

Diversity and foraging behaviour of pollinators in cashew (*Anacardium occidentale* Linn.) in Kerala, India

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ABSTRACT: Among the flower visitors in cashew 12 species were documented as pollinators. These belong to Apidae (four), Halictidae (four), Megachilidae (three) under Hymenoptera, and Syrphidae (one) under Dipteran. Species abundance was highest for Halictidae (49%), followed by Apidae (42.38%). In Halictidae, *Halictus* sp.1 was more abundant (18.54%), followed by *Lasioglossum* sp. (16.56%); while in Apidae, *Apis cerana indica* (21.85%) followed by *Tetragonula* sp. (17.22%). In diversity indices, Simpson diversity index (D) showed 0.16, Shannon-Weiner index (H) of 2.03 and Berger-Parker index (d) of 0.22. Foraging activity peaked between 10:00 and 13:00 h, where *A. c. indica* was most prevalent (12-35%). Mean foraging rate was highest for *A. c. indica* (15.4 flowers/trip), followed by *Lasioglossum* sp. (7.2 flowers/trip), *Helophilus* sp. (6.2 flowers/trip) and lowest for *Tetragonula* sp. (2.8 flowers/trip); while mean foraging speed was highest for *Tetragonula* sp. (6.19 s/flower), followed by *Halictus* sp. 1 (5.74 s/flower), *Helophilus* sp. (5.64 s/flower) and lowest for *Hoplonomia* sp. (1.49s/flower). Nesting sites of *Ceratina hieroglyphica* and *C. binghami* were also observed during the study.

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KEY WORDS: Apidae, Halictidae, diversity, *Apis cerana indica*, *Tetragonula* sp., *Lasioglossum* sp., nesting sites, bee pasturage

INTRODUCTION

Pollination is a crucial process in nature. Only five per cent of crops in nature are self-pollinated; the other 95 per cent are cross-pollinated, with 10 per cent relying on wind and 85 per cent on animal

pollination (Tewari, 1983; Vanitha and Raviprasad, 2019). Insects do 90 per cent of animal pollination (Buchmann and Nabhan, 1996). Nowadays, the worldwide demand for pollination services has increased as a result of a net growth in the value, demand, and land dedicated to insect-pollinated

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crops in recent decades (Aizen *et al.*, 2019). Cashew, *Anacardium occidentale* L., is a significant export crop in the tropics and supports the social and economic advancement of several nations globally (Bezerra *et al.*, 2007; Masawe 2009). Portuguese explorers brought it to India, the East Indies, and Africa in the sixteenth century (Mitchell and Mori, 1987). Cashew inflorescence contains two types of flowers; staminate (male) and hermaphrodite (complete). Staminate flower can be identified by a long stamen surrounded by short ones within the corolla tube while in hermaphrodite flower a stigma is also present, which is longer than the stamen. Cashew flower consists of five sepals, and five petals. Flowers are white during anthesis but changes to pink or shades of red after a day. Most of the flowers dry up gradually. Typically, it takes three to five months for various cashew varieties to finish the sequential anthesis in an inflorescence. Less than 10 per cent of the flowers in an inflorescence are bisexual, despite the fact that the overall number of blooms ranges between 200 and 1600 over the course of 70 to 90 days of flowering (Pavithran and Ravindranathan, 1974). Due to its andromonoecious nature, cashew is particularly attractive to insects for cross-pollination. The longer stamen and shorter style of the hermaphrodite flower make self-pollination challenging. Numerous studies have shown that low productivity in cashew is largely due to insufficient pollination (Freitas *et al.*, 2002; Holanda-Neto *et al.*, 2002; Eradasappa and Mohana., 2016). Studies have also shown the influence of pollinators in fruit set of cashew (Reddi, 1993; Freitas and Paxton, 1996; Vanitha and Raviprasad, 2019). Bees (Freitas *et al.*, 2002), flies (Roubik, 1995), moths (Kevan, 1975) and even ants (Khoo *et al.*, 1982; Dantas de Araujo, 1994) are considered as cashew pollinators in many studies. However, information about efficient pollinators in cashew and their foraging behaviour is limited. Documentation of pollinators in different locations is very important as it helps to address pollination deficiency thereby increasing productivity of cashew. Thus, the present study was undertaken to document diversity, species richness and foraging behaviour of pollinating insects in cashew plantation.

