DIVERSITY AND ABUNDANCE OF INSECT POLLINATORS IN A CASHEW AGROECOSYSTEM OF TAMIL NADU

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(Received 27th May 2024; accepted 18th Oct 2024)

Abstract. Pollination is crucial for both natural ecosystems and agriculture, with bees being the most effective pollinators. This study aims to investigate the diversity and abundance of insect pollinators in cashew (*Anacardium occidentale*) ecosystems in Madurai district, Tamil Nadu, India. The research conducted at two locations: Orchard, Agricultural college and Research institute (AC & RI), Madurai, and Saranthangi, Alanganallur block, from February to April 2021. Pollinator survey was performed on randomly selected cashew trees, with observations recorded during peak flowering periods. The insect pollinators were collected using sweep nets and preserved in 70% ethanol for identification at NBAIR, Bangalore. Results indicated that Indian Honey bee (*Apis cerana indica)* was the dominant pollinator in both locations, with a mean abundance of 5.19 and 5.02 individuals/m^2 at Saranthangi and Orchard AC & RI, respectively. Dammer bee (*Tetragonula iridipennis*) and *Ceratina binghami* were also abundant, with slight location-based variations in their peak activity times. Foraging activity peaked between 1000 and 1200 h, correlating with the anthesis and anther dehiscence of cashew flowers. Diversity indices, including Shannon's and Simpson indices, confirmed that pollinator species richness and evenness were higher in the morning hours, particularly between 1000 and 1100 h. This study highlights the critical role of pollinators, particularly *Apis cerana indica,* in cashew fruit set, demonstrating the importance of conserving insect pollinator diversity for improved crop yields. The findings also underscore the influence of time of day on pollinator activity, with peak activity aligning with flower anthesis.
Keywords: *Apis cerana indica, biodiversity indices, foraging behavior, relative abundance, Tetragonula iridipennis*

Introduction

Pollination plays an essential role in both natural ecosystems and agricultural productivity, providing critical environmental services (Ricketts et al., 2008). Among all pollinators, bees are the efficient (Potts et al., 2010), pollinating over 70% of cultivated plant species (Ricketts et al., 2008). Although honey production and other hive products are valuable, the primary role of honeybees is as crop pollinator, making their contribution to agriculture far more significant than their role in honey and beeswax production (Abrol, 2015). In India, cashew is cultivated on 1.105 million hectares, with an annual output of 743,000 metric tons in 2018–2019 (Anonymous, 2019).

Cashew is an andromonoecious plant, characterized by flowers with longer stamens than styles, and sticky pollen that complicates self-pollination, favoring insect-mediated cross-pollination. Despite this, cashew plants convert only about 27% of properly pollinated flowers into fruit. Under-pollination is a significant issue, resulting in a yield of just 10.5%, as demonstrated by stigmatic-pollen load evaluations. Studies show that

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2206_60976112

in natural conditions, 25 to 72% of stigmas remain unpollinated due to pollinator scarcity, leading to lower yields (Reddi, 1987). Research consistently indicates that fruit set in cashew is strongly influenced by pollinator activity (Freitas and Paxton, 1996; Reddi, 1993).

Globally, flies, moths, and bees are recognized as the primary pollinators of cashew. However, there remains a significant gap in understanding the key pollinators, their foraging behavior, and their pollination efficiency in specific regions (Vanitha and Raviprasad, 2019). Encouraging and supporting pollinator populations has been shown to dramatically improve pollination success, leading to as much as a 200% increase in cashew yields (Anonymous, 2017). Several studies have highlighted the role of poor pollination as a major contributor to low cashew productivity (Freitas et al., 2002; Holanda-Neto et al., 2002). For example, pollination by bees has been shown to increase fruit set and reduce fruit drop in other fruit crops like apples, peaches, and plums (Dulta and Verma, 1987; Partap et al., 2000).

In light of these findings, the current study was conducted to assess the diversity and relative abundance of insect pollinators in cashew orchards in Madurai district of Tamil Nadu, India.

Materials and methods

The study was conducted at two different locations such as Orchard, Agricultural College and Research Institute, Madurai (9°58’ N and 78° 12’ E) and Saranthangi, Alanganallur Block, Madurai District (10°5’ N and 78°10’ E). Survey was done in the field from February to April, 2021 to record the pollinator diversity. Observations were made on five randomly selected cashew trees for ten non-consecutive days of flowering period. The study was conducted for a period of one year from February 2021 to April 2021.

