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Insect pollinators of litchi with special reference to foraging behaviour of honey bees

Rakesh Das, Shantanu Jha and Agniva Halder

Abstract
An experiment was conducted in litchi orchard (Bombai variety) of Horticultural Research Station (latitude 22°56′39″N and longitude 88°30′56″E) of Bidhan Chandra Krishi Viswavidyalaya at Mandouri in Nadia district of West Bengal during February to March, 2019 to record the different insect pollinators with special reference to foraging behaviour of honey bees visiting litchi flowers. A total of 13 insect pollinators belonging to order Hymenoptera (comprising of 7 species viz., *Apis dorsata*, *Apis mellifera*, *Apis cerana indica*, *Apis florea*, *Lassioglossum* sp., *Vespa tropica* and *Camponotus compressus)*, Diptera (comprising of 5 species viz., *Episyrphus balteatus*, *Eristalis* sp., *Syrphus* sp., *Sacrcophaga sp.* and *Lucilia sericata*) and Coleoptera (comprising of single species viz., *Coccinella septumpunctata)* were found to visit litchi flowers during the period of study. The abundance (percentage of insect fauna/inflorescence/5 min.) of Hymenopterans (77.71%) was maximum followed by Dipterans (22.27%). Among Hymenopterans, *A. dorsata* (50.11%) was predominant visitor followed by *A. cerana indica* (11.80%), *A. florea* (8.68%) and *A. mellifera* (7.12%). The foraging speed (time spent in sec. per flower per forager) was recorded maximum during 9-11 am while, minimum during 3-5 pm for all the honey bees. The mean foraging speed was found to be maximum in *A. dorsata* (4.64 sec) while *A. florea* (3.32 sec) showed lowest. On the contrary, the foraging rate (number of flowers visited per min. per forager) was found to be highest during 3-5 pm for all the honey bees and the maximum and minimum mean foraging rate was recorded in *A. florea* (12.29) and *A. dorsata* (10.54) respectively.

Keywords: Litchi, insect pollinators, honeybees, abundance, foraging behaviour

Introduction
Pollination is an important step of seeds production in all spermatophytes (seed plants), resulting in the production of genetically diverse offspring (Dafni *et al.*, 2005) [5]. The beneficial value of pollination has become a crucial step in agriculture/horticulture production. Among the various pollinating agents insects are the basic one and generally considered best to obtain a good and profitable production (Badiyala and Garg, 1990; DuToit, 1994; Menzel and Waite, 2005) [3, 7, 14]. According to various sources, it is estimated that one third of the total human food supply relies on insect pollination (Jivan, 2013; Said *et al.*, 2015) [9, 19].

Litchi (*Litchi chinensis* S.) belongs to family Sapindaceae, is an important subtropical evergreen commercial fruit crop extensively grown in Indian subcontinents. Flowers are usually produced during later winter or early spring in season. Three types of flowers are found in litchi, which open in succession on the same panicle and the flowers vary in sexual development, length and functionality of the stamens and development and functionality of the pistil (Mustard *et al*., 1953; Stern and Gazit, 1998) [16, 25]. Type I flowers (Male 1 = M1) are functionally male, lack ovules and having 6-8 stamens which produce much pollen. Type II flowers are hermaphrodite but function as female (F) with well-developed pistil and stigma, having 5-8 stamens which do not dehisce. Type III flowers are male (Male 2 = M2), having 6-8 stamens which produce plentiful viable pollen. They also have a rudimentary pistil which lacking of style and stigma (Stern and Gazit, 1998) [25]. Anthesis of flowers occurs in overlapping cycles, normally of 10 days for Type I, 7-10 days for Type II and 7-10 days for Type III (Mustard *et al*., 1953; Stern and Gazit, 1996) [16, 24] which also varies with the weather and cultivar. In spite of presence of functional male and female flowers on a single tree, at the same time, self-pollination does not occur in litchi, as the hermaphrodite flowers are generally recognized as self-sterile and therefore, insect-pollination is necessary for the proper fruit set (Pandey and Yadava, 1970; Phadke and Naim, 1974) [17, 18]. Presence of plentiful amount of nectar in the self-sterile flowers, attracts insects like honey bees, flies, ants and wasp leading to entomophilic cross pollination. Among several insect visitors honey bees have been reported as the most beneficial insects on litchi (Groff, 1943) [8]. Pollination of entomophilous crops by honey bees is regarded as one of the effective and cheapest method for improving the yield and quality of the crops (King *et al*., 1989) [11].