MATERIALS AND METHODS

The present investigation was carried out at cashew orchards of Kerala Agricultural University (KAU)-Regional Agricultural Research Station, Pilicode, Kasaragod. The site is geographically located at 13°N; 75°E at an elevation of 15m MSL. Soil type is laterite with a pH of 5.5 to 6.5. The mean maximum and minimum temperature of the location is 33°C and 23°C respectively, and average annual rainfall is 3379mm. The staminate and hermaphrodite flowers in cashews were collected and familiarised with the help of a microscope. Various cashew germplasms were selected to document the diversity of pollinators in cashew. Pollinator diversity was assessed in selected cashew germplasms maintained under All India Coordinated Research Project on Cashew. Germplasm identities are withheld in accordance with project guidelines. Observations were recorded on ten randomly selected inflorescences from November 2023-March 2024. Insects visiting the inflorescences were collected using fine mesh aerial nets and were identified with the help of experts from National Bureau of Agricultural Insect Resources, Bengaluru and KAU. Abundance of pollinators were recorded by observing for ten minutes at hourly intervals during 08:00 to 15:00 h. Relative abundance of each species with respect to total species was also calculated and each species were placed in respective dominance classes given by Engelmann (1978), *i.e.* Eudominant (>32 -100 %), Dominant (32 - 10%), Subdominant (10 – 3.2 %), Recedent (3.2 – 1 %), Subrecedent (1 - 0.32%) and Sporadic (< 0.32%). Diversity indices like species richness (S), Shannon-Weiner diversity index (H), Simpson diversity index (D) and Berger-Parker index (d) were estimated using PAST software.

Foraging rate and foraging speed: Foraging rate and foraging speed of important species were also recorded by careful examination. Foraging speed is the time spent by a species on each flower. It was noted by using a stopwatch. The stopwatch was started when a pollinator sits on a flower and stopped when it flew away. Flying time from one flower to another was excluded. Foraging rate is the number of flowers visited by a species per trip

in the vicinity. The number of flowers visited by important species per trip was recorded at peak foraging hour. To find out the importance of pollinators in fruit set in cashew, bagging experiment was done, where ten inflorescences at bud stage was bagged to exclude any insect from visiting them and per cent fruit set was calculated.

RESULTS AND DISCUSSION

Diversity and abundance: Among all the insect species seen visiting cashew inflorescences, only twelve are considered as pollinators. Out of the 12 pollinators identified, four belongs to Apidae, four to Halictidae, three to Megachilidae and one to Syrphidae. In a study conducted by Sundararaju (2011), seven species such as *Pseudapis oxybeloides*, *Lasioglossum* sp. and *Halictus* sp. from family Halictidae and *Braunsapis* sp., *Ceratina smaragdula* and *Ceratina* sp. from family Apidae were identified from coastal Karnataka while *Ceratina (Pithitis) binghami* Cockerell, *C. smaragdula*, *Braunsapis* sp. and *P. oxybeloides* from coastal Tamil Nadu. According to Heard *et al.* (1990) *Apis mellifera* L., *Ligyra* sp. and *Helophilus hilaris* were efficient pollinators of cashew. Vanitha and Raviprasad (2019) identified

A. c. indica, *A. florea*, *Braunsapis picitarsus*, *Ceratina hieroglyphica*, *Tetragonula* sp., *Lasioglossum* sp., *Pseudapis oxybeloides* and *Seledonia* sp. as important cashew pollinators. Similarly, in this study 12 species were identified as pollinators and are listed in Table 1. Many species of ants were observed throughout the study, which may not be efficient pollinators. Bhattacharya (2004) states that ants are unlikely to act as pollinators as they search mainly for honeydew secretions by aphid or extra-floral secretions. Accidental pollination may occur due to their erratic movement but further studies are needed to confirm this.

