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Naveen Bakshi
Department of Entomology, Dr. YS Parmar University of Horticulture and Forestry, Nauni, Solan, Himachal Pradesh, India

Manju Devi
Department of Entomology, Dr. YS Parmar University of Horticulture and Forestry, Nauni, Solan, Himachal Pradesh, India

Harish Kumar Sharma
Department of Entomology, Dr. YS Parmar University of Horticulture and Forestry, Nauni, Solan, Himachal Pradesh, India

Correspondence
Naveen Bakshi
Department of Entomology, Dr. YS Parmar University of Horticulture and Forestry, Nauni, Solan, Himachal Pradesh, India

Studies on pollination efficiency of hive bees and *Episyrphus balteatus* on sweet cherry (*Prunus avium* L.)

Naveen Bakshi, Manju Devi and Harish Kumar Sharma

Abstract
The present study was conducted to determine the pollination indices and foraging behaviour of hive bees and most frequented syrphid (*Episyrphus balteatus*) in sweet cherry (*Prunus avium* L.) during 2014-15. The present investigation revealed that *Apis mellifera* activity was maximum (8.24 bees/m^2/5 min) followed by *A. cerana* (5.71) and *E. balteatus* (3.75), statistically being different from all insect visitors. *A. mellifera* visited higher number of flowers (6.46) than *A. cerana* (6.07) and *E. balteatus* (3.72). *A. cerana* spent significantly more time (10.7) per flower compared *A. mellifera* (8.22) and *E. balteatus* (5.94). Maximum numbers of loose pollen grains (4753.33) were adhered to the body of *A. mellifera*. *A. mellifera* scored highest pollination index (17.60) followed by *A. cerana* (12.33) and *E. balteatus* (6.22) on cherry bloom under open pollination.

Keywords: Pollination indices, foraging behavior, relative abundance, hive bees

1. Introduction
Pollination is one of the most important mechanisms in the maintenance and promotion of biodiversity and, in general, life on Earth [1]. Many ecosystems, including agro-ecosystem depend on pollinator diversity to maintain overall biological diversity. Pollination also benefits society by increasing food security and improving livelihoods [2]. Cherry is highly cross pollinated crop and requires pollinizer varieties and insect pollinators for effective pollination and fruit set. Early pollination soon after the opening of flower is desirable for good fruit set. The longer the delay in pollination, the smaller is the proportion of embryo sacs that are fertilized [3]. In general, the important insect pollinators of sweet cherry include honey bees, solitary bees (*Xylocopa* spp, *Andrena* spp., *Halictus* spp.), bumble bees, stingless bees (*Trigona* sp, *Melipona* sp.) and dipteran flies (*Syrphus* spp., *Bombilius* spp.)[4]. Efficiency of insect visitors on the crop is determined on the basis of pollination indices. Bohart and Nye [5] and Bohart *et al.* [6] assigned efficiency rating for each visitors on the basis of their loose pollen carrying capacities and then combined this factor with the size, hairiness and activity pattern of insects. Sharma [7] worked out the pollination indices of honey bees on apple, almond, apricot and peach. In present study, pollination efficiency of three dominant insect visitors (*Apis cerana. A. mellifera* and *E. balteatus*) have been worked out in cherry on the basis of relative abundance, foraging rate, foraging speed and loose pollen grains adhering to their body.

2. Materials and Methods
2.1 Pollination indices
The pollination indices of hive bees and *E. balteatus* were calculated on the basis of following parameters:

2.1.1 Relative abundance
For relative abundance of insect visitors, trees of same size and vigour (canopy) were selected in the orchard. The abundance of bees and other insect pollinators visiting flowers were recorded by number of insect visitors/5 minutes/m^2 of bloom at 1000, 1200 and 1500 h and were replicated 5 times. The observations were recorded using stop watch during full bloom for three sunny days.

2.1.2 Foraging rate
Foraging rate was determined by counting numbers of flowers visited per minute by insect visitors and were replicated 10 times at 1000, 1200 and 1500 h. The observations were recorded using stop watch for three sunny days.

2.1.3 Foraging speed
Foraging speed was observed as time spent (in seconds) by insect pollinators on a flower and were replicated 10 times at 1000, 1200 and 1500 h. The observations were recorded using stop watch for three sunny days.

