Original Research Article

Foraging behavior and pollination efficiency of honey bee species on Apple ber (*Z. mauritiana* Lamk.)

Abstract

Theforaging behavior and pollination efficiency of honey bee species on Apple ber (*Z. mauritiana* Lamk.)were carried out in the Apple ber orchard situated at the Horticulture Experimental Area and P.G. Laboratory of the Department of Entomology, CCS Haryana Agricultural University, Hisar during 2022.The maximum foraging rate was observed in *Apis dorsata*(19.47 flowers per minute) and lowest foraging rate was observed in*Apis florea* (8.29 flowers/minute). The maximum mean foraging speed was observed in *Apis florea* 6.22 seconds for nectar reward and it was lowest in *Apis dorsata* (2.33 seconds) for pollen reward. The loose pollen grains (LPG) carrying capacity was highest for *Apis dorsata* (109584) followed by *Apis mellifera* (71827) and it was lowest for *Apis florea* (42806). The maximum Relative Pollination efficiency (RPE) was recorded in *Apis dorsata* (16.21) followed by *Apis mellifera* (14.45) and it was lowest in case of *Apis cerana* (4.90). It was observed that pollen (13.18) and nectar+pollen (13.05) foragers exhibited maximum and second maximum RPE, respectively.

Key words: Pollination efficiency, pollination index, foraging behaviour, Apple ber

INTRODUCTION

Ber (*Ziziphus mauritiana* Lamk.) is one of the most common ancient fruit of India and China. It belongs to the family Rhamnaceae and the genus *Ziziphus*. It is tetraploid (2n=48) and is regarded as the 'King of arid fruits' for the poor people, hence rightly known as the 'Poor man's Apple' (Bal & Uppal, 1992).Ber (*Z. mauritiana*) full blooming season begins in September and lasts until November,flowers are protandrous; therefore, fruit set depends on cross-pollination by insects that are attracted by the fragrance and nectar of the flowers. Pollen of the Indian jujube (ber) is thick and heavy and is transferred from flower to flower by various honey bee species. Pollination is carried out by various native honey bee species in India, each with its own foraging behavior in diverse agro-climatic areas. Honey bees are regarded as environment-friendly and very effective agents for enhancing the production of cross-pollinated crops (Free, 1993). Poor quality of fruits and reduced yield may occur due to a lack of complete pollination (McGregor, 1976).Therefore,farming of the *Z. mauritiana* variety Apple ber is currently trending and it has a lot of advantages over traditional ber farming with high economic return and a longer shelf life of fruits. Apple ber fruits are sweet, crispy, juicy and delicious, similar to apple. In ber, meagre on honey bee pollination, foraging behavior and pollination efficiency of *Apis* spp. has been done in India, but comprehensive pollination studies in Apple ber have not been carried out.

MATERIAL AND METHOD

Foraging behavior offour honey bee species: Different aspects of foraging behavior of the four honey bee species associated were recorded visually by following parameters.

Working behavior/foraging mode: Foraging behavior of the four honey bee species were observed for their working behavior that included alighting, working, departure, body contacts with anthers and/or stigma (top or side workers) on 25 individuals for nectar, pollen and nectar+pollen foragers.

Nectar foragers: The foraging groups that visited Apple ber flowers only for nectar rewards and were designated as N foragers.

Pollen foragers: The foraging groups that visited Apple ber flowers only for pollen rewards and were designated as P foragers.

Nectar and pollen foragers: The foraging groups that visited Apple ber flowers for both nectar and pollen rewards and were designated as NP foragers.

Pollination efficiency of four honey bee species on Apple ber

Pollination efficiencyof different foragers (N, P, N+P) of four honey bee species were assessed on the basis of their relative abundance and foraging behavior parameters as per (Bohart & Nye, 1960) and as modified by (Nagar & Chaudhary, 2005). Following aspects were recorded:

Foraging rate: Foraging rate of different forager groups of the honey bee species was recorded in terms of number of flowers visited per minute for floral rewards. It included the handling time and the time taken by the bee to move to the next flower (i.e., the hovering time but not the flight time between two flowers). The number of flowers visited per minute by a honey bee constituted one bee observation. In all, 25 bee observations were made for N, P and N+P foragers of each species of honey bees.

Foraging speed: Foraging speed of different forager groups was recorded in terms of time spent by them on each flower for floral rewards viz. N, P and N+P, separately. The time spent by a honey bee on 10 different flowers was recorded and the average was taken as one bee observation. In all, 25 bee observations were made for N, P and N+P foragers of each species of honey bees. Handling time of the flower was considered as the time spent on the flower between alighting of the honey bee and its final departure from the flower.

