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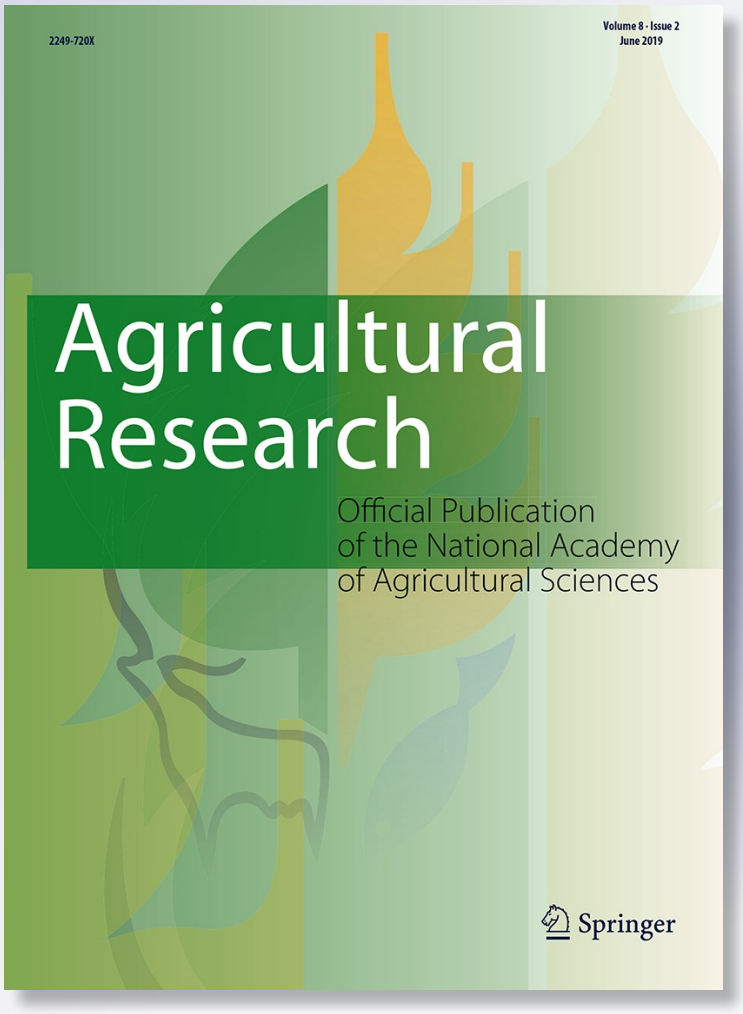

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FULL-LENGTH RESEARCH ARTICLE

Diversity, Species Richness and Foraging Behaviour of Pollinators in Cashew

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Abstract Insect visitors documented on cashew flowers during the present investigation include 40 species belonging to 13 families of three insect orders. The Hymenopterans were the major floral visitors comprising of bees, ants and wasps followed by dipterans. Among the 40 species recorded as flower visitors, only 13 are considered as pollinators of cashew, in which eight belong to Apidae and five belong to Halictidae. Among the two bee families, Apidae was the most abundant contributing 75.6% of the bee abundance. Within Apidae, the highest species abundance was recorded for *Braunsapis picitarsus* (20%) followed by *Apis cerana indica* (16.7%). Halictidae bees contributed to 24.4% of bee abundance, among which *Pseudapis oxybeloides* was most abundant (17.6%). Peak bee activity was recorded between 11.00 and 13.00 h for most of the bees. During 10.00–13.00 h, *B. picitarsus* was the most abundant (22–31%) followed by *P. oxybeloides* (18–25%), *A. c. indica* (12–15%), *Ceratina* sp. (8–13%) and *A. florea* (6–14%). Foraging rate was more for *A. c. indica* followed by *B. picitarsus* and *A. florea*. Lesser time was spent by *A. c. indica* for nectar and *P. oxybeloides* for pollen (i.e. 1–4 s), while longer time of 3–21, 8–16 and 5–11 s was spent by *A. florea*, *B. picitarsus* and *Tetragonula* sp., respectively. Bees of *C. hieroglyphica*, *Lasioglossum* sp. and *Seledonia* sp. spent 2–6 s per flower. Foraging rate was higher in *A. c. indica* and *B. picitarsus*, while foraging speed was lesser in *A. c. indica* and *P. oxybeloides*. Nesting sites of different bee species and the common bee flora in the study area were also recorded.

Keywords Cashew · Pollen · Anthers · Foragers · Nests · Activity · Bees · *Apis cerana indica* · *Apis florea* · *Braunsapis picitarsus* · *Ceratina hieroglyphica* · *Tetragonula* sp. · *Lasioglossum* sp. · *Pseudapis oxybeloides* · *Seledonia* sp.

Introduction

Pollination plays an important role in the reproduction and fruit set of flowering plant communities [6, 8]. In nature, only five per cent of the crops are self-pollinated and remaining 95% are cross-pollinated, in which 10% depend upon wind and 85% on animal pollination [32], in which insect pollination alone accounts 90% of animal pollination [6]. Cashew (*Anacardium occidentale* L., Fam: Anacardiaceae) is also an insect-pollinated crop being cultivated over an area of 10.72 lakh ha in India with an annual production of 7.25 lakh ton during the year 2014–2015 [9]. Cashew is andromonoecious having sticky pollen and even longer stamen of the hermaphrodite flower is shorter than style, thus making self-pollination difficult and hence favouring cross-pollination by insects. Several studies showed that fruit set in cashew is mainly influenced by activity of pollinators [12, 26]. Flies [27], moths [18] and bees [5, 14, 15] have been recorded as the major cashew pollinators worldwide, but little information is available about the effective pollinators of cashew, their foraging behaviour and their pollination efficiency. Hence, it is imperative to understand and address the issue of pollination in cashew so as to increase the productivity. Documentation is very important with relevance to pollinator diversity in a particular locality, followed by their

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abundance and foraging behaviour. Hence, the present investigation has been taken up to document insect pollinator diversity in cashew, their abundance and foraging behaviour in Puttur region of Karnataka, India.

