3.5 Comparative pollination efficiency of *Episyrphus balteatus* and *Eupeodes frequens* on mustard bloom

The data on pollination efficiency of two species of syrphids *viz. E. balteatus* and *E. frequens* foraging on mustard bloom is presented in Table 5. revealed that *E. balteatus* attained higher rank than *E. frequens*, indicating (6.93) and (5.83) pollination index for *E. balteatus* and *E. frequens*, respectively. No literature is available on pollination indices of syrphids on mustard bloom. Dev (2010) assigned (3.99) pollination index for *E. balteatus* on apple bloom. Whereas, Bakshi (2015) worked out (6.26) pollination index for *E. balteatus* on cherry bloom.

Table 5: Comparative pollination efficiency of *Episyrphus balteatus* and *Eupeodes frequens* on mustard bloom

Pollinator	Rank assigned on the basis of statistically analysis/efficiency			Average score	Relative abundance (syrphids/m^2/5min)	Pollination index
	Foraging rate	Foraging speed	Loose pollen grains			
E. balteatus	1*	1	2	1.33	5.21	6.93(2)
E. frequens	2	2	1	1.66	3.51	5.83(1)

* Figures in parentheses are rank assigned

4. Discussion

In the present study it was observed that *E. frequens* visited a statistically maximum number of flowers (11.20 flowers/min) than *E. balteatus* (8.26 flowers/min). There was no any previous study was reported on comparative foraging behaviour of these syrphid species. Devi *et al*. [7] conducted an experiment in which foraging rate of 17.42 flowers/min for syrphid flies (*E. balteatus*) was reported on mustard bloom which is more or less in agreement with present findings.

Bakshi [2] reported that *E. balteatus* visited 3.72 flowers/min of cherry crop which is very less as observed in the present study which could be due to the high dense inflorescence of mustard, which is different from the present findings because of variation in the environmental variations with the time.

A study conducted by Sharma and Rana [21] reported that the average number of flowers visited per minute by *E. balteatus* was 1.57, respectively on cherry bloom. The discrepancy in the present study would be because of the different floral resource. Further, the number of flowers visited per minute by any type of pollinator species depends upon the number of factors including instinctive foraging behavior, length of proboscis, floral structure particularly the corolla depth, type, density of flowers on the particular cultivar of the crop concerned and hours of the day.

In the present study it was observed that syrphids visited a maximum number of flowers during the afternoon hours (1200-1300hr) followed by evening (1500-1600hr) and morning (0900-1000hr). These findings are in agreement with those of Emtia and Ohnu [9], who reported *E. balteatus* as predominant hoverfly on phacelia (*Phacelia tanacetifolia*) and the frequency of approaching to probing was lower in the morning compared to that in the afternoon this may be explained by longer feeding which lowered the frequency of approaching the flowers of phacelia.

In the present study the average foraging speed of 6.45 sec/flower was recorded for *E. balteatus* which is more or less in agreement with the findings of Bakshi [2] who reported the foraging speed of *E. balteatus* foraging over cherry bloom as 5.94 sec/flower. Time spent per flower by insect pollinator depends upon the floral structure and length of proboscis of insect pollinator. Mustard flowers are bowl shaped and small in size than cherry flowers so that the handling time by syrphids is very less and spent less time on each floral bud.

In the present findings it was observed that syrphids spent maximum time on each flower during morning hours (0900-1000hr), followed by evening hours (1500-1600hr) and minimum at afternoon hours (1200-1300), similar observations were reported by Emtia and Ohno [9] who reported that *E. balteatus* foraged on phacelia (*P. tanacetifolia*) flowers longer to maximize energy intake in the morning, while in the afternoon it spends less time on each flower.

In the present experiment E. balteatus was observed as more abundant syrphid fly over mustard bloom than *Eupeodes frequens*, which found support from the findings of Sadeghi [19] who reported *E. balteatus* more abundant than *Eupeodes* sp. As compared to the present study only 2.97 syrphids/m^2/5min were observed on *Brassica oleracea* (Devi *et al.*) [8]. It is difficult to compare the relative preference exhibit by hoverfly species due to difference in plant species, environmental conditions and interaction effects, there for the other studies of relative abundance of syrphids on different crops are less comparable to the present study.

In the present study the maximum relative abundance of both the species was observed during morning hours (0900-1000hr) 5.85 syrphids/m^2/5min, followed by evening hours (1500-1600hr) 4.32 syrphids/m^2/5min and 2.91 syrphids/m^2/5min during afternoon (1200-1300hr). In a similar study conducted by Satapathy and Chandra [20] on abundance of *E. corollae* visiting *A. marmelos*, number of pollinators/spike/5min (5.40) were also observed during morning hours 6-9am followed by evening hours (3.40 pollinators/spike/5min) at 3-6pm and afternoon hours (1.20 pollinators/spike/5min) 12pm to 3pm. Singh *et al.* [24] reported maximum abundance of syrphids (2.87) during morning hours (1000hr) followed by (1.93) evening (1500hr) and in afternoon (2.27) (1200hr).

The difference could be due to different climatic conditions and different agro-ecological zone. It has been reported that a species of pollinators never visit in the same observation time, which might be due to food competition. In the present study area, since *A. mellifera* and *A. cerana* apiary was near-by so that to avoid competition more foraging of syrphids was observed in the morning hours. whereas, *A. mellifera* and *A. cerana* forage more during the afternoon, which can be supported by findings of Goswami and Khan [10] who reported high activity of Honeybees on mustard at 1200 hr *i.e.* (66.31 percent) as compared to other bees which were equally active at 1000hr (21.47 percent).

Floral preferences vary from species to species. Some syrphid species are highly specialized and some are generalized feeders (Haslett) [11]. This floral attractiveness may be due to many factors like flower color, shape, pollen and nectar availability (Sutherland *et al.*) [25], shelter and availability of prey (Colley and Luna) [6].

The number of loose pollen grains adhering to the body of *E. balteatus* and *E. frequens* varied from 430-520 and 280-340, respectively. The present findings are in more or less agreement with those of Sharma *et al.* [22], where, 140 loose pollen grains were found adhering to the body of *E. balteatus* foraging on radish under similar conditions. As evident from fig. 1, maximum mean number of loose pollen grains per forager adhered to the body of *E. balteatus* (475.6±17.3) as compared to *E. frequens* (305.4±10.5). The number of loose pollen grains adhering to the body of insect pollinator also depends upon the property of pollen grains and availability of pollen grains on each flower bud at the time of visitation of forager, hence the contradiction in present study would be because of different floral resource. Insect pollinators with different body size carry varying pollen load and behave efficiently on flower heads (Hoehn *et al.*) [12].

5. Conclusion

The foraging activities of syrphid flies varied significantly during different day hours. Foraging rate was observed maximum during 1200-1300 hr (afternoon) and minimum during 0900-1000 hr (morning). In the morning hours syrphids spent more time on each flower for feed on nectar and pollens and full fed till afternoon hence syrphids spent less time over each flower during afternoon. The abundance of syrphids was recorded significantly maximum during the morning hours and it starts decreasing with the time and almost ceased in the evening hours (1500-1600). *Episyrphus balteatus* adhere more number of loose pollen grains on their body then *Eupeodes frequens*. *E. balteatus* and E. frequens showed 6.93 and 5.83 pollination index, respectively. On the basis of pollination indices, *E. balteatus* attained higher rank than *E. frequens*, suggesting effectiveness and importance of syrphids as pollinators.

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