Detailed observations regarding the abundance and foraging activity of pollinators at hourly intervals were also made (Table 2). During 08:00 to 09:00 h, the activity of only three species was observed, and *Tetragonula* sp. was most abundant with 64.29 per cent followed by *Helophilus* sp. (21.43%). The activity of pollinators was more significant when sunshine was bright. Foraging activity was highest from 10:00 -13:00 h when *A. c. indica* was most abundant (12-35%), followed by *Halictus* sp. 1 (16-25%), *Lasioglossum* sp. (16-25%), *Tetragonula* sp. (2-16%) and *Hoplonomia* sp. (2-13%).

Table 1 Relative abundance (RA) and dominance status of each pollinator species

No	Species	RA (%)	Dominant class	Family	Order
1	<i>Apis cerana indica</i>	21.85	Dominant	Apidae (42.38%)	Hymenoptera
2	<i>Tetragonula</i> sp.	17.22	Dominant		
3	<i>Ceratina hieroglyphica</i>	1.99	Recedent		
4	<i>C. binghami</i>	1.32	Recedent		
5	<i>Halictus</i> sp. 1	18.54	Dominant	Halictidae (49%)	
6	<i>Halictus</i> sp. 2	7.29	Subdominant		
7	<i>Lasioglossum</i> sp.	16.56	Dominant		
8	<i>Hoplonomia</i> sp.	6.62	Subdominant		
9	<i>Megachile cephalotes</i>	1.32	Recedent	Megachilidae (2.65%)	
10	<i>M. lanata</i>	0.66	Subrecedent		
11	<i>M. laticeps</i>	0.66	Subrecedent		
12	<i>Helophilus</i> sp.	5.96	Subdominant	Syrphidae (5.96%)	Diptera

Table 2 Foraging activities of pollinators in cashew during 2023-24

Time (h)	Relative abundance of pollinators (%)												Total no. Observed
	<i>Apis cerana indica</i>	<i>Tetragonula</i> sp.	<i>Halictus</i> sp. 1	<i>Halictus</i> sp. 2	<i>Helophilus</i> sp.	<i>Lastioglossum</i> sp.	<i>Hoplonomia</i> sp.	<i>Megachile cephalotes</i>	<i>M. lanata</i>	<i>M. laticeps</i>	<i>Ceratina hieroglyphica</i>	<i>C. binghami</i>	
8:00-9:00	14.29 (2)	64.29 (9)	0.00 (0)	0.00 (0)	21.43 (3)	0.00 (0)	0.00 (0)	0.00 (0)	0.00 (0)	0.00 (0)	0.00 (0)	0.00 (0)	14
9:00-10:00	21.74 (5)	39.13 (9)	4.35 (1)	0.00 (0)	8.70 (2)	17.39 (4)	8.70 (2)	0.00 (0)	0.00 (0)	0.00 (0)	0.00 (0)	0.00 (0)	23
10:00-11:00	12.90 (4)	16.13 (5)	16.13 (5)	6.45 (2)	3.23 (1)	25.81 (8)	12.90 (4)	3.23 (1)	0.00 (0)	3.23 (1)	0.00 (0)	0.00 (0)	31
11:00-12:00	19.44 (7)	5.55 (2)	25.00 (9)	8.33 (3)	2.77 (1)	16.66 (6)	8.33 (3)	2.77 (1)	2.77 (1)	0.00 (0)	5.55 (2)	2.77 (1)	36
12:00-13:00	34.29 (12)	2.86 (1)	22.86 (8)	8.57 (3)	5.71 (2)	17.15 (6)	2.86 (1)	0.00 (0)	0.00 (0)	0.00 (0)	2.86 (1)	2.86 (1)	35
13:00-14:00	27.27 (3)	0.00 (0)	45.45 (5)	18.18 (2)	0.00 (0)	9.09 (1)	0.00 (0)	0.00 (0)	0.00 (0)	0.00 (0)	0.00 (0)	0.00 (0)	11
14:00-15:00	0.00 (0)	0.00 (0)	0.00 (0)	100 (1)	0.00 (0)	0.00 (0)	0.00 (0)	0.00 (0)	0.00 (0)	0.00 (0)	0.00 (0)	0.00 (0)	1
Total (Nos)	(33)	(26)	(28)	(11)	(9)	(25)	(10)	(2)	(1)	(1)	(3)	(2)	151