Tree selection methodology

In this study, five cashew trees were randomly selected within the orchard for pollinator observation. To ensure randomness and avoid bias, a simple random sampling technique was employed. The orchard was divided into grids, and each grid was assigned a number. Using a random number generator, five grid numbers were selected, and the corresponding cashew trees located in those grids were chosen for the study.

No exclusion criteria were applied, as the goal was to capture a representative sample of the overall pollinator activity in the orchard. Additionally, no stratified sampling was applied since the cashew trees within the orchard were of similar age, health, and had comparable floral densities, ensuring that the randomly selected trees were representative of the overall population. Each selected tree was observed for a set period of time to record the diversity and abundance of pollinators.

Insect collection

Insect collection was conducted using sweep nets to target flying insects within the selected one-square-meter flowering area of each cashew tree. For each tree, 20 sweeps were performed per sampling session, ensuring a consistent effort across all trees. Each sweep involved a single pass of the net through the designated area, covering as many

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2206_60976112

flowers as possible. The collection was carried out during the full blooming period of cashew, which typically occurs from January to March, depending on the region and climate conditions. Observations were made during peak pollinator activity hours, between 8:00 AM and 12:00 PM, when insect foraging behavior is typically more active. This period ensured optimal data collection on pollinator diversity and abundance as the flowers were fully open and available for pollination during this time. The duration of each collection session was approximately 10 min per tree, during which only insects actively flying or foraging on flowers were targeted. Care was taken to minimize disturbance to the trees and flowers during the collection process. The captured insects were immediately transferred to collection containers for further identification and analysis.

Preservation of insects

After collection, insects were immediately handled with care to preserve their physical and genetic integrity. Specimens were transferred into vials containing 70% ethanol within 15–30 min of capture to prevent decomposition and ensure preservation. Each vial was labelled with essential data such as date, location, and tree number. In cases where immediate preservation was not possible, insects were kept in cool, shaded containers until processed.

Insects' identification

The pollinators collected in the field were identified with the help of Dr. U. Amala, Scientist, NBAIR, Bangalore.

Foraging behavior of insect pollinators

Observations were made on the number of insects visiting inflorescences of cashew in 1 m^2 of bloom area for 10 min at hourly intervals at 0800-0900, 0900-1000, 1000-1100, 1100-1200, 1200-1300, 1300-1400, 1400-1500, 1500-1600 (Mushtaq, 2013) to know the foraging activity of pollinators. This was replicated five times. It was observed for ten non-consecutive days of flowering period from third week of February, 2021 to last week of April, 2021.

Species richness

Species richness is the measure of total number of pollinator species recorded at hourly intervals from 0800 to 1600 h (Gotelli and Colwell, 2011).

Diversity indices

Diversity indices were calculated to know the species diversity in a population. It was based on the species richness and species abundance of the population. Diversity indices such as Simpson Index, Shannon Diversity index and Berger Parker index were calculated at hourly intervals from 0800 to 1600 h of the day.

Simpson's indices

The proportion of species i in relation to the total number of species (*pi*) was determined, squared and added together (Kachhawa et al., 2020).

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$$\text{Simpson's index (D)} = \sum_{i=1}^{s} pi^2$$

$$\text{Simpson's index of biodiversity} = 1 - \sum_{i=1}^{s} pi^2$$

$$\text{Simpson's reciprocal index (1/D)} = 1/\sum_{i=1}^{s} pi^2$$

Shannon's diversity index

The proportion of species i to the total number of species (*pi*) was computed and then summed up across all species and multiplied by -1 (Davila et al., 2012)

$$\text{Shannon's diversity index (H)} = -\sum_{i=0}^{s} pi \ln pi$$

$$\text{Shannon's index} = -\sum_{i=0}^{s} pi\ log2\ pi$$

$$\text{Shannon's diversity index} = -\sum_{i=0}^{s} pi\ log10\ pi$$

Species richness (S) is the total number of species in a community. By dividing H by Hmax (where Hmax = ln S), Shannon's equality (EH) was calculated. Equality defines complete evenness as a number between 0 and 1.

$$\text{Shannon's equality (EH)} = H/Hmax$$

Berger-Parker index

The Berger-Parker index (d) measures the relative importance of the most abundant species and was calculated using the formula

$$d = nmax/N$$

where nmax is the no. of individuals corresponding to the most abundant species and N is the total number of individuals (Salas et al., 2006). The values range between 0 and 1, higher value denotes lower diversity. It is contrary in nature to other diversity indices.