In order to achieve the benefit of efficient use of farm inputs and varietal capacity, efficient and assured pollination for enhanced quantity and quality production in the present scenario is needed. Assured pollination can only be achieved by managing optimum levels of various pollinators.
By keeping this view in mind the present study was carried out to record the different insect pollinators along with the foraging behaviour of honey bees visiting litchi flowers.

Materials and Methods

Experimental Location

The experiment was conducted in litchi orchard (Bombai variety) of Horticultural Research Station of Bidhan Chandra Krishi Viswavidyalaya at Mandouri in Nadia district of West Bengal during February to March, 2019. The coordinates of the experimental farm is latitude 22°56′39″N and longitude 88°30′56″E with the elevation of about 9.75 meters above the Mean Sea Level (MSL).

Diversity and Relative abundance of insect pollinators

Observations of flower-visiting insects were taken up from the start of flowering until approximate 90% of the flower faded. The collected foraging insects were killed and were subsequently identified by using the literature available elsewhere. Photographs of the different insect visitors were also taken.
The number of insect pollinators visiting the flowers was studied on randomly selected five plants during morning to afternoon (7 am to 5 pm) hour at seven days interval. Observations were made from four directions of the plant and in each direction, an inflorescence with blooms was observed for 5 min from which the relative abundance of these insect visitors was calculated by using the formula:

Relative abundance (%) = (Population of a particular species visiting flowers/ Total population of all species visiting flowers) x 100

Foraging behaviour of honey bees

Different aspects of foraging behaviour in terms of foraging rate and foraging speed of four different honey bees (*Apis dorsata, Apis mellifera, Apis cerana indica* and *Apis florea*) were observed during the course of study.
Foraging rate of the *Apis* spp. was recorded in terms of the number of flowers visited per minute per forager. Whereas, foraging speed of the *Apis* spp. was recorded in terms of the time spent by each species on a flower.
All the observations were recorded throughout blooming period of the crop once in a week at following intervals viz., 7-9 am, 9-11 am, 11-1 pm, 1-3 pm and 3-5 pm.

Results and Discussion

Diversity of insect pollinators visiting litchi flowers

The insect pollinators visiting the litchi flowers were collected and identified by using the available literature and listed in Table 1 along with their systematic position and the photographs are shown in Figure 1.

Table 1: List of different insect visitors.

Sl. No.	Name	Scientific Name	Family	Order
1.	Rock bee	*Apis dorsata*	Apidae	Hymenoptera
2.	Italian bee	*Apis mellifera*		
3.	Indian bee	*Apis cerana indica*		
4.	Little bee	*Apis florea*		
5.	Sweat bee	*Lassioglossum* sp.	Halictidae	
6.	Wasp	*Vespa tropica*	Vespidae	
7.	Ant	*Camponotus compressus*	Formicidae	
8.	Syrphid	*Episyrphys balteatus*	Syrphidae	Diptera
9.	Syrphid	*Eristalis* sp.		
10.	Syrphid	*Syrphus* sp.		
11.	Flesh fly	*Sarcophaga* sp.	Sarcophagidae	
12.	Blow fly	*Lucilia sericata*	Calliphoridae	
13.	Lady bird beetle	*Coccinella septumpunctata*	Coccinellidae	Coleoptera