Note: Figures in brackets are number of bee pollinators recorded

Table 3 Foraging speed, foraging rate and peak foraging hours of important pollinators in cashew

No	Species	Foraging rate (nos/trip)		Foraging speed (s)		Peak foraging hours (h)
		Mean	Range	Mean	Range	
1	<i>A. c. indica</i>	15.4	9-22	2.15	1-3	11:00-13:00
2	<i>Helophilus</i> sp.	6.2	4-9	5.64	4-7	8:00-10:00
3	<i>Lasioglossum</i> sp.	7.2	4-10	2.03	1-4	10:00-13:00
4	<i>Halictus</i> sp.1	5.4	3-8	5.74	4-7	10:00-13:00
5	<i>Tetragonula</i> sp.	2.8	2-4	6.19	4-9	8:00-11:00
6	<i>Hoplonomia</i> sp.	4.4	2-7	1.49	1-3	10:00-12:00
7	<i>Halictus</i> sp.2	4.2	3-6	2.17	1-4	11:00-13:00

Pollinator activity decreased afterwards, especially during evening hours. Heard *et al.* (1990) also revealed that nocturnal insects have no role in pollinating cashew. As per Singh and Adhikary (2021) honeybee pollination can enhance both the quantitative and qualitative traits of many fruit crops depending on the site conditions. Anthesis in cashew starts at 06:00 and is completed by 10: 00 h, but stigma receptivity is maximum after 6 hours, at around 12:00 noon (Pushpalatha, 2000). Since the peak foraging of pollinators occurs during forenoon when flowers are open and receptive, effective pollination takes place.

Diversity indices such as Shannon-Weiner Diversity Index (H), Simpson Diversity Index (D), Species Richness (S), and the Berger-Parker Index (d) was calculated for pollinators observed during the study period. A total of 12 pollinator species were recorded during the study, indicating a species richness of 12. The Simpson diversity index ($D = 0.155$) and the Shannon–Wiener index ($H = 2.029$)

reflect a high level of pollinator diversity in cashew at the study site. Furthermore, a Berger–Parker index value of 0.22 suggests that the pollinator community was relatively evenly distributed, with no single species exerting dominance.

Foraging rate and foraging speed: Mean foraging rate was highest for *A. c. indica* (15.4 flowers/ trip) followed by *Lasioglossum* sp. (7.2 flowers/ trip), *Helophilus* sp. (6.2 flowers/trip), and *Halictus* sp. 1 (5.4 flowers/trip). It was least for *Tetragonula* sp. (2.8 flowers/trip). Increased foraging rate ensures the delivery of pollen grains thereby increase the fruit set (Mitchell and Waser, 1992). Mean foraging speed was found to be maximum for *Tetragonula* sp. (6.19 s/flower) followed by *Halictus* sp. 1 (5.74 s/flower) and *Helophilus* sp. (5.64 s/flower); and the least for *Hoplonomia* sp. (1.49s/flower). Peak foraging hours also differ with species. Sundararaju (2011) recorded the time spent by pollinators on cashew flowers in the range of 0.8 - 9.0s for *A. c. indica*, 1.2- 22.2s for *A. florea*,