Statistical analysis

The field data on foraging behavior, obtained from the study was transformed to square root values and then analyzed in SPSS software. Grouping of means were done by Duncan Multiple Range Test (DMRT) at 5 per cent probability to know the best treatments. Data were analyzed using python packages for creating graphs to visualize the Relative abundance and Diversity indices of pollinators.

Results

The Foraging behavior of pollinators/floral visitors on cashew (*Plates 1–17*) at two different locations during various time intervals of the day was discussed in *Tables 1* and *2* and *Figure 1*. In Both locations show similar mean number of individuals of Indian Honey bee (*Apis cerana indica)* per square meter of bloom area

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
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(5.19 individuals/m^2 for Saranthangi, Madurai and 5.02 individuals/m^2 for orchard, AC & RI Madurai). The peak abundance for *A. cerana indica* is observed during the same time interval (1000-1100 h) in both locations. The overall trend of foraging activity follows a similar pattern, with higher activity during the morning hours, and a slight decrease in the afternoon. In Saranthangi, the mean number of Dammer Bee (*Tetragonula iridipennis*) individuals per square meter of bloom area is slightly higher (4.27 individuals/m^2) compared to Orchard AC & RI (3.98 individuals/m^2). In orchard, AC & RI, Madurai, the mean number of *C. binghami* individuals per square meter of bloom area is slightly higher (2.58 individuals/m^2) compared to Saranthangi, Madurai (1.77 individuals/m^2). The peak abundance of *C. binghami* was observed during the same time interval (1100-1200 h) in both locations. The foraging behavior of *C. binghami* at both locations exhibits a largely similar pattern, with minor difference in mean abundance. In Saranthangi, Madurai has a slightly higher mean abundance of *Eristalinus* species from Diptera compared to Orchard, Madurai and the peak abundance time differs between the two locations, occurring later in the morning (1000-1100) in Saranthangi, Madurai, and earlier (0800-0900 h and 0900-1000 h) in Orchard, Madurai. It is followed by *Stomorhina* sp was slightly higher in Saranthangi, Madurai compared to Orchard, Madurai. The difference in mean abundance between the two locations was approximately 0.14 individuals/m^2 bloom area/10 min. Next to as the *Eurema hecabe* was slightly higher mean abundance in Orchard when compared to the area of Saranthangi. The difference in mean abundance between the two locations is approximately 0.08 individuals/m^2 bloom area/10 min.

Hymenopteran floral visitors of cashew

Plate 1. Apis cerana indica

Plate 2. Tetragonula iridipennis

Plate 3. Braunsapis sp.

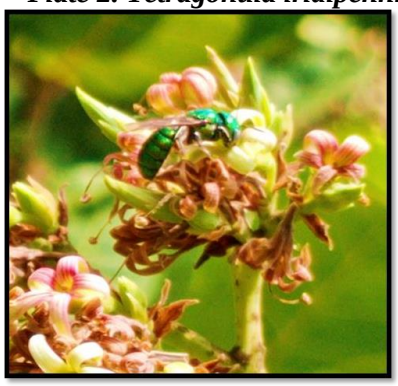

Plate 4. Ceratina binghami

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2206_60976112

Plate 5. Pepsis sp.

Plate 6. Nomia sp.

Plate 7. Amegilla zonata

Plate 8. Camponotus sericeus

Dipteran floral visitors of cashew

Plate 9. Eristalinus sp.

Plate 10. Ischiodon scutellaris

Plate 11. Stomorhina sp.