During the observation thirteen insect species belonging to three orders and eight families of class insecta (Table 1) were recorded during the blooming period of litchi plants. Among them Hymenopteran were predominant comprising of seven species from four different families namely Apidae, Halictidae, Vespidae and Formicidae. The family Apidae was most abundant comprising of four species of honey bees namely, Rock bee, *Apis dorsata*, Itallian bee, *Apis mellifera*, Indian bee, *Apis cerana indica* and little bee, *Apis florea*. On the contrary, the rest three families were represented each by single species of insect visitors namely, sweat bee, *Lassioglossum* sp. (Halictidae), wasp, *Vespa tropica* (Vespidae) and ant, *Camponotus compressus* (Formicidae). However, Diptera was the second dominant insect visiting order on litchi flowers comprising of five species from three different families viz., Syrphidae, Sarcophagidae and Calliphoridae. Family Syrphidae was represented by three different species of hover flies viz., *Episyrphus balteatus*, *Eristalis* sp. and *Syrphus* sp. while, the rest two families having single species of insect visitors each. Families Sarcophagidae and Calliphoridae each were represented by flesh fly, *Sarcophaga* sp. and blow fly, *Lucilia sericata* respectively. Coleoptera was least diversified order visiting litchi flowers comprising single species viz., lady bird beetle, *Coccinella septumpunctata* from the family Coccinellidae.
In the proximity of present finding, Kumar *et al.*, (2013) [13] found a total of 12 insect species belonging to the order Hymenoptera and Diptera visited the flowers during the entire blossom period of litchi. Similarly in another study, Srivastava *et al*., (2017) [23] reported 20 pollinator species under 23 genera of 8 families belonging to orders Diptera, Hymenoptera and Coleoptera visiting litchi flowers in Muzaffarpur, Bihar.

Relative abundance of pollinators

Relative abundance of pollinators was recorded on litchi flowers at seven days interval during March, 2019 following the methods mentioned earlier. The number of pollinators recorded per inflorescence of litchi is presented in Table 2 and the diagram is shown in Figure 2.

Table 2: Observations for abundance (percentage of insect fauna per inflorescence per 5 min) of different insect pollinators on litchi flowers.

Pollinators \ Date	07.03.2019	14.03.2019	21.03.2019	28.03.2019	Total	Mean	Mean % population
Apis dorsata	1.42	2.71	3.57	1.28	8.98	2.25	50.11
Apis mellifera	0.14	0.14	0.71	0.28	1.27	0.32	7.12
Apis cerana indica	0.42	0.71	0.85	0.14	2.12	0.53	11.80
Apis florea	0.28	0.42	0.71	0.14	1.55	0.39	8.68
Syrphids	0.71	1.14	1.57	0.57	3.99	1.00	22.27
Total	2.97	5.12	7.41	2.41	17.91	4.49	

Among the different insect pollinators, *A. dorsata* was the predominant species found to visit the litchi flowers during the entire blooming period. The average population of *A. dorsata* as was recorded 2.53 per inflorescence which represented 50.11% of population of total insect pollinators visiting litchi flowers. Syrphids in totality were the second dominant insect visitors with an average of 1.00 insect per inflorescence constituting 22.27% of total insect fauna. Apart from, *A. dorsata*, the rest three honey bees (*A. mellifera*, *A. cerana indica* and *A. florea*) were also found to visit the flowers throughout the blooming period but comparatively with much lower population load. Abundance of Indian bee, *A. cerana indica* was recorded to be 11.80% sequentially followed by little bee, *A. florea* with 8.68% share and *A. mellifera* with 7.12% share. Mean population load of those were 0.53, 0.39 and 0.32 per inflorescence respectively. Whereas, the other insects were found to visit the litchi flowers occasionally during entire flowering.

It was further observed that, the pollinator populations increased at succeeding period of flower opening. A peak population of all the pollinators (7.41 insects per inflorescence) was observed on 21st March, 2019 and after that the populations gradually declined towards the cessation of the flowers. Average number of insects per inflorescence during the flowering period was recorded to be 4.49.