Loose pollen grains carrying capacity: The pollen and nectar+pollen foragers of four honey bee species were captured from the Apple ber flowers gently with the help of forceps and killed immediately in 70 per cent ethanol in vials (15ml capacity) after amputating the hind pair legs very gently before preservation. These vials were stored in the freezer for further analysis. The vials were shaken thoroughly to remove the loose pollen grains sticking on the body of honey bee species. Total volume of the rinsate was made to 3 ml before pollen count. An aliquot of 0.01 ml (replicated 5 times) was taken and with the help of haemocytometer and binocular microscope (10×15 magnifications) the number of pollen grains were counted. Total number of pollen grains were calculated in the whole rinsate. Ten individuals of each foraging group of the four honey bee species were observed for counting the pollen grains.

Relative Pollination efficiency (RPE): Relative Pollination efficiency (RPE) of different foragers (N, P, N+P) of four honey bee species were assessed on the basis of their relative abundance and foraging behavior parameters as per (Bohart & Nye, 1960) and as modified by (Nagar & Chaudhary, 2005).

This approach was said to be more accurate for determining an insect's efficacy as a pollinator.

a. The minimum time spent per flower was given the highest rank and vice-versa
b. The maximum number of flowers visited per minute was given the highest rank and vice-versa
c. The insect carrying maximum number of loose pollen grains on their body was given the highest rank and vice-versa

The ranks were assigned on the basis of statistical analysis of the data on a 0-5 scale. Mid scores were assigned to the values statistically non-significant from both the lower and higher values for attributes.

Average efficiency ratings thus, obtained was multiplied by the mean population abundance of each foraging group in order to obtain the pollination index (PI).

Pollination Index (PI) = Mean pollination efficiency (PE) × Mean abundance

These different foragers groups of the honey bee species were then further rated as per the PI ratings.

RESULT AND DISCUSSION

Working behavior/foraging mode of four different honey bee species on Apple ber bloom

Nectar foragers (N)

This foraging behavior was observed in foragers of all four honey bee species studied. In case of *A. florea* a forager landed on the side of flower, after gathering nectar, the forager departed successively from the top of the flower. Similar foraging behavior was also shown by *A. mellifera*. However, *A. dorsata* shown a different pattern of foraging behavior. The foragers of *A. dorsata* landed on the side of the flower, after gathering nectar, the forager departed successively from the side of the flower to the neighboring flower. Similar foraging behavior was also shown by *A. cerana*. The findings are supported by Braun et al. (1953) where they found that the nectar seeking was more prevalent in the morning andSingh et al. (2012) recorded that the proportion of nectar foragers was much higher for *A. cerana* (91.61%) and *A. dorsata* (82.50%) than *A. mellifera* (58.15%).

Pollen foragers (P)

In case of *A. florea* a pollen forager were the top workers. The pollen foragers mainly lend on the top portion of flower and due to small size of Apple ber flower, *A. florea* make full body contact with reproductive parts so the pollen grains adhere to their body efficiently. The departure of *A. florea* take place form the top of flower to the adjacent flowers and *A. cerana* was also exhibit the same pattern. Similarly, in case of *A. dorsata* the pollen foragers were the top workers but due to large body size of *A. dorsata* the pollen foragers mainly lend on the top portion of flower. Similar trend was observed in case of *A. mellifera*. These present findings are in line with the findings of who reported pollen foraging behavior in honey bees (Braun et al., 1953) on (*Trifolium pratense* L.) while Singh et al. (2012) and Jat et al. (2017) on (*Trifolium alexandrinum* L.).

Nectar and pollen foragers (N+P)

Foraging habit that included both side and top foraging was present in population of all four honey bee species on Apple ber bloom. The foragers who were side workers perched on the petals, grab the flower with their forelegs, and pierced their proboscis in the basal area of flower to collect only nectar. While nectar collection is the main purpose of these movements, pollens get attached to their body and they store these pollens in pollen basket which is present on their hind legs. By landing on petals and moving towards the top of flowers, these foragers also served as top workers. While performing this excellent foraging activity, the pollen foragers' bodies consistently made partial contact with the stigma and anthers. These findings are supported by Singh et al. (2012) in *Trifolium alexandrinum* L. who reported the highest proportion of *A. mellifera* bees were engaged in N+P foragers (37.76%) followed by *A. dorsata* (17.50%) and *A. cerana* (8.39%).