2.1.4 Loose pollen grain
Number of loose pollen grains adhering to the body of important insect pollinators was determined by capturing the forager and killing immediately in measured quantity (5 ml) of 70 per cent alcohol in glass vials. Foragers were collected directly by means of forceps but the hind legs of foragers (in case of hive bees) were amputated before killing in alcohol. From the rinstate, an aliquot of 0.02 ml (replicated three times), were taken on a counting dish and the pollen grains were counted under binocular microscope. After that total numbers of pollen grains in the whole rinsate were calculated.
Pollination indices of pollinators was worked out on the basis of their relative abundance and foraging behaviour, such as foraging rate, foraging speed, loose pollen grains sticking on their bodies. In order to have fair assessment, rating was assigned and calculated by following way:
Pollination efficiency of the insect visitors was assessed on the basis of their relative abundance and foraging behaviour such as foraging speed, foraging rate and the amount of loose pollen grains sticking to their bodies. The ranking was given as follows:

1. The minimum time spent per flower was given the highest rank and vice-versa.
2. The maximum flower visited per minute was given the highest rank and vice-versa.
3. The insect carrying maximum number of loose pollen grains was given the highest rank and lowest rank was assigned to insect visitors with least number of pollen grains sticking to their bodies.

Ranks were assigned on the basis of statistical analysis of the data. Different scores were given to the values which differed significantly. Mid scores were assigned to the values which are statistically non-significant from both the lower and higher values for an attribute.
Average efficiency ratings thus obtained were multiplied by the mean population of each pollinator in order to obtain the pollination indices.

2.2 Foraging behaviour of bees
The hive bees on cherry were observed for their foraging for nectar and/or pollen. In addition, observations were recorded on the body contacts of most frequent insect visitors with anthers and or stigma, whether working from the top of the flower (top workers: which stand on the anthers and push its tongue and frontal parts of its body towards the nectarines and touch the stigma and anthers) or side (side workers: bee which pushes its tongue for obtaining nectar between the stamen filaments having gap, while standing on petals with meso and meta thoracic legs) were also recorded. A total of 20 individuals of hive bees were observed for their foraging behavior and categorized as:

a. Top worker/side worker
b. Percentage of top worker/side worker
c. Nectar collector or pollen collector
d. Both nectar and pollen gatherer

2.3 Statistical analysis
The data were analyzed statistically by using randomized block design (RBD) factorial and t- test as per the formulae given by Gomez and Gomez, 1986 [8].

3. Results and Discussion
3.1 Pollination indices
The observations recorded for pollination indices of *A. mellifera*, *A. cerana* and *E. balteatus* is given below.

3.1.1 Relative abundance
Relative abundance of insect visitors (no. of insects /m^2/5 minute) on cherry at full bloom during different day hours at different distances at Katrain, Kullu during April, 2015 has been presented in Table1.

Table 1: Relative abundance of insect visitors on cherry at full bloom during different day hours at different distances at Katrain, Kullu in April, 2015

Insect visitors	Activity of insect visitors (number of insects / m^2 / 5 minutes)				
	25m	50m	75m	100m	Mean
A. mellifera	11.50(3.52)*	8.85(3.11)	7.44(2.86)	5.17(2.44)	8.24(2.98)
A. cerana	5.06(2.44)	7.06(2.77)	5.94(2.57)	4.78(2.36)	5.71(2.54)
E. balteatus	5.56(2.51)	3.00(1.94)	3.67(2.14)	2.78(1.92)	3.75(2.13)
Other syrphids	1.28(1.48)	1.00(1.38)	0.94(1.39)	1.11(1.42)	1.08(1.42)
Wild bees	1.94(1.71)	0.89(1.36)	1.28(1.47)	1.61(1.58)	1.43(1.53)
Other insect visitors	0.78(1.30)	0.67(1.27)	0.50(1.20)	0.89(1.35)	0.71(1.28)
Mean	4.35(2.16)	3.58(1.97)	3.30(1.94)	2.72(1.85)	

CD (P=0.05): insect visitors = 0.18, distance = 0.14, interactions = 0.35
* Figures in the parentheses are $\sqrt{x+1}$ transformed values