Materials and methods

The present study was carried out in 40 ha of cashew plantations of ICAR-Directorate of Cashew Research, Puttur, Karnataka. The region is a hilly track between the West Coast and the Western Ghats of India, located at 12.77°N and 75.22°E at an average elevation of 87 metres. The vegetation cover of the study site was dominated by cashew which was grown as a monocrop, but areca nut (*Areca catechu*), rubber (*Hevea brasiliensis*) and other forest cover surrounds the study site. Weather parameters prevailed at the study location during the observations are given in Table 1. To record the diversity of insect visitors/pollinators, the observations were made daily on randomly selected cashew trees in full bloom at regular intervals, and insect species visiting cashew flowers regularly and repeatedly were recorded between January and May of 2015 and 2016. The flower visitors were collected with fine mesh sweep nets and got identified with the help of experts at National Bureau of Agricultural Insect Resources, Bengaluru, and University of Agricultural Sciences, GKVK, Bengaluru, and the voucher specimens submitted at these institutes.

Abundance of different insect visitors/pollinators was studied in different fixed plots having 3–8-year-old cashew plants of Bhaskara variety. The total number of different insects visiting on ten randomly selected inflorescences was observed for 10 min at hourly intervals from 800 to 1700 h. The observations were recorded when cashew was at full bloom during 20 different days and mean was calculated. The relative abundance of each species/group was also calculated in relation to total species. The bee diversities of the cashew plantations were estimated from the data set of the field studies conducted in 2014–2017. The richness (S) of the bee species was estimated based on the efficient pollinators of cashew. The Simpson index (D), Shannon diversity index (H) and Berger–Parker index (d) were calculated as follows:

$$D = N(N-1)/\sum n(n-1); \quad H = \sum Pi * (LN(Pi)); \quad d = N\max/N,$$

where pi is the proportion of individuals found in species i estimated as $pi = ni/N$, where ni is the number of individuals in species I and N is the total number of individuals.

Foraging activity, visitation rate and time spent on each flower of important insect pollinators were also recorded by careful visual observation using stop clock. To record the foraging rate of pollinators, the number of flowers visited by important species per trip in vicinity was recorded at peak foraging hour. Foraging speed of

Table 1 Weather parameters prevailed during observational period at the study location during 2015 and 2016 *Source*: DCR Annual Report 2015 and 2016

Month	Temperature (°C)		Humidity (%)		Rainy (day)	Rainfall (mm)	Mean wind velocity (km/h)	Sunshine (h)	Pan Evaporation (mm)
	Max	Min	FN	AN					
2015									
Jan	33.8	19.4	78	38	0	0	2.1	8.2	3.5
Feb	35.7	20.7	72	36	0	0	2.4	8.3	3.6
Mar	33.6	22.7	83	48	0	2.0	2.7	8.0	4.3
April	37.2	22.3	88	52	0	0	2.7	7.4	6.2
May	33.9	24.0	90	58	5	210.0	2.1	4.5	4.7
Jun	31.2	24.5	90	75	16	500.0	2.6	3.6	2.8
2016									
Jan	34.6	22.1	79	41	0	0	1.7	7.6	7.3
Feb	34.9	22.4	75	39	0	0	2.2	7.7	4.0
Mar	35.3	25.1	76	45	0	0	2.8	8.0	4.4
April	35.0	25.6	69	48	1	6.6	3.0	8.8	5.3
May	36.1	25.0	79	58	8	98.5	2.7	7.0	3.7
Jun	30.2	22.8	90	84	25	836.7	2.1	1.8	2.2

Rainfall is the monthly total, while other parameters are monthly mean values

important pollinators was recorded in terms of time spent on each flower at peak activity following the method of Free [11]. The common flowering weed plants in and around cashew plantations were also observed for the flower visitors of cashew, and the important flora was identified by consulting the experts. The weather parameters during the observation period were provided as table.

Results and Discussion

In general, different cashew types require 3–5 months to complete the sequential anthesis in an inflorescence. Although the total number of flowers in an inflorescence varies from 200 to 1600 over a period of 70–90 days of flowering period, less than 10% of those are bisexual flowers [23]. Insect visitors documented on cashew flowers during the present investigation include 40 species belonging to 13 families of three insect orders. The Hymenopterans were the major floral visitors comprising of bees (belonging to Apidae and Halictidae), ants and wasps followed by dipterans (Table 2). The list excluded pests of cashew flowers (several lepidopterans, hemipterans and coleopterans damage cashew flowers), predators (except ants and wasps that visit cashew flowers for nectar from extra floral nectarines [EFN] and floral nectar, respectively) and parasitoids of cashew pests which are not pollinators. The present investigation revealed that cashew flowers are visited by diverse group of insects. However, some species visited cashew flowers with less frequency and not collecting pollen grains, hence considered as flower visitors but not pollinators. In mango (*Mangifera indica* F.), another member of same Anacardiaceae family, wasps, ants, flies, butterflies, beetles, bees as well as wind were regarded as pollinators [2, 3], wherein dipteran flies (*Stomorhina* sp., *Chrysomya* sp., and *Sarcophaga* sp.) were reported as important pollinators [16], which is not the case in cashew. Insect pollinators visiting cashew flowers for pollen or nectar and carrying considerable amount of pollen grains on their body parts were considered as pollinators.

Among the 40 species recorded as flower visitors of cashew, only 13 are considered as pollinators of cashew, in which eight species belong to Apidae and five species belong to Halictidae. Earlier, Sundararaju [29, 30] had recorded halictid bees, namely *P. oxybeloides* (Smith), *Lasioglossum* sp. and one unidentified species, and honey bees, namely *A. c. indica* and *A. florea*, on cashew flowers in coastal Karnataka. Subsequently, seven bee species from coastal Karnataka and four species from coastal Tamil Nadu were reported as pollinators of cashew [31]. As per Frietas [13], *Apis mellifera* L. and *Centris tarsata* Smith were the efficient pollinators of cashew in Brazil, the home of cashew. Many of the dipterans are just visitors of cashew flowers, not foraging into the flowers to collect pollen or nectar, and their exact role is yet to be studied. Similarly, wasps like sphecids and vespids move among cashew flowers frequently which might be for nectar as well as prey insects. Similarly, several ant species move over the cashew inflorescence throughout the day period in abundance, but the major need is for EFN at the base of flowers and buds as well as the honey dew from certain sucking pests attacking cashew inflorescences. Still, the erratic movement of ants over the flowers may collect pollen and pollinate the flowers, which need further analysis. In mango also, it was observed that ants like *Camponotus* sp. and *Iridomyrmex* sp. were continuously moving on sepals and petals of each flower avoiding the middle part of the flower [16].