Pollination efficiency of four honey bee species on Apple ber

Foraging rate of four different honey bee species

Foraging rate i.e., number of flowers visited per minute by a honey bee forager for various floral reward is governed by various factors including type of resources availability (Free, 1993), ambient weather conditions, foraging behavior of different foragers and specific features related to the floral morphology of crop.Depending on the species of honey bees and the various floral rewards, the mean

foraging rate differed substantially (Table 1).Foraging rate was maximum for *A. dorsata* (19.47 flowers/minute), followed by *A. cerana* (11.33), *A. mellifera* (10.31) and minimum foraging rate was observed with *A. florea* as it visited only 8.29 flowers/minute. These findings are in support to Devi etal. (1989) who also recorded the mean foraging rate of *A. florea*but with lower values as it visited only 6-7 flowers per minute and *A. cerana* visited only 6-12 flowers per minute. While Shyam & Deka (2021) also recorded similar foraging rate in *A. cerana* (12.76 flower per minute). Whereas, Devi et al. (1989) recorded great variation in foraging rate between various foragers viz., *Ceratina* sp. visits (15-18 flowers per minute), *Trigona* sp. visits (9-15 flowers) and the highest flowers visit by *Bembix* sp.(25-33 flowers per minute). While considered these values for interactions between various floral rewards and honey bees the P forager of *A. dorsata* visited maximum 20.09 flowers/minute followed by N+P foragers of *A. dorsata* (19.77), N forager of *A. dorsata* (18.55). These were succeeded by N forager of *A. cerana* (12.17), N+P foragers of *A. cerana* (11.39), N forager of *A. mellifera* (10.85), N+P foragers of *A. mellifera* (10.66) and P forager of *A. cerana* (10.41) while lowest foraging rate was observed in *A. florea* for pollen reward (7.89 flowers/minute). Such studies on intra and inter- specific forager groups of honey bee species are not reported in the literature.

Table 1:Foraging rate of different honey bee species on Apple ber bloom during 2022

Honey beespecies	**Meanno.offlowersvisited/minute**			
	Nectar	**Pollen**	**Nectar +Pollen**	**Overall Mean**
Apisflorea	8.89*	7.89	8.04	**8.29**
A.mellifera	10.85	9.41	10.66	**10.31**
A.dorsata	18.55	20.09	19.77	**19.47**
A.cerana	12.17	10.41	11.39	**11.33**
CD(p≤0.05)		0.15		**0.09**
SE(m)		0.03		**0.05**
Overall Mean	**12.62**	**11.95**	**12.47**	
CD(p≤0.05)		**0.07**		
SE(m)		**0.03**		

*Values are the mean of 25 observations

Foraging speed of four different honey bee species

The mean foraging speed is the time spent per flower by different honey bee foragers in seconds (Table 2). The foragers spent maximum time for nectar reward (5.29 seconds/flower) followed by nectar+pollen reward (4.59 seconds) while for pollen reward, foragers of four different honey bee species spent (3.87 seconds). The maximum mean foraging speed for *A. florea* and *A. cerana* as these spent 5.66 and 5.18 seconds/flower, respectively and the minimum for *A. dorsata* (3.28 seconds). These findings are in support to Devi et al. (1989) who also recorded the mean foraging speed of different foragers as *A. florea*spent 2-5 seconds/flower and *A. cerana* spent 3-5 seconds/flower while Shyam & Deka (2021) observed the foraging behavior of *A. cerana* and according to their study the foraging speed of *A. cerana* was 4.48 seconds and number of flowers visited by *A. cerana* per trip was 202.While considering the nectar foragers of different honey bee species it was recorded that the maximum mean foraging speed of *A. florea* (6.22 seconds) followed by *A. cerana*(5.79seconds), *A. mellifera* (4.90 seconds) and minimum with *A. dorsata* (4.27 seconds). However, the observations of N+P foragers of different honey bee species it was recorded that the maximum mean foraging speed of *A. florea* (5.56 seconds) followed by *A. cerana*(5.35seconds), *A. mellifera* (4.19 seconds) and minimum with *A. dorsata* (3.26 seconds). While considering the P foragers of different honey bee species it was recorded that the maximum mean foraging speed of *A. florea* (5.21 seconds) followed by *A. cerana*(4.4 seconds), *A. mellifera* (3.55 seconds) and minimum by *A. dorsata* (2.33 seconds).

Such studies on intra and inter- specific forager groups of honey bee species are not reported in Apple ber in the literature.