It was inferred from the Table (1) that *A. mellifera* activity was maximum (8.24 bees/m^2/5 min) followed by *A. cerana* (5.71) and *E. balteatus* (3.75), statistically being different from all insect visitors. The activity of other syrphids (1.08 insects/ m^2/5min), wild bees (1.43) and other insect visitors (0.71), statistically being same.
Significantly higher number (11.50 bees/ m^2/5 minute) of *A. mellifera* were observed at 25 m distance. The activity of *A. mellifera* was statistically same at 50 m (8.85 bees) and 75 m (7.44 bees) distance which differed significantly from the activity at 25 m and 100 m distance. The lowest activity (5.17 bees/ m^2/5 min) was recorded by relative abundance of insect visitors on cherry bloom at 100 m distance. No such trend was, however, observed in the activity of others insect groups which were visiting cherry bloom from their native habitat. These observations clearly indicated the impact of placement

of introduced *A. mellifera* colonies on increase in its population. The population of *A. mellifera* on cherry flowers was comparatively more upto 75 m distance. The population of indigenous hive bees *A. cerana* varied non–significantly from 7.06 bees/ m^2/5 min at 50 m to 4.78 bees at 100 m.

The observations further revealed that *A. cerana* population was good on cherry flowers and played important role in its pollination in temperate area like Katrain, Kullu. The number of syrphids visiting cherry bloom as such was quite high and among syrphids, *E. balteatus* was dominant. *E. balteatus* activity was recorded 5.56, 3.67, 3.00 and 2.78 insects/ m^2/5 min, respectively at 25 m, 75 m, 50 m and 100 m distances. The activity of other syrphids varied from 0.94 (at 75 m) to 1.28 (at 25 m). The data further revealed that wild bees and other insect visitors population was comparatively low at all distances and their population varied from 0.89 to 1.94 insects /m^2/ 5 min and 0.50 to 0.89 /m^2/5 min, respectively. The trend of *A. mellifera* and other insect visitors to the cherry bloom was almost similar to that recorded by scan sampling.

Sharma and Rana [9] conducted pollination studies on cherry at Katrain area (Kullu) of Himachal Pradesh and reported that hive bees formed the highest percentage (69.56 and 73.49 during 1998 & 1999) of insect visitors to cherry bloom. *A. cerana* was the dominating insect visitor (40.66% and 49.48% in 1998 and 1999) followed by *A. mellifera* and syrphid flies. In general, there was a decreasing trend in the honey bee abundance with increase in the distance from the hives.

3.1.2 Foraging rate

Foraging rate of important insect visitors on cherry bloom during 2015 is presented in Table 2. This table shows that *A. mellifera* and *A. cerana* visited more number of flowers per minute i.e. 6.46 & 6.07 respectively (significantly same). *E. balteatus* (3.72 flowers/min) which was significantly different with other visitors. Least number of flowers (3.72) were visited by *E. balteatus*. The foraging rate irrespective of species was more at 1000 h (6.73) and 1200 h (6.11) than at 1500 h (5.07).

The observations on foraging rate is in proximity to Sharma and Rana [9],who reported that the number of flowers visited per minute by *A. mellifera*, *A. cerana* and syrphid flies were 7.00 ± 2.82, 6.83 ± 2.76 and 1.57 ± 0.72, respectively on cherry bloom in Katrain, Kullu. The observations recorded later [10] in cherry were also supported present studies which stated that, *A. mellifera* and *A. cerana* and *E. balteatus* foraged on 6.70, 6.60 and 3.0 cherry flowers per minute, respectively.

Table 2: Foraging rate of important insect visitors on cherry bloom at Katrain, Kullu during 2015

Insect Visitors	Foraging rate (number of flowers visited/ minute)			
	1000 h	1200 h	1500 h	Mean
A. mellifera	7.00(2.74)*	6.70(2.68)	5.67(2.47)	6.46(2.63)
A. cerana	8.73(2.60)	7.97(2.91)	6.50(2.64)	6.07(2.58)
E. balteatus	4.47(2.22)	3.67(2.03)	3.03(1.87)	3.72(2.04)
Mean	6.73(2.66)	6.11(2.55)	5.07(2.33)	

CD (P=0.05): pollinators = 0.15, day hours = 0.15, interaction = NS
* Figures in the parentheses are $\sqrt{x+1}$ transformed values

3.1.3 Foraging speed

Foraging speed of insect visitors on cherry bloom at Katrain, Kullu during 2015 is presented in Table 3. The data showed that *A. cerana* spent significantly more time per flower (10.7 sec/flower) followed by *A. mellifera* (8.22 sec.) and *E. balteatus* (5.94 sec.), respectively.