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Lepidopteran floral visitors of cashew

Plate 12. Castalius rosimon

Plate 13. Euploea core

Plate 14. Tirumala limniace

Plate 15. Lampides boeticus

Plate 16. Catopsilia Pomona

Plate 17. Delias eucharis

In *Table 1 Apidae* species were found to be higher at 1100-1200 h of the day i.e., 3.99 individuals/m^2 bloom area/10 min followed by 1000-1100 h (3.88 individuals/m^2 bloom area/10 min), whereas, non-*Apis* Hymenopterans, Dipterans and Lepidopterans were present in higher numbers during 1000-1100 h with mean of 1.17, 1.35, 0.56 individuals/m^2 bloom area/10 min followed by 0900-1000 h (1.14, 1.05, 0.42 individuals/m^2 bloom area/10 min), respectively. The least number of individuals i.e., 0.48 ± 0.14 and 0.52 ± 0.06 individuals/m^2 bloom area/10 min were noticed with respect to *Castalius rosimon* of Lepidopteran order and *Pepsis* sp. of Hymenopteran order. Minimum number of 0.18 ± 0.05 and 0.16 ± 0.05 individuals/m^2 bloom area/10 min was noticed in *C. rosimon* and *D. eucharis* of Lepidopteran order, respectively.

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Hymenopterans such as *C. binghami*, *Braunsapis* sp., *Amegilla zonata* and *Halictus* sp. were present in lesser numbers. In case of Dipterans and Lepidopterans, they were found in meagre numbers.

In *Table 2* Mean number of 2.00 individuals/m^2 bloom area/10 min by non-*Apis* Hymenopterans were seen at 1100-1200 h, followed by 1.59 individuals/m^2 bloom area/10 min at 1300-1400 h of the day. Dipteran species were maximum at 1000-1100 h of the day (1.35 individuals/m^2 bloom area/10 min) followed by 0900-1000 h with the population of 1.02 individuals/m^2 bloom area/10 min. Lepidopterans such as *E. core* were found active during the morning hours of 0800-0900 h with 0.43 individuals/m^2 bloom area/10 min. Minimum number of 0.03 individuals/m^2 bloom area/10 min were observed during the afternoon hours from 1300-1400 h of the day. In comparison of two locations, based on the foraging activity of pollinators in cashew, dominated by *A. cerana indica* followed by *T. iridipennis* and *C. binghami***.**

The peak foraging activity of *A. cerana indica* was maximum at 0900-1200 h and there was decrease in their activity between 1200-1400 h, thereafter, it showed a slight increase in their activity during 1400-1600 h of the day. The foraging activity of *T. iridipennis* was higher from 0800-1300 h, but drastically decreases from 1300-1600 h of the day. Maximum activity of *Ceratina* sp. and *Braunsapis* sp. was recorded during 1000-1300 h. Dipterans activity was maximum during morning hours of 0800-1200 h, whereas it was minimum during the afternoon hours. Lepidopteran activity reached its peak during the morning hours of 0800-1100 h of the day.

The results of the present study revealed that the peak foraging activity of the pollinators occurred between 1000 and 1300 h of the day, which corresponds to the anthesis and peak phase of anther dehiscence of cashew flowers, which occurs between 1000 and 1200 h.

Table 1. *Foraging behavior of pollinators/floral visitors on cashew at Orchard, AC & RI, Madurai during various time intervals of the day*

