

RESEARCH ARTICLE

Influence of Indian Honey Bees and Other Pollinators on The Yield Improvement of Moringa

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ABSTRACT

A pollinator survey was conducted in the Oddanchatram block of Dindigul district, where moringa is grown on a large scale. Several insect pollinators including honey bees, flies, beetles and butterflies were observed in the moringa ecosystem. The foraging behaviour of *A. ceranaindica* was increased during 0800 to 0900 h, followed by *Amegilla zonata*, and *Episyrpussp.* Working hours were high in *A. ceranaindica* followed by those of *Amegilla zonata*, *Polistessp.*, *A. dorsata*, and *Xylocopasp.* In terms of handling time, *A. ceranaindica* spent more time, followed by *A. dorsata*, *Amegilla zonata*, and *Xylocopasp.*, while *Polistes* sp. expended less time. The present study indicated that *A. ceranaindica* was the most abundant pollinator. Yield parameters viz., fruit length, fruit girth, individual fruit weight, and number of fruits per tree were maximum in bee pollinated than control. The colony growth parameters, viz., sealed honey area, pollen area, sealed brood area, and adult bee population, also developed in bee pollinated field. Therefore, by managing Indian honey bee colonies, we can make money on both moringa and colony yield.

Keywords: Indian honey bee; Foragingbehaviour; Moringa Yield; Colony growth parameters; Efficiency

INTRODUCTION

Pollinators are essential for the reproduction of many wildflowers and foods. Honey bees, bumblebees, solitary bees, hover flies, beetles, butterflies, and moths are the most frequently visiting insect pollinators (Ollerton *et al.*, 2011). Many vegetable crops depend on honey bees for their reproduction and seed set.

Moringa oleifera L., commonly known as moringa, is a vegetable native to India. It has nutritional and medicinal properties and serves as a multipurpose tree, hence the name "Miracle tree". It is a perennial, drought-tolerant, fast-growing, and one of the most useful trees in the world (Fuglie, 2005). In India, the cultivation of moringa occurs mainly in the southern states, especially Tamil Nadu. In Tamil Nadu, it is grown on about 7500 ha in Dindigul, Thoothukudi, Karur, and Erode districts. Globally, the moringa market is estimated at more than Rs. 27,000 crore, which is expected to cross Rs. 47,000 crore by 2020, growing at a rate of 9 percent per year. In India, moringa trees are grown on about 40,000 ha (India Agristat, 2018).

Moringa flowers twice a year, once in February–May and later in September–November. The flowers are highly cross-pollinated due to their heteromorphic nature. The moringa flowers are white to cream-coloured, zygomorphic, and gullet-type (Jyothi *et al.*, 1990). The size is 2.5 cm, and the white petals and yellowish sepals form a vertical line of symmetry, bending gracefully to offer up its anthers and stigma to bees and other pollinators. Its fruits are green-coloured, 20 - 30 cm-long fruits with globular seeds that have three papery wings (Ravikumar and Sheeja, 2012).

Pushpalatha and Hariprasad (2015) mentioned that during fertilisation, the maximum number of seeds (yield) is fixed. Moringa offers nectar and pollen as food sources for pollinators. Effective nototribic pollination in moringa was recorded in the presence of *Xylocopa* sp. and *Amegilla* sp., both of which carry pollen on the body and considered efficient foragers. The carpenter bees (*X. latipes*D. and *X. pubescens.*) have been found to be the most consistent and suitable pollinators in moringa. Sunbirds have also been observed to be vigorous pollinators. In spite of this, its pollination

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ecology and honey bee mediated fruit setting related studies have not been studied in depth. Hence, the current study was conducted to unveil the role of Indian honey bees in moringa pollination and its yield improvement.

MATERIAL AND METHODS

A local variety of Kappalpattimoringa trees cultivated in the Oddanchatram block of Dindigul district were selected for the study (Plate 1). It is situated at an altitude of 302 m above MSL and lies at 10° 30' 24.4" N latitude and 77° 50' 18.7" E longitude. The area receives good rainfall during the north-east monsoon (October to December). The minimum temperature ranges from 18°C to 21°C and the maximum from 30°C to 33°C, with a relative humidity of 70 to 85%.