The present findings are in line with the findings of Kitroo and Abrol (1996) [12] and Abrol (2006) [2] who reported that honey bee species *Apis dorsata*; *A. mellifera*; *A. cerana* and *A. florea* were the most dominant and efficient pollinators of litchi flowers and represented more than 65% of the total pollinating insects. In another study Kumar *et al.*, (2013) [13] recorded that among the total insect visitors, hymenopterans were the most dominant constituting 74.69% of the total fauna and rest 25.21% represented by others. Among these insects, honey bees *A. dorsata*, *A. mellifera*, *A. cerana* and *A. florea* were the dominant flower visitors.

Foraging behaviour of four honey bees

Foraging behaviour of four different species of honey bees viz., *Apis dorsata*, *Apis mellifera*, *Apis cerana indica* and *Apis florea* were also observed during the course of study. To study the foraging behaviour, observations regarding foraging rate in terms of number of flowers visited per minute per forager and foraging speed in terms of time spent by each species on a flower were taken.

All the observations were recorded throughout blooming period of the crop once in a week at following time periods viz., 7-9 am, 9-11 am, 11-1 pm, 1-3 pm and 3-5 pm.

Data, thus collected throughout blooming period regarding foraging rate and foraging speed were summarised and presented here. During the study of foraging activity of four *Apis* spp., it was observed that all the honey bees started their foraging nearly 7.00-7.30 am in the morning and no activity was found upto 4.45-5.15 pm.

Foraging speed

Foraging speed of different honey bees in terms of time spent by each species on a flower is presented in Table 3 and the corresponding diagram is shown in Figure 3.

Table 3: Foraging speed (time spent in second per flower per forager) of *Apis* spp.

Pollinators \ Time	7am-9am	9am-11am	11am-1pm	1pm-3pm	3pm-5pm	Total	Mean
Apis dorsata	4.67	5.38	5.03	4.49	3.62	23.19	4.64
Apis mellifera	3.88	5.21	4.78	3.07	2.63	19.57	3.91
Apis cerana indica	3.51	3.98	3.80	2.87	2.61	16.77	3.35
Apis florea	3.53	3.92	3.69	2.86	2.59	16.59	3.32

With start of foraging nearly at 7-7.30 am, the foraging speed of all the honey bees were observed, highest of it had been recorded during 9-11 am which gradually declined towards the succeeding time of the day. *A. dorsata* started foraging with foraging speed of 4.67 sec., then reached to peak of activity with speed of 5.38 sec. during 9-11 am. After that, the activity gradually declined and lowest foraging speed was recorded during 3-5 pm with 3.62 sec. Similarly, for *A. mellifera* maximum and minimum speeds were 5.21 and 2.63 sec., for *A. cerana indica* these were 3.98 and 2.61 sec. and for *A. florea* 3.92 and 2.59 sec. respectively. Among the honey bees, the mean foraging speed throughout the day period were found to be maximum for *A. dorsata* (4.64) sequentially followed by *A. mellifera* (3.91), *A. cerana indica* (3.35) and *A. florea* (3.32).

Similar results were also documented by Mishra and Kumar (2018) [15]. They recorded the maximum foraging speed in *A. dorsata* (10.28 sec.) followed by *A. mellifera* (9.15 sec.) and minimum in case of *A. florea* being 6.97 sec. Similarly, the maximum foraging speed was observed at 09.00 h in all three species while the minimum foraging rate was observed at 15.00 h in all the species.

Foraging rate

Foraging rate of different honey bees in terms of number of flowers visited per minute per forager is presented in Table 4 and the correspondence diagram is shown in Figure 4.

Table 4: Foraging rate (number of flowers visited per min. per forager) of *Apis* spp.