S. No.	Pollinators/floral visitors	No. of individuals/m^2 bloom area/10 min*								Mean
		0800-0900 h	0900-1000 h	1000-1100 h	1100-1200 h	1200-1300 h	1300-1400 h	1400-1500 h	1500-1600 h	
Hymenoptera-Apidae										
1.	*A. cerana indica*	6.22±0.29 (2.49)^{a}	6.66±0.37 (2.58)^{a}	7.20±0.42 (2.68)^{a}	6.10±0.23 (2.47)^{a}	2.90±0.16 (1.70)^{c}	2.06±0.15 (1.44)^{b}	4.00±0.30 (2.00)^{a}	4.98±0.42 (2.23)^{a}	5.02
2.	*T. iridipennis*	4.88±0.24 (2.21)^{b}	5.38±0.24 (2.32)^{b}	5.76±0.30 (2.40)^{b}	4.04±0.24 (2.01)^{c}	4.76±0.21 (2.18)^{a}	2.02±0.44 (1.42)^{b}	2.42±0.34 (1.56)^{b}	2.56±0.51 (1.60)^{b}	3.98
3.	*C. binghami*	0.00±0.00 (0.71)^{e}	0.56±0.10 (0.75)^{efg}	2.58±0.14 (1.61)^{d}	4.42±0.11 (2.10)^{bc}	3.26±0.35 (1.81)^{bc}	2.46±0.33 (1.57)^{ab}	0.68±0.19 (0.82)^{c}	0.00±0.00 (0.71)^{e}	1.75
4.	*Braunsapis* sp.	0.00±0.00 (0.71)^{e}	0.28±0.12 (0.53)^{g}	3.16±0.06 (1.78)^{c}	4.62±0.13 (2.15)^{b}	3.58±0.16 (1.89)^{b}	2.68±0.16 (1.64)^{a}	0.22±0.12 (0.47)^{d}	0.02±0.02 (0.14)^{e}	1.82
5.	*Amegilla zonata*	0.32±0.04 (0.57)^{cd}	0.58±0.09 (0.76)^{efg}	0.72±0.09 (0.85)^{g}	0.76±0.10 (0.87)^{ef}	0.52±0.10 (0.72)^{ef}	0.24±0.04 (0.49)^{d}	0.14±0.05 (0.37)^{d}	1.30±0.12 (1.14)^{c}	0.57
Mean		2.28	2.69	3.88	3.99	3.00	1.89	1.49	1.77	2.62
Other than Apidae										
6.	*Halictus sp.*	0.16±0.07 (0.40)^{de}	1.66±0.25 (1.29)^{c}	1.82±0.22 (1.35)^{e}	1.42±0.14 (1.19)^{d}	1.24±0.22 (1.11)^{d}	1.14±0.13 (1.07)^{c}	0.56±0.18 (0.75)^{c}	0.68±0.11 (0.82)^{d}	1.09
7.	*Pepsis* sp.	0.36±0.06 (0.60)^{cd}	0.62±0.08 (0.79)^{ef}	0.52±0.06 (0.72)^{g}	0.66±0.10 (0.81)^{f}	0.64±0.08 (0.80)^{e}	0.14±0.04 (0.37)^{d}	0.08±0.04 (0.28)^{d}	1.14±0.17 (1.07)^{c}	0.52
Mean		0.26	1.14	1.17	1.04	0.94	0.64	0.32	0.91	0.80
Diptera										
8.	*Eristalinus* sp.	0.42±0.06 (0.65)^{c}	1.14±0.18 (1.07)^{d}	1.46±0.12 (1.21)^{ef}	0.96±0.14 (0.98)^{e}	0.48±0.07 (0.69)^{ef}	0.00±0.00 (0.71)^{d}	0.12±0.04 (0.35)^{d}	0.62±0.13 (0.79)^{d}	0.65

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
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9.	*Stomorhina* sp.	0.44±0.08 (0.66)^{c}	1.18±0.10 (1.09)^{cd}	1.32±0.13 (1.15)^{f}	0.64±0.09 (0.80)^{f}	0.32±0.09 (0.57)^{f}	0.16±0.06 (0.40)^{d}	0.00±0.00 (0.71)^{d}	0.00±0.00 (0.71)^{e}	0.51
10.	*I. scutellaris*	0.26±0.08 (0.51)^{cd}	0.82±0.11 (0.91)^{de}	1.28±0.13 (1.13)^{f}	0.50±0.08 (0.71)^{fg}	0.22±0.09 (0.47)^{fg}	0.12±0.04 (0.35)^{d}	0.00±0.00 (0.71)^{d}	0.00±0.00 (0.71)^{e}	0.40
Mean		0.37	1.05	1.35	0.70	0.34	0.09	0.04	0.21	0.52
Lepidoptera										
11.	*Castalius rosimon*	0.34±0.09 (0.58)^{cd}	0.38±0.10 (0.62)^{fg}	0.48±0.14 (0.69)^{g}	0.18±0.05 (0.42)^{h}	0.22±0.06 (0.47)^{fg}	0.00±0.00 (0.71)^{d}	0.06±0.04 (0.24)^{d}	0.12±0.05 (0.35)^{e}	0.22
12.	*Delias eucharis*	0.26±0.07 (0.51)^{cd}	0.38±0.12 (0.62)^{fg}	0.60±0.10 (0.77)^{g}	0.16±0.05 (0.40)^{h}	0.24±0.05 (0.49)^{fg}	0.00±0.00 (0.71)^{d}	0.00±0.00 (0.71)^{d}	0.08±0.04 (0.28)^{e}	0.22
13.	*Eurema hecabe*	0.44±0.06 (0.66)^{c}	0.50±0.08 (0.71)^{efg}	0.60±0.13 (0.77)^{g}	0.34±0.05 (0.58)^{gh}	0.00±0.00 (0.71)^{h}	0.00±0.00 (0.71)^{d}	0.20±0.05 (0.45)^{d}	0.32±0.04 (0.57)^{de}	0.30
Mean		0.35	0.42	0.56	0.23	0.15	0.00	0.09	0.17	0.25
Sed		0.05	0.08	0.08	0.06	0.07	0.08	0.08	0.09	
CD (0.05)		0.10	0.16	0.16	0.121	0.14	0.16	0.16	0.18	