In the orchard, five randomly selected trees were marked. In each randomly selected tree, five inflorescences were selected for studying the pollinator's abundance and foraging behaviour. The natural pollinator visitation per five inflorescences per 5 min was observed in each of the five trees, and the final data was expressed as pollinator count/25 inflorescences/5 min. This data was recorded every hour for 12 hours [from 0600 (6 a.m.) to 1800 (6 p.m.)]. Populations of insect visitors were recorded for a period of 10 days during peak flowering (after 20% of flowering) during February 2018, with each day's data serving as a replication; thus, ten replications were recorded. Pollinator visitation was recorded after the opening of flowers reached a stage when the petals changed to a light yellow or started to wither. Moringa pollen grains are very small (0.033 mm) and yellow in colour (Plate 2).

Floral handling time

The time spent by various pollinators on an inflorescence was recorded using a stopwatch and expressed in seconds per inflorescence. Observations were noted at peak flowering periods.

Working hours of insect visitors in moringa inflorescence

During the peak flowering period, the initiation and cessation times of pollinators were recorded. The time when they started foraging and stopped visiting the inflorescence was recorded for 10 days, and the mean was worked out.

Managing Indian honey bee colonies

The peak flowering of moringas was recorded in the moringa orchard. Pesticide spraying was avoided during the entire flowering period. The

Indian bee hives were transported into the orchard at night during peak flowering. Three Indian honey bee colonies with a young, mated queen with six frames of strength (with sufficient sealed brood and honey storage) were placed in the centre of the orchard. Observations were made during the peak flowering period by *in situ* counting insects. Hives were kept in the metal stand with a water pan to restrict the movement of ants and other insects.

Observations recorded

(i) In situ counting of pollinators

Insect visitors and pollinators found on moringa inflorescences were sampled. The number of honey bees and insect visitors visiting moringa inflorescences was counted by visual observation for 12 hours during peak flowering days. Observations were made on the number of insects visiting the 25 inflorescences / 5mins.

(ii) Number of fruits per plant

The number of fruits per plant was recorded at harvest for ten consecutive pickings starting on the 50th day after the start of flowering.

(iii) Size of fruit per plant

The length and girth of individual fruits were measured in every treatment and expressed in cm.

(iv) Fruit yield

The fruit yield (weight in kg) was recorded at each picking for ten consecutive pickings from five trees in each treatment and expressed as kg per tree. The individual fruit weight was recorded from twenty randomly selected fruits per tree from five trees and expressed as g/fruit.

Evaluation of the colony growth parameters of Indian bee hives kept in moringa orchards

(i) Area of sealed brood

Using a transparent OHP sheet with 1cm² markings, the sealed brood area was recorded. The total number of squares was counted and expressed in cm² (Plate 3).

(ii) Area of pollen storage

Pollen storage is important for the growth and health of the honey bees. The pollen storage area was also recorded, as said in sealed brood area counting (Plate 3).

(iii) Area of Honey Storage

The area of honey storage is an indication of the growth and prosperity of the colony. In general, honey bees store nectar in super frames. The area of honey storage was worked out as described in the sealed brood area (Plate 3).

(iv) The population of adult bees

The population of adult bees was also recorded using a transparent OHP sheet with grid markings. For each grid, the bee population was worked out and expressed as the number of bees per cm² (Plate 3).

Statistical analysis

The data obtained were subjected to statistical analysis employing complete randomized design (CRD) analysis, and means were compared with a critical difference (CD) using MS Excel.