Based on the observations on foraging activity of different flower visitors recorded in cashew during the study, 13 bee species were considered as pollinators of cashew. Among the two bee families, Apidae was the most abundant with eight species contributing 75.6% of the bee abundance. And within Apidae, the highest species abundance was recorded for *Braunsapis picitarsus* (20%) followed by *A. c. indica* (16.7%) (Table 3). 24.4% of bee abundance was by Halictidae bees comprising of five species, among which *P. oxybeloides* was the most abundant species (17.6%). This is in accordance with Sundararaju [30] who reported *P. oxybeloides* as dominant halictid bee visiting cashew in coastal Karnataka region. It should be noted that relative abundance of bee species on cashew may vary with location. In general, the species dominance largely depends on the adaptability of the population with reasonable influence of weather parameters [22] and varies with location. Diversity indices of prominent bee pollinators of cashew were calculated. Simpson diversity index of 0.11 and Shannon diversity index of 2.3 show rich diversity of bees in cashew plantations of the study location. Similarly, Berger–Parker index of 0.21 reveals that bee population is not dominated by a single species, which is also apparent from the relative abundance of bees where abundance of predominant species itself is 20% and closely followed by other species (Table 4).

Based on the abundance and foraging activity, eight bee species were considered as main pollinators of cashew, viz. *A. c. indica, A. florea, Braunsapis picitarsus, Ceratina hieroglyphica, Tetragonula* sp., *Lasioglossum* sp., *Pseudapis oxybeloides* and *Seledonia* sp. (Fig. 1). Hence, detailed observations were made on these eight species. During morning hours between 8.00 and 9.00 h, only three bee species were noticed foraging on cashew inflorescences, in which *Tetragonula* sp. was the abundant (80%) followed by *A. c. indica*. The stingless bees were actively

Table 2 List of flower visitors of cashew at Puttur, Karnataka

Sl. no.	Common name	Scientific name	Family	Order
1	Reed bees	*Braunsapis picitarsus* (Cameron)[a]	Apidae	Hymenoptera
2	Small carpenter bee	*Ceratina hieroglyphica* Smith[a]	Apidae	Hymenoptera
3	Small carpenter bee	*Ceratina binghami*[a]	Apidae	Hymenoptera
4	Small carpenter bee	*Ceratina* sp.	Apidae	Hymenoptera
5		*Braunsapis* sp.[a]	Apidae	Hymenoptera
6	Sweat bee	*Pseudapis oxybeloides* Smith[a]	Halictidae	Hymenoptera
7	Sweat bee	*Pseudapis* sp.	Halictidae	Hymenoptera
8	Sweat bee	*Lasioglossum* sp. 1[a]	Halictidae	Hymenoptera
9	Sweat bee	*Lasioglossum* sp. 2	Halictidae	Hymenoptera
10	Sweat bee	*Seledonia* sp.[a]	Halictidae	Hymenoptera
11	Asian hive bee	*Apis cerana indica* F.[a]	Apidae	Hymenoptera
12	Indian little bee	*Apis florea* L.[a]	Apidae	Hymenoptera
13	Stingless bee	*Tetragonula* sp.[a]	Apidae	Hymenoptera
14	Potter wasp	*Eumenes* sp.	Vespidae	Hymenoptera
15	–	*Antepipona* sp.	Vespidae	Hymenoptera
16	Blow fly	*Stomorhina*	Calliphoridae	Diptera
17	–	Undetermined sp.	Calliphoridae	Diptera
18	–	Undetermined sp.	Sciaridae	Diptera
19	–	Undetermined sp.	Tabanidae	Diptera
20	Hover fly	*Paragus* sp.	Syrphidae	Diptera
21	Hover fly	*Ischiodon scutellatis*	Syrphidae	Diptera
22	Hover fly	Undetermined sp.	Syrphidae	Diptera
23	–	Undetermined sp.	Cecidomyidae	Diptera
24	–	Undetermined sp. 1.	Bombyliidae	Diptera
25	–	Undetermined sp. 2.	Bombyliidae	Diptera
26	–	Undetermined sp.	Muscidae	Diptera
27	Carpenter bee	*Xylocopa* sp.	Apidae	Hymenoptera
28	–	*Chalybion bengalense*	Sphecidae	Hymenoptera
29	–	Undetermined sp.	Lycaenidae/nymphalidae	Lepidoptera
30	Carpenter ant	*Camponotus compressus* F.	Formicidae	Hymenoptera
31	Black golden ant	*Camponotus sericius* F.	Formicidae	Hymenoptera
32	–	*Prenolepis naoroji* Forel	Formicidae	Hymenoptera
33	Yellow Crazy ant	*Anaplolepis gracillipes* Smith	Formicidae	Hymenoptera
34	Weaver ant	*Oecophylla smaragdina* (F.)	Formicidae	Hymenoptera
35	Cocktail ant	*Crematogaster* sp.	Formicidae	Hymenoptera
36	–	*Monomorium* sp.	Formicidae	Hymenoptera
37	Short legged hunchback ant	*Myrmecaria brunnea* Saunders	Formicidae	Hymenoptera
38	White footed ghost ant	*Technomyrmex albipes* Smith	Formicidae	Hymenoptera
39	Odour ant	*Tapinoma melanocephalum* F.	Formicidae	Hymenoptera
40	Arboreal bicoloured ant	*Tetreponera rufonigra* Jerdon	Formicidae	Hymenoptera

[a]Important and abundant species

moving over the panicles mostly for EFN from leaves, flower base, developing nuts and fruits, nectar, etc. When there was sufficient sunshine, activities of other bee species were noticed and the peak bee activity was noticed from 11.00 to 13.00 h for most of the bees except *Tetragonula* sp. During 10.00 to 13.00 h, *B. picitarsus* was the most abundant species (22–31%) followed by *P. oxybeloides* (18–25%), *A. c. indica* (12–15%), *Ceratina* sp. (8–13%) and *A. florea* (6–14%) (Table 5). Later, a drastic decrease in bee abundance was observed during afternoon and