*Each value is a mean of ten observations with five replications
Figures in in parentheses are transformed values Mean ± S. E. In a column, means followed by same letter are on par by DMRT (p = 0.05)

Table 2. *Foraging behavior of pollinators/floral visitors on cashew at Saranthangi, Madurai during various time intervals of the day*

	Pollinators/ floral visitors	**No. of individuals/m^2 bloom area/10 min***								**Mean**
		0800-0900 h	**0900-1000 h**	**1000-1100 h**	**1100-1200 h**	**1200-1300 h**	**1300-1400 h**	**1400-1500 h**	**1500-1600 h**	
Hymenoptera-Apidae										
1.	*A. cerana indica*	6.52±0.42 (2.55)^{a}	6.88±0.31 (2.62)^{a}	7.38±0.52 (2.72)^{a}	6.24±0.28 (2.50)^{a}	2.98±0.35 (1.73)^{b}	2.12±0.20 (1.46)^{c}	4.22±0.38 (2.05)^{a}	5.16±0.42 (2.27)^{a}	5.19
2.	*T. iridipennis*	5.52±0.30 (2.28)^{b}	5.56±0.32 (2.36)^{b}	6.36±0.44 (2.52)^{a}	4.20±0.39 (2.05)^{b}	4.98±0.46 (2.23)^{a}	2.32±0.38 (1.52)^{bc}	2.58±0.38 (1.61)^{b}	2.64±0.53 (1.62)^{b}	4.27
3.	*Ceratina sp.*	0.16±0.06 (0.40)^{ef}	1.88±0.28 (1.37)^{c}	3.00±0.26 (1.73)^{b}	4.48±0.35 (2.12)^{b}	4.34±0.55 (2.08)^{a}	3.42±0.38 (1.85)^{a}	0.48±0.11 (0.69)^{c}	0.34±0.11 (0.58)^{c}	2.26
4.	*C. binghami*	0.00±0.00 (0.71)^{f}	0.70±0.12 (0.84)^{de}	2.66±0.21 (1.63)^{bc}	4.14±0.19 (2.03)^{b}	3.08±0.49 (1.75)^{b}	2.76±0.18 (1.66)^{ab}	0.52±0.15 (0.72)^{c}	0.30±0.12 (0.55)^{c}	1.77
Mean		3.05	3.76	4.85	4.77	3.85	2.66	1.95	2.11	3.37
Other than Apidae										
5.	*Hoplonomia sp.*	0.00±0.00 (0.71)^{f}	0.38±0.11 (0.62)^{e}	2.19±0.18 (1.48)^{c}	3.96±0.20 (1.99)^{b}	3.08±0.49 (1.75)^{b}	2.76±0.18 (1.66)^{ab}	0.52±0.15 (0.72)^{c}	0.30±0.12 (0.55)^{c}	1.65
6.	*Camponotus sp.*	0.68±0.10 (0.82)^{c}	0.68±0.11 (0.82)^{de}	0.88±0.09 (0.94)^{de}	0.04±0.03 (0.20)^{e}	0.08±0.03 (0.28)^{c}	0.42±0.04 (0.65)^{d}	0.48±0.04 (0.69)^{c}	0.30±0.04 (0.55)^{c}	0.45
Mean		0.34	0.53	1.54	2.00	1.58	1.59	0.50	0.30	1.05
Diptera										
7.	*Eristalinus sp.*	0.32±0.07 (0.57)^{de}	0.98±0.17 (0.99)^{d}	1.32±0.16 (1.15)^{d}	0.86±0.17 (0.93)^{c}	0.34±0.08 (0.58)^{c}	0.00±0.00 (0.71)^{e}	0.12±0.04 (0.35)^{d}	0.42±0.05 (0.65)^{c}	0.55
8.	*Stomorhina sp.*	0.68±0.12 (0.82)^{c}	1.06±0.18 (1.03)^{d}	1.38±0.16 (1.17)^{d}	0.48±0.06 (0.69)^{d}	0.02±0.02 (0.14)^{c}	0.02±0.02 (0.14)^{e}	0.16±0.06 (0.40)^{cd}	0.32±0.11 (0.57)^{c}	0.52
Mean		0.50	1.02	1.35	0.67	0.18	0.01	0.14	0.37	0.54
Lepidoptera										
9.	*Euploea core*	0.44±0.07 (0.66)^{cd}	0.36±0.07 (0.60)^{e}	0.20±0.06 (0.45)^{f}	0.00±0.00 (0.71)^{e}	0.12±0.04 (0.35)^{c}	0.00±0.00 (0.71)^{e}	0.00±0.00 (0.71)^{d}	0.24±0.05 (0.49)^{c}	0.17
10.	*Eurema hecabe*	0.42±0.06 (0.65)^{cd}	0.44±0.08 (0.66)^{e}	0.50±0.12 (0.71)^{ef}	0.16±0.04 (0.40)^{e}	0.00±0.00 (0.71)^{c}	0.06±0.03 (0.24)^{e}	0.22±0.04 (0.47)^{cd}	0.26±0.03 (0.51)^{c}	0.26
Mean		0.43	0.40	0.35	0.08	0.06	0.03	0.11	0.25	0.22
Sed		0.06	0.09	0.09	0.08	0.12	0.08	0.08	0.11	
CD (0.05)		0.12	0.18	0.18	0.16	0.24	0.16	0.16	0.22	