RESULTS AND DISCUSSION

Study on pollinator abundance and foraging behaviour in moringa

A total of 27 species of pollinators were observed in the moringa ecosystem, among which the major insect pollinators were shown in Plate 4. The abundance of insect pollinators visiting moringa flowers at different times of the day was given in Table 1. The mean population of *Apis cerana indica* Fab. was at 0800 to 0900 h (4.80 / 25 inflorescences / 5 min), followed by 1000 to 1100 h (4.70/ 25 inflorescences / 5 min) and 1100 to 1200 h (4.50 / 25 inflorescences / 5 min). The mean population of *Amegilla zonata* L. was found to be maximum (2.33 / 25 inflorescences / 5 min) at 1200 to 1300 h, followed by 1100 to 1200 h (2.11 / 25 inflorescences / 5 min) and 0800 to 0900 h (2.00/ 25 inflorescences / 5 min). The population of *Episyrpus* sp. visiting moringa inflorescence was found to be high at 0800 to 0900 and 1000 to 1100 h (1.40 / 25 inflorescences / 5 min). The mean population of *Oriensgoloides* M. was higher at 0500 to 0600 h (1.00 / 25 inflorescences / 5 min), followed by 1200 to 0100 h (0.75 / 25 inflorescences / 5 min), 1000 to 1100 h, and 0200 to 0300 h (0.50 / 25 inflorescences / 5 min).

Floral handling time

Floral handling time varied depending on the rewards from the inflorescence. Among the foragers, *A. cerana indica* spent more time, followed by *A. dorsata* F., *A. zonata*, and *Xylocopa* sp., while *Polistes* sp. expended less time in moringa inflorescence (Figure 1).

Working hours in a day

The mean working period in a day for the important pollinators was worked out based on the time from the commencement of foraging to cessation (Figure 2). *A. zonata* arrived at the moringa inflorescences earliest, followed by *A.*

cerana indica. However, among the major pollinators, *A. cerana indica* has longer working hours, followed by *A. zonata*, *Polistes* sp., *A. dorsata*, and *Xylocopa* sp.

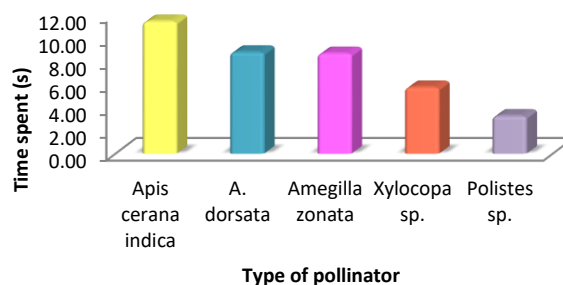


Figure 1. Floral handling by major insect pollinators on moringa flowers during a single visit

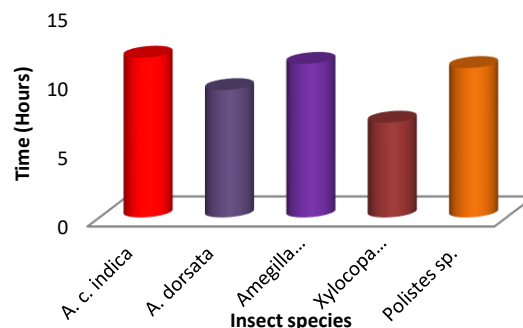


Figure 2. Working hours of major insect pollinators on moringa flowers

In situ enumeration of pollinators

The numbers of pollinators were recorded at both managed and unmanaged moringa orchards. The population of *A. cerana indica* visiting moringa inflorescence at the nearest point from the hive was significantly higher, with those visiting inflorescence at the control orchard being the minimum (Figure 3). While analysing the mean population of different pollinators at both fields from the hive, *A. cerana indica* was the highest, followed by *A. zonata*, *Xylocopa* sp., *A. dorsata*, *Polistes* sp., *Danaus chrysippus* L., and *Papilio polytes* L., which were significantly varying with each other. *Pieris rapae* L. was observed to have the lowest counts among the floral visitors.