Table 3 Relative abundance of Hymenopteran bee pollinators of cashew

Sl. no.	Family	Species	Species abundance (%)	Total abundance (%)
1	Apidae	*Apis cerana indica*	16.7	73.4
2		*Apis florea*	10.3	
3		*Braunsapis picitarsus*	20.0	
4		*Braunsapis* sp.	8.1	
5		*C. hieroglyphica*	11.4	
6		*Ceratina binghami*	1.5	
7		*Ceratina* sp.	0.4	
8		*Tetragonula* sp.	5.0	
9	Halictidae	*Lasioglossum* sp. 1	2.2	26.6
10		*Lasioglossum* sp. 2	0.6	
11		*P. oxybeloides*	17.6	
12		*Pseudapis* sp.	3.1	
13		*Seledonia* sp.	3.1	

Table 4 Diversity indices of hymenopteran bee pollinators of cashew

Diversity indices	
Richness	13.00
Simpson index	0.11
Shannon index	2.30
Berger–Parker index	0.21

evening hours. When the inflorescences were exposed for insect visits between 17.50 and 8.30 h alone, there was no fruit set, indicating the possibility of any crepuscular pollinators of cashew to be rare (Vanitha, unpublished). Besides, pollinator exclusion studies by bagging experiments indicated that bees are efficient pollinators of cashew increasing fruit set, and effective fruit production requires more activities of bees [5], which shows the ecological service provided by bees in cashew.

Most species of bees visited the flowers simultaneously, and activities of *A. c. indica*, *A. florea* and *Tetragonula* sp. were noticed throughout the observation period. In rapeseed, mustard and certain oil seeds, visitation frequency of *A. dorsata*, *A. mellifera* and *A. florea* was low in the morning and reached peak between 11.00 and 13.00 h and again declined in the evening [17, 28]. In Haryana, Chaudhary [7] reported that the solitary bees (viz. *Nomia curvipes* F., *Megachile hera* Bingham, *Braunaspis moderata* Cam, *Chalcidoma creusa* F., *Sphicods fumipennis* Smith, *Bombus* sp., *Xylocopa* sp. and *Andrena sacrissima* Cameron) started foraging late (around 10.00 h), compared with social bees that foraged from 09.00 h onwards on rapeseed and mustard. As reported earlier by Mevetty et al. [20], the density of insects on blossom depends on several factors including floral characters and weather conditions. In Niger, peak foraging period of *Halictus* sp. was seen at 12.00 h and of *Ceratina* sp. in mustard at 10.00 h [22]. The foraging activity of the bee species on cashew drastically reduced when there were wind and intermittent rains, and resumed when the conditions turned normal. This confirms with earlier reports of Prasad et al. [24] and Verma [33], who reported that the foraging activity of pollinators was negatively related to relative humidity and wind velocity.

In the present observation, mean number of bees observed was just 0.062 per inflorescence/10 min during 8.00–9.00 h, 0.67 during 11.00–12.00 h and just 0.03 during 16.00–17.00 h (derived from Table 4). Earlier, visit of 2–3 numbers of *A. c. indica* and 2–5 numbers of *P. oxybeloides* in 15 inflorescences during a period of 20 min was documented by Sundararaju [31]. Peak anthesis of cashew flowers occurs between 9.00 and 11.00 h [25] and more than 85% open during forenoon hours. It is important to note that peak foraging period of pollinators occurs when maximum flowers remain open, which is very much advantageous for effective pollination in cashew.

Foraging rate in terms of number of flowers visited/trip was more for *A. c. indica* (6–20) followed by *A. florea* (3–11) and *B. picitarsus* (4–7), while most of the other bees visited 2–5 flowers per trip (Table 6). High visitation frequency of bees may increase the chances of pollen delivery and thus enhance the chance that a flower matures into a fruit [21]. Among the flower visitors of mango, *Chrysomya* displayed higher visitation frequencies and visited more flowers within the allotted time [16]. The pollen load/bee species was maximum in *P. oxybeloides*, *B. picitarsus* and *Seledonia* sp. The cashew pollen grains