5.0- 25.1s for *Ceratina binghami* and 2.0- 22.0s for *Braunsapis* sp. while Vanitha and Raviprasad (2019) noted that *A. c. indica* spent 1-4 s, *A. florea* 3-21s, *B. picitarsus* 8-16s and *Pseudapis oxybeloides* 1-4s. The number of flowers visited by these bees falls in the range of 6-20, 3-11, 4-7 and 2-5 respectively (Table 3). Foraging speed may vary between species based on their foraging behaviour or flower structure (Free, 1993).

Fruit set: From the bagging experiment done to take observation regarding fruit set in cashew, no fruit development was recorded in bagged inflorescences, as all flowers dried and became damaged. Fruit set was observed in all unbagged, open-pollinated inflorescences, highlighting the crucial role of pollinators in cashew yield. Despite successful pollination in unbagged inflorescences, the overall fruit set was low (reaching only 7.17%). This finding agrees with Vanitha and Raviprasad (2020), who reported a comparable fruit set (7.96%) under open pollination. They also emphasized that hermaphrodite flowers require pollination within four hours of peak stigma receptivity, indicating the necessity of adequate pollinator populations for improved cashew yield.

Nesting sites: Even though *A. c. indica* was observed in the field; bee hives were not on site. Nevertheless, this study identified nesting sites of two pollinators, *Ceratina hieroglyphica* and *C. binghami*, inside dried branches of cashew trees. Mostly, they occupy stumps left after the pruning of branches. A typical nest has a clean circular entrance hole, which helps identify it. The adult insects scoop out the soft central pith region to make the nests. The entrance hole of *C. hieroglyphica* nest was about 3.1mm wide, and the nest was about 15cm deep. Different life stages were observed inside the nest, separated by cells made of powdered wood. Cells containing younger stages were seen towards the entrance, while older stages were in deep cells. The nest of *C. binghami* was 3.3mm wide and about 13cm deep. These findings are in line with those observed by Vanitha (2023). Even though nests of these two species were observed in the field, they rarely visited the cashew inflorescences.

Bee pasturage/ bee flora: Vegetation that provides pollen and nectar to the bees are collectively called bee pasturage/ bee flora. Understanding flowering plants that are valuable as bee pasture will help in maintaining the bee colonies. In our preliminary study during limited period, mainly three species such as *Stachytarpheta* sp., *Mimosa pudica* and *Rungia* sp. were noted as bee pasture. *Ceratina* spp. were attracted to *Stachytarpheta* sp., *Mimosa pudica* and *Rungia* sp. while *Megachile* sp., *A. c. indica* and *Tetragonula* sp. were attracted to *Mimosa pudica*. Sundararaju (2011) reported the presence of cashew pollinators on *Mimosa pudica*, *Blumea* sp., *Acacia pennata*, *Rungia repens*, *Lindernia antipoda*, *Leucas aspera*, *Muntingia calabura* etc. Further studies on different bee pasturage existing near the plantations, flowering phenology and pollinator abundance will help to understand the foraging range of bees, their choice of flora, survival during non-flowering period etc. and thereby make sure the conservation of pollinators during off season.

Documentation of cashew pollinators is fundamental for elucidating their importance in pollination and ecosystem functioning. In the study location, twelve species of insects were identified as pollinators of cashew, among which the Indian honeybee, *A. c. indica*, was most abundant. Knowledge regarding important pollinators, nesting sites, and bee pasturage can help researchers and farmers conserve efficient pollinators, thereby increasing the productivity of cashew plantations. Understanding peak hours of foraging can ensure proper conservation of these pollinators by protecting them from pesticide sprays. A proper understanding of their activity and bee flora can provide favourable conditions for pollinators during the off-season.

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