Yield attributes of moringas, aided by the Indian bee colonies

This field experiment was conducted to quantify the role of pollination by Indian honey bees on the yield and yield parameters of moringa. The number of fruits per tree was significantly different from one another in both managed and control orchards (Figure 4). The fruit length was longer in the managed orchard (55.64 cm) than in the control (44.32 cm), with a 20.34% increase (Table 2). The

fruit girth in the managed field (7.92 cm) was higher than the control (7.86 cm) with a 1.10% increase, followed by the individual fruit weight, which was higher in the managed field (99.36 g) than the control (90.00 g) with a 9.42% increase. The number of fruits (202.00) and total fruit weight (41.32kg) were also higher in the managed field than the control (151.00 and 32.54) with a 25.24% and 21.30% increase, respectively.

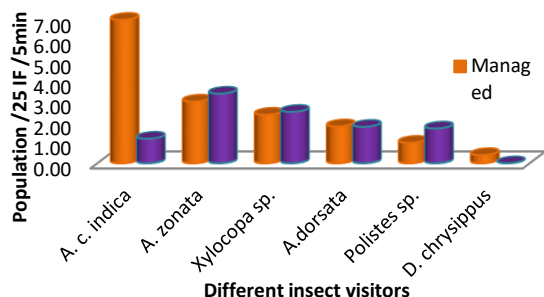


Figure 3. Pollinators range in managed and control field

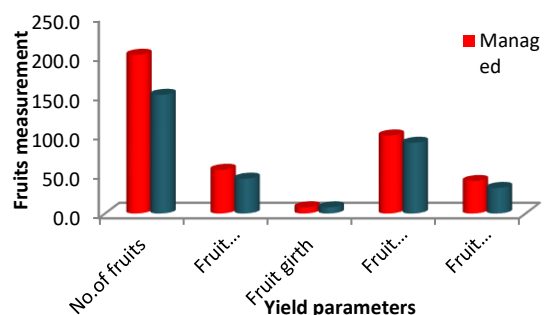


Figure 4. Yield parameters in managed and control field

Colony growth parameter from a hive of *A.ceranaindica*

The colony growth parameters, including sealed honey, pollen, sealed brood, and population of bees, were observed from the hive kept in a moringa orchard. There was an increase in colony growth during the period of the experiment. The sealed honey area (39.72%), pollen area (63.93%), sealed brood area (40.68%), and population of adult bees (52.6%) also increased within a month (Figure 5).

With respect to number of individuals and number of species, most pollinators belonged to the order Hymenoptera compared to others. Our studies are in line with earlier studies showing that moringa flowers produce both nectar and pollen, which attract bees and make them the main pollinators (Jyothi et al., 1990). Palanichamy et al. (1995) listed moringa as one of the pasturage plants of *Apisflore* F. Our observations are in concurrence with Chukunda (2016), who also

concluded that *Xylocopa* sp., *P.rapae*, and *D.chrysippus* are the important pollinators in moringa.

Relative abundance and peak foraging activities of the insect visitors during different hours of the day

The relative abundance and peak foraging activities of the insect visitors were higher during the morning hours. The mean population of *A. ceranaindica* was at its maximum at 0800 to 0900 h. Our results are in agreement with Said et al. (2015), who observed that *A. cerana* initiated their foraging activities on floral heads of sunflower early in the morning and ceased in the late or evening hours of the day, i.e., 1800 h. Individuals of *A. cerana* generally commence their foraging activity early in the morning hours, which reaches its peak in the noon hours of the day. Palanichamy et al. (1995) studied the pollen collection by *A. florea*, which was higher at about 10 h in moringa. Vasanthakumar et al. (2018) documented seventeen species of pollinators in mango inflorescences.

Yield improvement

The number of seeds produced in the fruits is directly associated with the number of pollen grains that reach the stigma and fertilise the oosphere. Bee pollination in the moringa orchard increased the number of fruits, fruit length, individual fruit weight, and final total yield. The pollination effectiveness in tomatoes was determined by measuring fruit set, size, weight, and seed content (Vincius-Silva et al., 2017). In the case of citrus, the quantity and quality of fruit production are influenced by bees (Malerbo-Souza et al., 2004). In avocado, the introduction of beehives during flowering significantly improves fruit set, yield, and the mean fruit weight (Vithanage, 1990).