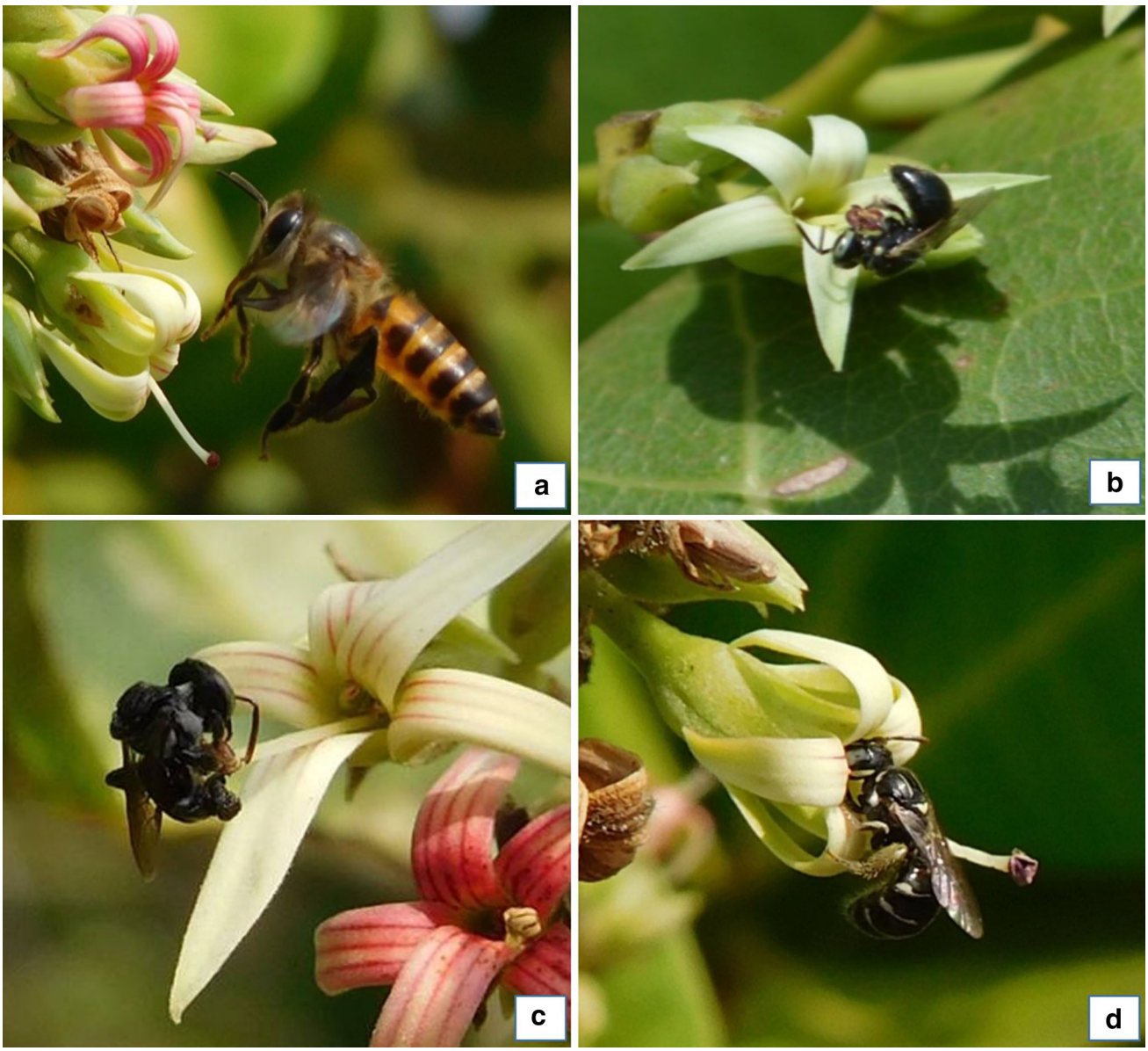

Fig. 1 Foraging of common bee species on cashew flowers **a** *A. c. indica*. **b** *B. picitarsus*. **c** *Tetragonula* sp. **d** *C. hieroglyphica*

collected on different body parts of common bee species are provided in Fig. 2. Foraging speed in terms of time spent on each cashew flower varied between bee species. Whenever pollen was collected, the time spent on a flower was minimum for collection of either pollen or nectar than collection of both. Time spent by *A. c. indica* for nectar and *P. oxybeloides* for pollen was short (i.e. 1–4 s), while it was 3–21, 8–16 and 5–11 s for *A. florea*, *B. picitarsus* and *Tetragonula* sp., respectively. Bees of *C. hieroglyphica*, *Lasioglossum* sp. and *Seledonia* sp. spent 2–6 s on individual flower. Earlier, Sundararaju [30, 31] recorded time spent per flower by *P. oxybeloides, A. c. indica*, *A. florea*, *C. binghami* and *Braunsapis* sp. as 1–18, 0.8–9.0, 1.2–22.2 and 5–25.1 and 2–22 s, respectively. In mustard, foraging speed of *Trigona* sp., *Halictus* sp. and *Ceratina* sp. varied widely between 2–58, 3–90 and 2–110 s per flower, respectively [22]. The difference in the time spent on the flowers may be dependent on many factors such as the size of flower and also the amount of viscosity of the nectar present in the flowers. Further, foraging speed of the insect depends upon foraging behaviour of the visitors and floral structure of the crop [11].

Bees, in general, visited cashew flowers for nectar and pollen as closely observed visually. Certain bees visited mainly for pollen, while a few bees for nectar and EFN (Table 7). For *Tetragonula* sp., foraging reward was nectar from EFN following pollen and nectar. Sundararaju [30] also had reported nectar and pollen collection by *T.*

Table 5 Temporal variation in foraging activity of major insect pollinators of cashew

Time (h)	Relative abundance of major pollinator species (%)								Insects observed (nos)
	A. c. indica	*A. flora*	*Braunsapis* sp.	*Pseudapis* sp.	*Ceratina* sp.	*Seledonia* sp.	*Lasioglossum* sp.	*Tetragonula* sp.	
8.00–9.00	16.00 (4.0)	4.00 (1)	0.00 (0)	0.00 (0)	0.00 (0)	0.00 (0)	0.00 (0)	80.00 (20)	25
9.00–10.00	13.73 (7)	7.84 (4)	5.88 (3)	5.88 (3)	3.92 (2)	15.69 (8)	15.69 (8)	31.37 (16)	51
10.00–11.00	14.86 (22)	6.76 (10)	22.30 (33)	18.24 (27)	8.11 (12)	8.78 (13)	10.14 (15)	10.81 (16)	148
11.00–12.00 noon	12.64 (33)	6.13 (16)	31.42 (82)	19.54 (51)	13.03 (34)	6.51 (17)	4.21 (11)	6.51 (17)	261
12.00–13.00	15.09 (35)	8.19 (19)	29.31 (68)	19.83 (46)	13.79 (32)	6.03 (14)	5.60 (13)	2.16 (5)	233
13.00–14.00	14.67 (22)	14.00 (21)	26.00 (39)	25.33 (38)	11.33 (17)	2.00 (3)	4.67 (7)	2.00 (3)	150
14.00–15.00	34.69 (17)	22.45 (11)	12.24 (6)	6.12 (3)	12.24 (6)	0.00 (0)	2.04 (1)	10.20 (5)	49
15.00–16.00	47.83 (11)	30.43 (7)	4.35 (1)	0.00 (0)	8.70 (2)	0.00(0)	4.35 (1)	4.35 (1)	23
16.00–17.00	61.54 (8)	23.08 (3)	0.00 (0)	0.00 (0)	0.00 (0)	0.00 (0)	0.00 (0)	7.69 (1)	12
Insects observed (nos)	159	92	233	168	105	55	56	84	952