Time / Pollinators	7am-9am	9am-11am	11am-1pm	1pm-3pm	3pm-5pm	Total	Mean
Apis dorsata	10.43	9.33	9.67	11.05	12.25	52.73	10.54
Apis mellifera	10.71	9.51	10.75	11.67	12.98	55.62	11.12
Apis cerana indica	11.17	11.89	12.02	12.84	13.39	61.31	12.26
Apis florea	11.03	11.78	12.31	12.88	13.43	61.43	12.29

Among the four honey bees, *A. florea* having the highest mean foraging rate (12.29) which was sequentially followed by *A. cerana indica* (12.26), *A. mellifera* (11.12) and *A. dorsata* (10.54). A gradual increase in foraging rate was observed in case of *A. cerana indica* and *A. mellifera*, where lowest and maximum numbers of flowers were visited at 7-9 am (11.17 and 11.03) and 3-5 pm (13.39 and 13.43) respectively. Though the trend be same in *A. dorsata* and *A. mellifera*, the general rate of foraging were at lower magnitude having its lowest and highest were at 9-11 am (9.33 and 9.51) and at 3-5 pm (12.25 and 12.98) respectively.

In earlier study Mishra and Kumar (2018) [15] also recorded that among different honey bees, maximum foraging rate (no. of flowers visited per minute) was observed in *A. florea* (14.17) followed by *A. mellifera* (11.61) and *A. dorsata* (10.41). Similarly, the maximum and minimum foraging rate was observed at 15.00 hr. and 09.00 hr. in all the three species respectively.

Both the foraging speed and foraging rate are inter-connected with each other and coupled with floral biology. When bees spent more time in a single flower, visited less number of flowers. In the present study, it was observed satisfactorily that *A. dorsata* spent more time in a single flower than others and visited less number of flowers. The answer might be due to the fact that the body weight of the honey bees was an important factor for determining the foraging activity, where heavy weight species need more food to meet their requirement, hence spent more time in single flower and visited less number of flowers in unit time. Similar results were also observed by Mishra and Kumar (2018) [15].

Further it was also noted that all the bees spent more time in flowers during the early time of day period, while less in later period. This is due to the flower biology, as the anthesis and dehiscence of litchi flowers mostly occur in early period of the day, facilitate the availability of pollens to the foragers. As well as nectar secretion starts in early period and on the succeeding period of day it declines due to increase in day temperature. Apart from this, foraging activity of bees is also greatly affected by the atmospheric condition. In many studies, it has been revealed that with increase in day temperature, the activities of bees greatly reduce and vice versa. A significant negative correlation ($r = -0.09$) was found by Abou-Shaara *et al*., (2013) [1] between foraging activity and temperature.

Earlier, Singh *et al*., (2006) [21] recorded the maximum number of bee foragers/minute/panicle at 10.30-11.30 hr., followed by 11.30- 12.30 hr., while the least number was recorded at 15.30-16.30 hr. in litchi and the peak foraging activity was recorded between 09.00-10.00 hr. The study supports the present findings. Similarly, Bhatnagar and Karnatak (2010) [4] revealed that in litchi total time spent per bee per flower was highest (5.83 sec.) in the morning at 09.00-11.00 hr. Khan (1929), Das and Chaudhury (1958) and Shukla (1968) [10, 6, 20], while working on the floral biology of litchi, demonstrated that dehiscence in a maximum number of flowers occurred between 07.00 and 12.00 hr. Singh *et al*., (2012) [22] reported that anthesis of litchi flowers occurred both during day and night, with peak opening in the early morning (6.00 hr.) and dehiscence began about one day after floral anthesis and continued upto three days, with not all the anthers in a flower dehiscing simultaneously. This took place continuously, occurring more frequently between 08.00 and 10.00 hr., with no apparent environmental, cultural or genetic effect. Further, nectar secreted only in the morning and the pollinators forage primarily between 06.00 and 12.00 hr. although foraging continues later in the day at much lower levels. This indicates synchronisation with foraging rate and time of honey bees.