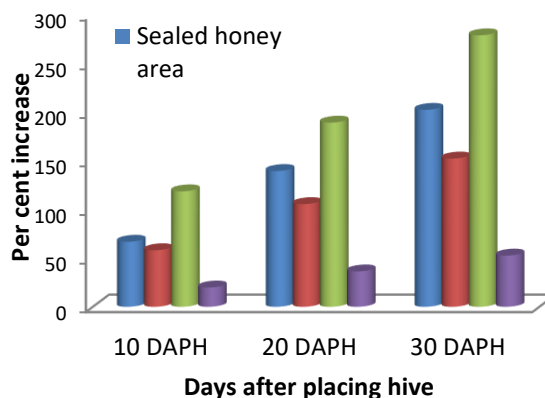


Figure 5. *A. cerana indica* colony growth parameters of hives

Plate 1. Indian bee colonies placed in a moringaorchrd at Oddanchatram, Dindigul District



Plate 2. Moringa flower and pollen under stereo zoom microscope

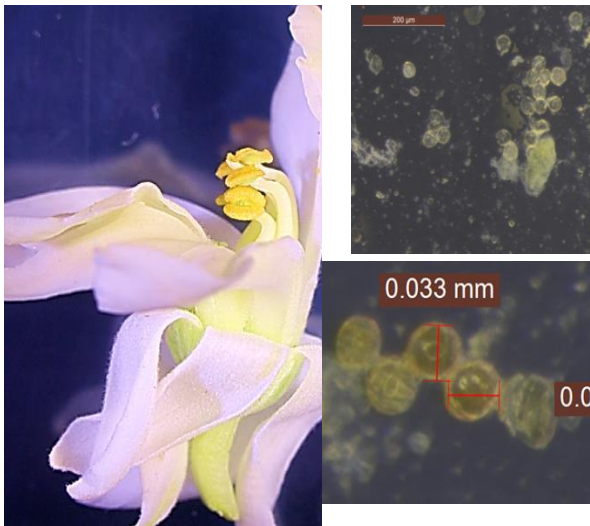


Plate 3. Transparent OHP sheet with grid markings used for counting measuring brood, pollen and honey areas adult bee population in a comb



Plate 4. Different floral visitors of moringa inflorescence



a. *A. ceranaindica*



b. *A. dorsata*



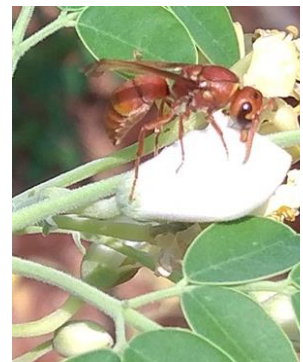
c. *A. zonata*



d. *A. quadifasciata*



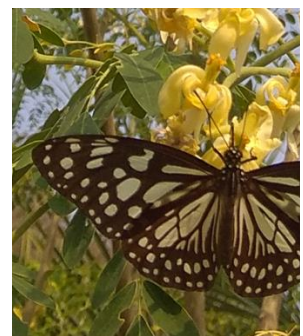
e. *Xylocopa* sp.



f. *Polistes* sp.



g. *P. polytes*



h. *Tirumalalimniace*C.



Table 1. Abundance of major insect pollinators on moringa inflorescence (25 inflorescences / 5 min)