Table 2: ForagingspeedofdifferenthoneybeespeciesonAppleberbloomduring2022

Honeybeespecies	Meanforagingspeed(timespent/flower)			
	Pollen	**Nectar**	**Nectar+Pollen**	**Mean**
Apisflorea	5.21*	6.22	5.56	**5.66**
A.dorsata	2.33	4.27	3.26	**3.28**
A. mellifera	3.55	4.90	4.19	**4.20**
A.cerana	4.40	5.79	5.35	**5.18**
CD(p≤0.05)	0.44	NS	NS	**0.44**
SE(m)	**0.15**	**0.22**	**0.21**	**0.12**
Mean	**3.87**	**5.29**	**4.59**	

*Values are the mean of 25 observations

Loose pollen grains sticking on the bodies of four different honey bee species

The maximum mean number of loose pollen grains (LPG) was carried by *A. dorsata* (109584) followed by *A. mellifera* (71827) and *A. cerana* (64180) while *Apis florea* carried the minimum number of loose pollen grains (42806) (Table 3) and these observations find support from Singh & Mall (2020) they revealed that *A. dorsata* have highest loose pollen grains carrying capacity (94516.6 pollen grains) followed by *A. mellifera* (90399.6), *A. cerana* (68093.1) and least loose pollen grains carrying capacity was observed in *A. florea* (46226.1 pollen grains) in *Cucumis sativus*. In contrast Chundawat et al. (1979) reported that *Musca domestica* was responsible for more pollen transfer then various *Apis* species in *Z. mauritiana*. However, the LPG on the body of P and N+P foragers were 76796 and 67403 respectively and these findings are supported by Devi et al. (1989), Diagne et al. (2019) and Singh & Mall (2020) they also reported that the pollen foragers have larger amount of loose pollen grains carrying capacity than nectar+pollen foragers.The current findings clearly demonstrated a relationship between body size and a selected honey bee species ability to transport loose pollen grains. The larger body size of *A. dorsata* carried the maximum load of pollens, the medium body size of *A. mellifera* and *A. cerana* carried intermediate loads of pollen, and the smaller *A. florea* carried the minimum load of pollens.

Table 3: Meannumberofloosepollengrainsstickingonthebody ofdifferent honey bee species foraging on Apple ber during 2022

Honeybeespecies	Meannumberofloosepollengrains		
	Pollen	**Nectar+Pollen**	**Mean**
Apisflorea	48966.00*	36646.00	**42806.00**
A.dorsata	117457.00	101710.00	**109584.00**
A.mellifera	74202.00	69452.00	**71827.00**
A.cerana	66557.00	61802.00	**64180.00**
CD(p≤0.05)	**1358**		**2716**

SE(m)	**443**		**887**
Mean	**76795.50**	**67403**	
CD(p≤0.05)	**1921**		
SE(m)	**627**		

*Values are the mean of 30 observations

Relative pollination efficiency (RPE) of four different honey bee species

The *A. dorsata* was the most efficient pollinators of Apple ber with the mean maximum RPE of 16.21 followed by *A. mellifera* (14.45) and *A. florea* (10.35) while *A. cerana* was the least efficient in terms of RPE (4.90) (Table 4). The other prominent observation emerged from the results that the honey bees foraging for the pollen (13.18) and Nectar+Pollen (13.05) were most efficient pollinators compared to those foraging for nectar alone with an RPE of (8.21).The P foragers of *A. dorsata* recorded maximum RPE of 21 that was followed by P foragers of *A. mellifera* (18.81), N+P foragers of *A. dorsata* (17.5) and N+P foragers of *A. mellifera* (15.67) and it is mainly because, *A. dorsata* carrying maximum loose pollen grain (109584.00), high foraging rate and highest rank in foraging speed that made *A. dorsata* more efficient pollinators then other three honey bee species while *A. mellifera* on the other hand recorded average foraging rate, foraging speed and moderate loose pollen grain carrying capacity.The foragers show lowest RPE value comprised of N+P foragers of *A. florea* (13),N foragers of *A. dorsata* (10.15), N foragers of *A. florea* (9.39), N foragers of *A. mellifera* (8.88) and P foragers of *A. florea* (8.67) and it is mainly because of minimum loose pollen grain carrying capacity of *A. florea* (42806.00)and in previous studies this confirms that nectar foragers are very less efficient pollinators and having less RPE of only (8.21). The lowest RPE recorded for N+P foragers of *A. cerana* (6.03), N foragers of *A. cerana* (4.43) and P foragers of *A. cerana* (4.26).The observations of Jat et al. (2017) are in support of the present findings who also reported that *A. dorsata* with a RPE of 13.0 was the most effective pollinators of *T. alexandrinum*, followed by *A. mellifera* (10.7) and *A. florea* was the least effective with an RPE as low as 3.6. These findings make it very evident that *A. dorsata* was the most effective pollinator of Apple berflowers.

Table 4: Relative pollination efficiency of different foragers (N, P, N+P) of four different honey bee species

Honey bee species	Nectar	Pollen	Nectar + Pollen	Mean
Apis florea	9.39	8.67	13	**10.35**
A. dorsata	10.15	21	17.5	**16.21**
A. mellifera	8.88	18.81	15.67	**14.45**
A. cerana	4.43	4.26	6.03	**4.90**
Mean	**8.21**	**13.18**	**13.05**	

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