Figures in parenthesis are number of bees recorded

Table 6 Foraging rate and foraging speed of important bee pollinators of cashew

Insect pollinator species	Foraging rate (nos/trip)		Peak foraging hours	Foraging speed (s)		Pollen load/insect	
	Mean	Range		Mean	Range	Mean	Range
A. c. indica	11.2	6–20	10.00–15.00	3.0	1–4	166.0	89–196
A. florea	6.4	3–11	10.00–14.00	10.9	3–21	49.6	41–66
B. picitarsus	5.3	4–7	11.00–13.00	11.5	8–16	804.9	524–924
C. hieroglyphica	3.8	3–5	11.00–14.00	4.3	2–6	187.1	74–334
Tetragonula sp.	2.5	2–3	08.00–14.00	8.5	5–11	135.1	84–156
Lasioglossum sp. 1	2.7	2–3	11.00–13.00	3.6	2–5	123.3	79–136
P. oxybeloides	3.9	3–5	11.00–13.00	3.1	1–4	813.9	502–998
Seledonia sp.	3.7	3–5	11.00–13.00	3.3	2–5	786.6	456–902

irridipennis in cashew flowers. Lasioglossum bees also collected nectar from EFN besides pollen and nectar, whereas pollen was the major foraging reward for *B. picitarsus*, *C. hieroglyphica*, *P. oxybeloides*, *Lasioglossum* sp. and *Seledonia* sp. followed by nectar. This is in accord with Sundararaju [30, 31]. Since pollen was the foraging reward for most of the bee species, fresh male flowers were mostly preferred. Interestingly, bees of *B. picitarsus* were noticed to alight directly on the anthers of long stamen to collect pollen grains from dehisced anther lobes. Similarly, *P. oxybeloides* also collected pollen grains directly from anthers of long stamens at flight itself. Most bees collected pollen followed by nectar in the same male flower or nectar followed by pollen. Nevertheless, it was observed that the same hermaphrodite flower was visited by multiple bee species consequently, thus effecting pollination.

For *A. c. indica* and *A. florea*, nectar was the major foraging reward, which collected pollen accidentally upon touch of its body parts on anthers, and both male and hermaphrodite flowers were equally visited by them. These bees while resting on flowers, pollen grains get adhered to the body parts of bees especially abdomen and thus ensuring pollination in subsequent visits. The same pattern was also observed in case of *Apis mellifera* while visiting cashew flowers [12]. Almost all bee species preferred fresh flowers with white petals for foraging; however, bee species such as *A. c. indica*, *A. florea*, *C. hieroglyphica* and *Seledonia* sp. also rarely visited a day- or two-day old flower for nectar, especially during early morning and afternoon hours (Table 7). Nesting sites were also observed for the major pollinating bees (Table 7). It is well known that *Apis* spp. make bee hives, and such bee hives were

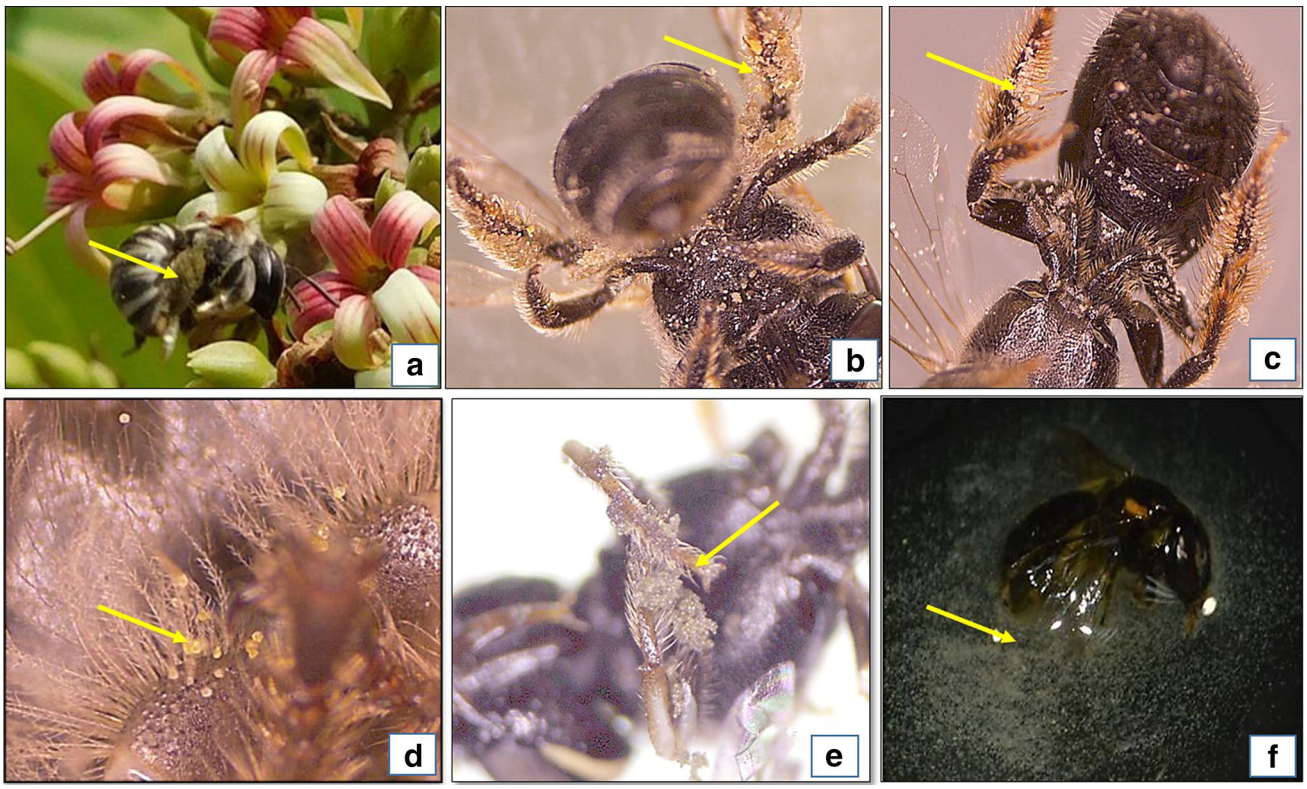

Fig. 2 Cashew pollen grains collected on bee body parts **a** *P. oxybeloides* (field view—hind leg), **b** *P. oxybeloides*, **c** *B. picitarsus*, **d** *A. c. indica*, **e** *C. hieroglyphica*, **f** dislodged pollen grains collected by a *B. picitarsus* bee

Table 7 Foraging reward, preferred flower and nesting sites of important bee pollinators in cashew