Species/ Time of day	0600- 0700	0700- 0800	0800- 0900	0900- 1000	1000- 1100	1100- 1200	1200- 1300	1300- 1400	1400- 1500	1500- 1600	1600- 1700	1700- 1800	Mean
<i>A. ceranaindica</i>	0.40 (0.95) _b	1.90 (1.55) _a	4.80 (2.30) _a	4.00 (2.12) _a	4.70 (2.28) _a	4.50 (2.24) _a	3.80 (2.07) _a	3.30 (1.95) _a	3.20 (1.92) _a	3.60 (2.02) _a	4.00 (2.12) _a	2.10 (1.61) _a	3.36 (1.96) _a
<i>A. zonata</i>	1.13 (1.27) _a	0.88 (1.17) _b	2.00 (1.58) _b	1.90 (1.55) _b	1.78 (1.51) _a	2.11 (1.62) _{AB}	2.33 (1.68) _b	1.80 (1.52) _b	1.67 (1.47) _b	1.67 (1.47) _b	1.11 (1.27) _b	1.60 (1.45) _{AB}	1.66 (1.47) _b
<i>Episyrrhus</i> sp.	0.00 (0.71) _c	1.13 (1.27) _b	1.40 (1.22) _b	1.40 (1.38) _b	0.00 (0.71) _b	0.00 (0.71) _d	0.00 (0.71) _d	0.00 (0.71) _c	1.00 (1.22) _{bc}	1.25 (1.32) _b	1.22 (1.31) _b	1.00 (1.22) _b	0.67 (1.08) _c
<i>O. golooides</i>	0.00 (0.71) _c	0.00 (0.71) _c	0.00 (0.71) _c	1.00 (1.22) _c	0.50 (1.00) _b	1.00 (1.22) _c	0.75 (1.12) _c	1.00 (1.22) _b	0.50 (1.00) _c	1.00 (1.22) _b	1.00 (1.22) _b	1.00 (1.22) _b	0.65 (1.07) _c
Mean	0.38 (0.94) _D	0.98 (1.21) _C	1.95 (1.57) _A	2.08 (1.60) _A	1.74 (1.50) _{AB}	1.90 (1.55) _{AB}	1.72 (1.49) _{AB}	1.53 (1.42) _B	1.59 (1.45) _{AB}	1.88 (1.54) _{AB}	1.83 (1.53) _{AB}	1.43 (1.39) _B	
	Treatment		0.07										
	Hours		0.16										
CD @ 5%	T * H		0.30										

*Mean of ten observations, figures in parentheses are square root transformed values; in a column, means followed by common lower case alphabet (s) are significantly different. In a row means followed by a common upper case alphabet are significantly different.

Table 2. Mean of yield parameters between managed and control moringa orchards

Yield parameters*	Managed	Control	% increase
Number of fruits / tree	202.00	151.00	25.24
Fruit length (cm)	55.64	44.32	20.34
Fruit girth (cm)	7.92	7.86	1.10
Individual Fruit weight (Kg/fruit)	99.36	90.00	9.42
Total Fruit weight/tree (Kg/ tree)	41.32	32.54	21.30

*Mean of five trees yield (10 harvest)

CONCLUSION

Based on the present results, hymenopterans like *A. ceranaindica*, *Xylocopa* sp., *A. zonata*, and *A. dorsata* were the most efficient pollinators, followed by dipterans and lepidopterans. Most of the foragers visit moringa inflorescences during the morning hours, when the nectar flow is higher. The lowest pollinator abundance was observed in the early morning. *Xylocopa* sp. was the most visited insect species among all pollinators, but we couldn't manage it. While *A. ceranaindica* was the most abundant pollinator with the maximum working hours and handling time. Also, we can manage them in the moringa orchard; hence, they can be considered the most efficient pollinator in the moringa ecosystem. Maximum colony growth of the food storage area and adult bee population were observed in bee colonies. Also, moringa yield parameters, including fruit numbers and size, were improved by managing honey bees. By augmenting Indian honey bee colonies in moringa orchards, we can increase the quality and quantity of moringa fruits.

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Ethics statement

No specific permits were required for the described field studies because no human or animal subjects were involved in this research.

Consent for publication

All the authors agreed to publish the content.

Competing interests

There was no conflict of interest in the publication of this content

Data availability

All the data of this manuscript are included in the MS. No separate external data source is required.

Author contributions

Research work-SC, Idea conceptualization-SMR, Experiments-SC, Guidance-SMR, SA, Writing original draft -SC, Writing- reviewing & editing-SC, SMR, SA.

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