Table 3: Foraging speed of insect visitors on cherry bloom at Katrain, Kullu during 2015

Insect Visitors	Foraging speed (time spent, in sec/flower)			
	1000 h	1200 h	1500 h	Mean
A. mellifera	8.9(3.14)*	8.4(3.06)	7.40(2.88)	8.22(3.02)
A. cerana	15.23(4.02)	9.5(3.23)	7.40(2.90)	10.7(3.38)
E. balteatus	6.4(2.71)	4.6(2.35)	6.90(2.80)	5.94(2.62)
Mean	10.17(3.29)	7.48(2.88)	7.22(2.86)	

CD (P=0.05): pollinators = 0.26, day hours = 0.26, interaction = 0.45
* Figures in the parentheses are $\sqrt{x+1}$ transformed values

The present results are in close proximity to Sharma and Rana [9], who reported that the time spent per flower by *A. mellifera*, and *A. cerana* were 6.25 and 6.58 sec., respectively. But their observations on foraging speed of *E. balteatus* (31.71 sec.) differed greatly with present findings (5.94 sec).

3.1.4 Loose pollen grains

Numbers of loose pollen grains adhering to the body of insect pollinators are represented in the Table 4. The data in the table clearly indicates that maximum numbers of loose pollen grains (4753.33) were adhered to the body of *A. mellifera*. The number of loose pollen grains (3726.67) adhering to the body of *A. cerana* differed significantly from other two insects. The lowest number of loose pollen grains (1400.00) was counted on the body of *E. balteatus*. Similar trend for loose pollen grains was reported by Sharma and Rana[9]. However the number of loose pollen grains on the body was comparatively low in comparison to present studies, the range values being 1225-2230, 1450-1913 and 92-183 for *A. mellifera, A. cerana and Episyrphus* sp. Free and Williams [11] observed that the mean number of pollen grains found on the bodies of honey bees gathering pollen and honey bees collecting nectar on sweet cherry flowers were 13357 and 5790.

Table 4: Number of loose pollen grains adhering to the body of important insect pollinators

Insect Visitors	Number of loose pollen grains
Apis mellifera	4753.33
Apis cerana	3726.67
Episyrphus balteatus	1400.00
CD (P=0.05)	718.69

3.1.5 Pollination index

Pollination index of important pollinators of cherry is depicted in Table 5. *A. mellifera* scored highest pollination index (20.60) followed by *A. cerana* (12.33) and *E. balteatus* (6.26) on cherry bloom under open condition.

Pollination efficiency of insect pollinators has been evaluated on the basis of number of characteristics. Free [12]; Atwal [13] and McGregor [14] considered the relative effectiveness of insect pollinators on the basis of their abundance alone. Efficiency of visitors on crops can also be worked out on the basis of pollination index. Bohart and Nye [5] and Bohart *et al.* [6] assigned efficiency rating for each visitor on the basis of its loose pollen grains on body and combined this factor with size, hairyness and activity pattern of insect. Pollination indices of insect visitors were calculated on the basis of efficiency rating for each species of insect visitors multiplied with its relative abundance. In present investigations, pollination indices have been worked out by keeping in view

the different criteria. Based on the relative pollination efficiency of important insect pollinators for whom the pollination index were worked out were arranged in the following order i.e. *A. mellifera*, *A. cerana* and *E. balteatus*. The studies received support from Kumar and Gupta [15] who have also reported higher pollination index for *A. mellifera* for the studies of stone fruits (almond, apricot, plum and peach). No literature is available on pollination index of insect pollination on cherry crop. However, Dev [16] reported that *A. cerana* scored highest pollination index (34.04) followed by *A. mellifera* (12.58) and *E. balteatus* (3.99) on apple bloom under open condition.