Bee species	Foraging reward	Preferred flower		Nest/nesting site
		♂/♀	Fresh or old	
A. c. indica	Nectar > pollen	Both	Fresh > a day old	Hive
A. florea	Nectar > pollen	Both	Fresh > a day old	Hive
B. picitarsus	Pollen > nectar	♂ > ♀	Fresh	Dried sticks of cashew trees
C. hieroglyphica	Pollen > nectar	♂	Fresh > a day old	Dried sticks of cashew trees
Tetragonula sp.	Pollen > nectar from EFN > nectar	♂ > ♀	Fresh	Holes (lamp posts, tubes, bamboo culms)
Lasioglossum sp. 1	Pollen > nectar > nectar from EFN	♂ > ♀	Fresh	–
P. oxybeloides	Pollen > nectar	♂ > ♀	Fresh	Soil, lateritic stone
Seledonia sp.	Pollen > nectar	♂ > ♀	Fresh > a day old	–

seen on cashew trunks and branches as well. Nests of *B. picitarsus* and *C. hieroglyphica* were noticed inside burrows of tiny dried sticks of cashew with clear roundish entrance hole (Fig. 3a, b). *Tetragonula* bees nested inside holes in lamp posts, tubes and bamboo culms. Interestingly, nests of *P. oxybeloides* were noticed in barren soil exposed to sunlight as well as in the hard lateritic stones (Fig. 3c). These nests were deep inside beyond 40 cm in the hard lateritic stones.

The knowledge on other bee pasturage existing in the cashew plantations is also important to understand the bee foraging range and choice of plants. The bees are automated micromanipulators by which man can harvest floral sources that would be otherwise unobtainable [19]. According to Baptist and Punchihewa [4], the flowering plants of an area having good value as bee pasture are necessary to maintain bee colonies. During flowering period of cashew, most of the bee species foraged on cashew, but during non-flowering period, bees also foraged on surrounding trees such as areca nut (*Areca catechu*), coconut (*Cocus nucifera*), neem (*Azadirachta indica*), Gulmohar (*Delonix regia*), acacia (*Acacia* spp.), golden

Fig. 3 Nesting sites of bees: **a** nest entrance of *C. hieroglyphica* with bee, **b** developmental stages of *B. picitarsus* inside the split open dried cashew stem, **c** *P. oxybeloides* coming out through nest entrance in lateritic stone

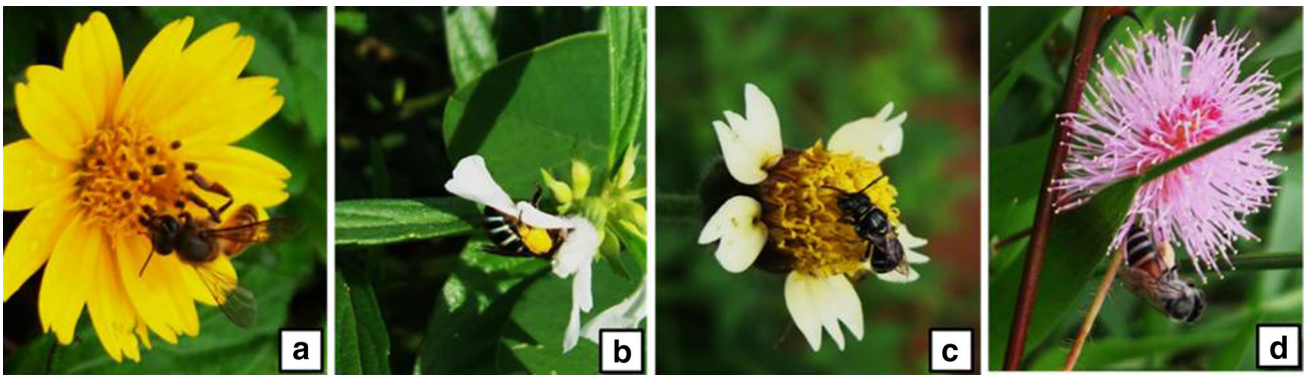

Fig. 4 Foraging of bees on common weed species in cashew plantations **a** *A. c. indica* on *W. trilobata*, **b** *A. florea* on *L. aspera*, **c** *C. hieroglyphica* on *T. procumbens*, **d** *A. florea* on *M. pudica*

showers (*Peltophorum pterocarpum*) and *Terminalia* spp. and also different weed flora in the cashew plantations that flower during different time periods. Weed species visited by bees include *Leucas aspera, Wedelia trilobata, Mimosa pudica, Melastoma malabathricum, Spermacoce hispida, Blumea* sp., *Antigonon leptopus, Tridox procumbens, Passiflora foetida, Alternanthera* sp., *Gompherena* sp., *Lantana camara*, *Ixora* sp., *Terminalia* sp. and *Caesalpinia* spp. which are common in the study location (Fig. 4). It was reported that during lean period of cashew, halictid bees sustained on *Spermacoce ocymoides* B., *S. stricta*, *M. pudica*, *Caesalpinia mimosoides* [30], *Lindernia antipoda*, *Acacia pennata*, *Rungia repens*, *L. aspera*, *Muntingia calabura* and *Blumea* sp. [31] in cashew plantations of coastal Karnataka, whereas in Tamil Nadu, *Ocimum americanum*, *O. adscendens*, *Cleome viscosa*, *Oldenlandia umbellate*, *L. aspera* and *Celosia* sp. were found as floral resources in cashew plantations [31]. Abundance and occurrence of pollen and nectar sources within the surrounding area of an apiary are important factors for better bee keeping [1, 10]. In the present study area, all three *Apis* spp., viz. *A. c. indica, A. florea* and *A. dorsata*, foraged on *L. aspera*, *M. pudica* and *W. trilobata.* Besides these three weeds, *B. picitarsus* and *C. hieroglyphica* were also commonly foraged on *A. leptopus* and *S. hispida*, while, *P. oxybeloides* was noticed on *M. pudica*. Earlier, visits of *P. oxybeloides* on *Blumea* sp. and *Rungia* sp. were reported by Sundararaju [31].