Conclusion

In conclusion, the present study revealed that a total number of thirteen insect species from two different orders viz. Hymenoptera and Diptera found to visit the litchi flowers. Hymenopterans pollinators (77.71%) were dominant followed by Dipteran syrphids (22.27%) during the entire blooming period. Among Hymenopterans, *A. dorsata* (50.11%) was predominant visitor followed by *A. cerana indica* (11.80%), *A. florea* (8.68%) and *A. mellifera* (7.12%). The mean foraging speed (time spent in sec. per flower per forager) was found to be maximum in *A. dorsata* (4.64 sec.) while *A. florea* (3.32 sec.) showed lowest. Whereas, maximum and minimum mean foraging rate (number of flowers visited per min. per forager) was recorded in *A. florea* (12.29) and *A. dorsata* (10.54) respectively. Maximum foraging speed was recorded during early period, while maximum foraging rate observed during later period of the day. Further, maximum pollinators were found to forage early in the day and very few in the later period. Hence, being an entomophilous plant, litchi requires adequate visit of insect pollinators which will help in better pollination resulted into better fruit set. Thus to allow the frequent visit of different pollinators decision should be taken regarding any chemical measure during the flowering period.

Acknowledgement

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1.1: *Apis dorsata*

1.2: Apis mellifera

1.3: *Apis cerana indica*

1.4: *Apis florea*

1.5: *Lassioglossum* sp. 1.6: *Episyrphys balteatus*

1.7: *Eristalis* sp. 1.8: *Lucilia sericata*

1.9: *Sarcophaga* sp. 1.10: *Vespa tropica*

Fig 1: Insect pollinators of litchi

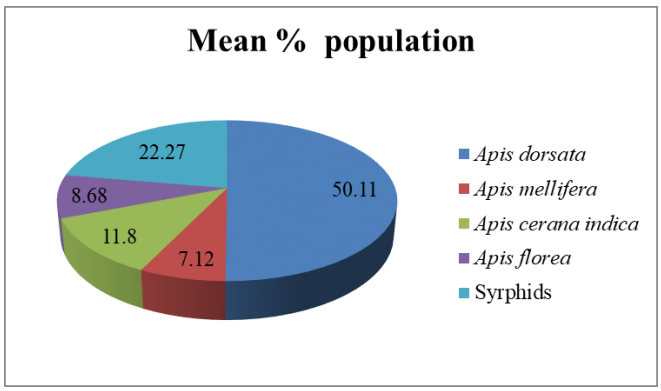

Fig 2: Abundance of insect pollinators (percentage of insect fauna per inflorescence per 5 min)

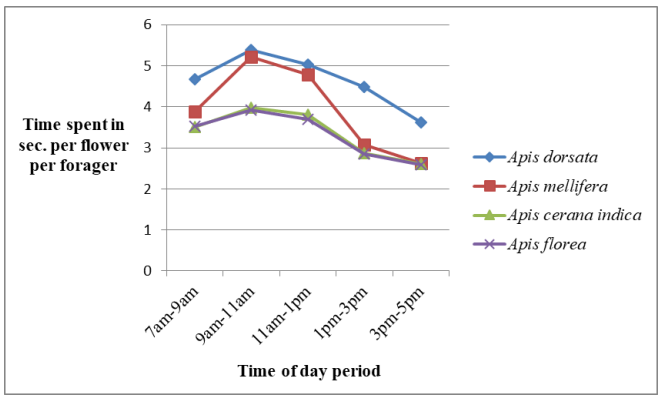

Fig 3: Foraging speed (time spent in second per flower per forager) of *Apis* spp.

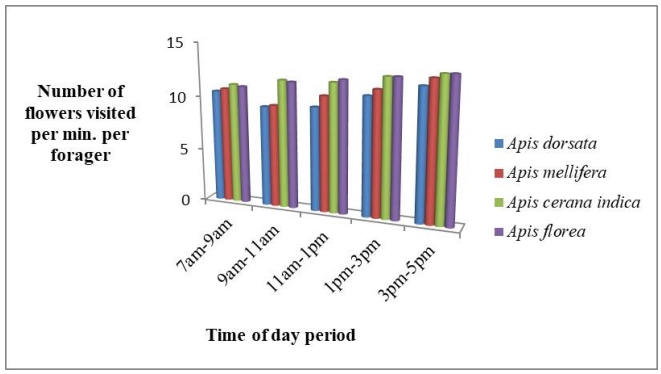

Fig 4: Foraging rate (number of flowers visited per min. per forager) of *Apis* spp.

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