Table 5: Pollination index of important pollinators of cherry during 2015

Pollinators	Rank assigned on the basis of statistical analysis			Average	Relative abundance (number/m^2/5min)	Pollination index
	Foraging rate	Foraging speed	Loose pollen grains			
A. mellifera	2.5	2	3	2.5	8.24	20.60
A. cerana	2.5	1	2	2.16	5.71	12.33
E. balteatus	1	3	1	1.67	3.75	6.26

3.2 Foraging behaviour of hivebees

3.2.1 Proportion of nectar and / or pollen gatherer of hive bees

Data on the proportion of nectar and / or pollen gatherer of hive bees and *E. balteatus* foraging on cherry bloom is presented in Fig. 1. The data revealed that hive bees visited cherry bloom either for pollen or nectar or for both. The proportion in *A. cerana* was 45, 35 and 20 per cent as nectar, pollen and both (nectar + pollen), respectively and 30, 50, 20 per cent respectively in *A. mellifera*.

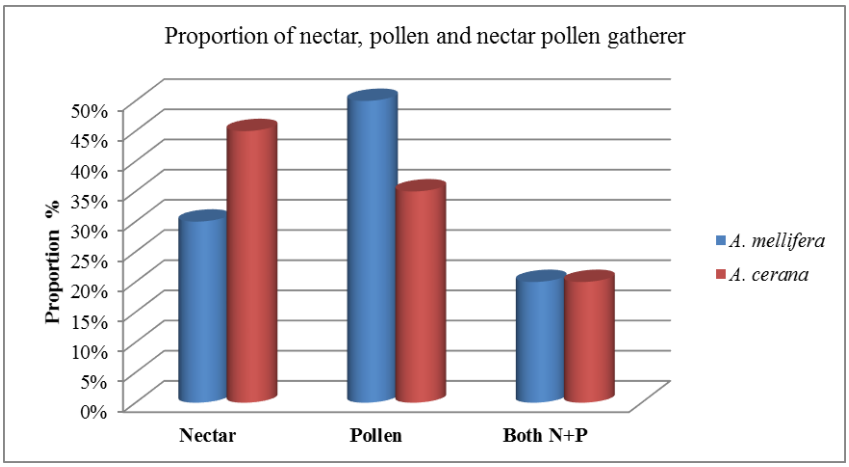

Fig 1: Proportion of nectar, pollen and nectar pollen gatherer in hive bees

Bee visit flowers to collect nectar and pollen. The activity of bees on the flower for nectar and pollen or both depends on the relative availability of nectar and pollen at that time and the food requirement of their colonies. Ratio of nectar gathers to pollen gathers were found to vary greatly on different days and at different times on the same days in apple, pear, apricot, peach, plum and sweat cherry [17]. The present findings are in line with Parker [18] and Vansell [19], who showed that honey bees visiting cherry, plum, pear and apple flowers collected either pollen only, or nectar only, or both. Proportion of bee collecting nectar and pollen also varies during different day hours.

3.2.2 Proportion of side and top workers of hive bees

Data on side and top workers of hive bees foraging on cherry bloom presented in Fig. 2 showed that the proportion of top worker (70%) was slightly higher in *A. mellifera* than *A. cerana* (65%). The proportion of side worker was more in *A. cerana* (35%) than *A. mellifera* (30%). Similar observations have been reported by Dashad [20] in apple at Nauni, Solan, who have also found highest proportion of top worker in *A. mellifera* (58.94%) than *A. cerana indica* (46.81%).

Fig 2: proportion of side and top workers in hive bees

4. Conclusion

A. mellifera visited higher number of flowers per minute (6.46) than *A. cerana* (6.07) and *E. balteatus* (3.72). The foraging rate (irrespective of species) was more at 1000 h. *A. Cerana* spent significantly more time (6.50 sec.) per flower compared to *A. mellifera* (5.67 sec.) and *E. balteatus* (3.03 sec.). Maximum number of loose pollen grains (4753.33) were adhered to the body of *A. mellifera* followed by *A. cerana* (3726.67) and *E. balteatus* (1400.00).*A. mellifera* scored higher pollination index (17.6) followed by *A. cerana*(12.33). Least pollination index is obtained by *E. balteatus* (6.22).This suggested that hive bees are more efficient pollinators of cherry. However, role and efficiency of other insect pollinators like syrphids is supplementing pollination of various crops including cherry.

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