Conclusions

Among the 40 species recorded as flower visitors of cashew in the study location, 13 species are considered as pollinators of cashew including wild bees. Nesting sites of different bee species and the common bee flora in the study area were also recorded. Observations revealed that bees are very important in pollination of cashew, and this study highlights the systematic documentation of various bee species important for cashew, helping the researchers, cashew farmers and beekeepers to plan for proper management and conservation of bee species. Though pollination is a free service provided by bees including several wild bees, they need to be conserved and protected from insecticidal sprays to enhance cashew pollination and productivity. Knowledge on bee flora in and around the

cashew plantations, especially during non-flowering period of cashew, is also important for conservation of bees.

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References

1. Akratanakal P (1987) Beekeeping in Asia. FAO, United Nations, p 112
2. Aliakbarpour H, Salmah CMR (2010) Diurnal activity of four species of thrips (Thysanoptera: Thripidae) and efficiencies of tree non-destructive sampling techniques for thrips in mango inflorescences. J Econ Entomol 103:631–640
3. Bally ISE (2006) *Mangifera indica* (Mango). In: Elevitch CR (ed) species profiles for pacific island agroforestry. Permanent agriculture resources (PAR), Holualoa, Hawaii, pp 1–26
4. Baptist BA, Punchihewa RWK (1980) A preliminary analysis of the principal factors which will affect apiary honey production in Sri Lanka. In: Proceedings of the 2nd conference of apiculture in tropical climates, New Delhi, pp 75–81
5. Bhattacharya A (2004) Flower visitors and fruit set of *Anacardium occidentale*. Ann Bot Fenn 41:385–392
6. Buchmann LS, Nabhan PG (1996) The forgotten pollinators. Island Press, Washington, DC, p 292
7. Chaudhary OP (2003) Evaluation of honey bee flora of the north eastern region of Haryana. J Palynol (India) 39:127–141
8. Corbet SA, Williams IH, Osborne JL (1991) Bees and the pollination of crops and wild flowers in the European community. Bee World 72(2):47–59
9. DCCD (2015) Directorate of cocoa and cashew development, Kochin. Cashew statistics. Area, production and productivity. http://dccd.gov.in/Content.aspx?mid=1075&tid=1. Accessed on 18 may 2017
10. Free JB (1970) Insect pollination of crops. Academic Press, London, p 544
11. Free JB (1993) Insect pollination of crops, 2nd edn. Academic Press, London, p 544
12. Freitas BM, Paxton RJ (1996) The role of wind and insects in cashew (*Anacardium occidentale*) pollination in NE Brazil. J Agric Sci 126:319–326
13. Freitas BM (1997) Changes with time in the germinability of cashew (*Anacardium occidentale*) pollen grains found on different body areas of its pollinator bees. Rev Bras Biol 57:289–294
14. Freitas BM, Paxton RJ (1998) A comparison of two pollinators: the introduced honey bee *Apis mellifera* and an indigenous bee *Centris tarsata* on cashew *Anacardium occidentale* in its native range of NE Brazil. J Appl Ecol 35(1):109–121
15. Heard TA, Vithanage V, Chacko EK (1990) Pollination biology of cashew in the northern territory of Australia. Aust J Agric Res 41:1101–1114
16. Huda AN, Che Salmah MR, Abu Hassan A, Hamdan A, Abdul Razak MN (2015) Pollination services of mango flower pollinators. J Insect Sci 15(1):113. https://doi.org/10.1093/jisesa/iev090
17. Kapil RP, Grewal GS, Kumar S, Atwal S (1971) Insect pollinators of rape seed and mustard. Ind J Entomol 33(1):61–66
18. Kevan PG (1975) Pollination and environmental conservation. Environ Conserv 2:293–298
19. Kevan PG (1984) Bee botany: pollination, foraging and floral calendar. Expert committee on beekeeping with *Apis mellifera* in tropical and sub-tropical Asia. FAO, Rome, pp 51–55
20. Mevetty PBE, Pinnisch R, Scarth R (1989) The significance of floral characteristics in seed production of four summer rape cultivar: a line with pollination cytoplasm. Can J Plant Sci 69(3):915–918
21. Mitchell RJ, Waser NM (1992) Adaptive significance of *Ipomopsis aggregate* nectar production: pollination success of single flowers. Ecology 73:633–638
22. Navatha L (2012) Pollinator diversity and abundance in certain oilseed crops. M.Sc., Dissertation. Submitted in Department of Entomology, Sri Venkateshwara Agricultural College, Tirupathi, Acharya N.G. Ranga Agricultural University, Rajendranagar, Hyderabad, 194p
23. Pavithran K, Ravindranathan PP (1974) Studies on the floral biology in cashew, *Anacardium occidentale* L. J Plant Crops 1:32–33
24. Prasad D, Hameed SP, Singh R, Singh B (1989) Foraging behaviour of insect pollinators on brown mustard, *Brassica juncea* in Bihar, India. Indian Bee J 51(4):131–133
25. Rao VNM, Hassan MV (1957) Preliminary studies on the floral biology of cashew (*Anacardium occidentale* L.). Indian J Agric Sci 27:277–288
26. Reddi EUB (1993) Pollination studies of cashew in India: an overview. In: Veeresh GK, Umashaankar R, Ganeshaiah KN (eds) Proceedings of international symposium on pollen tropical, UAS, Bangalore, pp 321–324
27. Roubik DW (1995) Pollination of cultivated plants in the tropics, vol 118. FAO, Rome
28. Sihag RC (1986) Insect pollination increases seed production in cruciferous and umbelliferous crops. J Apic Res 25:121–126
29. Sundararaju D (2000) Foraging behaviour of pollinators on cashew. The Cashew 14:17–20
30. Sundararaju D (2003) Occurrence of bee fauna and extent of pollination in insecticide sprayed ecosystem of cashew. J Palynol 39:121–135
31. Sundararaju D (2011) Studies on extent of pollination and fruit set in cashew. J Plant Crops 39(1):157–160
32. Tewari GN, Singh K (1983) Role of pollinators in vegetable seed production. Indian Bee J 45:51
33. Verma LR (1990) Beekeeping. In: Integrated mountain development: economic and scientific perspectives. ICIMOD senior fellowship series, no. 4 (V50B). Oxford and IBH Publishing Co. Pvt. Ltd, India. ISBN 81-204-0538-2