*Each value is a mean of ten observations with five replications
Figures in parentheses are $\sqrt{x+0.5}$ transformed values Mean ± S. E. In a column, means followed by same letter are on par by DMRT (p = 0.05)

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In orchard – AC & RI Madurai, the most abundant pollinator species were *A. cerana indica* (40.12%), followed by *T. iridipennis* (31.82%) and *C. binghami* (13.96%). In contrast, Saranthangi, Madurai, *A. cerana indica* (41.5%), *T. iridipennis* (34.16%), and *C. binghami* (14.16%) were the predominant species observed which was shown in *Figure 1*.

The diversity indices of major pollinators/floral visitors of cashew were observed at Orchard, AC & RI, Madurai and Saranthangi, Madurai which was shown in *Figure 2*. The species richness of major pollinators/floral visitors at AC & RI, Madurai was 13. The species richness was found to be maximum (13) during 0900-1200 h of the day and was minimum (9) during 1300-1400 h. In Saranthangi, Madurai, species richness was 10. It was higher (10) during 0900-1000, 1000-1100 and 1500-1600 h of the day and lower (8) in case of 0800-0900 h and 1300-1400 h. During 1400-1500 h of the day, species richness of pollinators/floral visitors was 9. Species richness was in the range of 9 to 13 at AC & RI, Madurai, whereas, it was in the range of 8-10 at Saranthangi, Madurai So, we conclude that Species richness was higher at 0900-1200 h and lower at 1300-1400 h. Shannon's H index and Shannon's E index were greater i.e., 2.18 and 0.85 during 1000-1100 h. Next to that, a value of 2.05 (H index) and 0.80 (E index) were recorded at 1100-1200 h. Lower value of H and E index *viz.*, 1.48 and 0.64 was noticed during 1400-1500 h of the day. Simpson's D index was 0.15 and 0.16 at 1000-1100 and 1100-1200 h, respectively. In contrast, Saranthangi, Madurai when compare to other times of the day, the largest values of 1.93 and 0.84 for Shannon's H and E indices were reported between 1000 and 1100 h. Subsequently, between 0900-1100 h and 1100-1200 h, respectively, a H index and an E index of 1.79 and 0.82, 1.75 and 0.76 were noted. With values of 0.18 and 0.82, Simpson 's D index and Simpson's index of biodiversity were comparable between 1000-1100 h and 1100-1200 h of the day. This suggests that during that period, A. *cerana indica* was a more abundant pollinator species than the others. During 1000-1100 h, Shannon's H index and E index was maximum, followed by 1100-1200 h and minimum value was obtained during 1400-1500 h of the day.

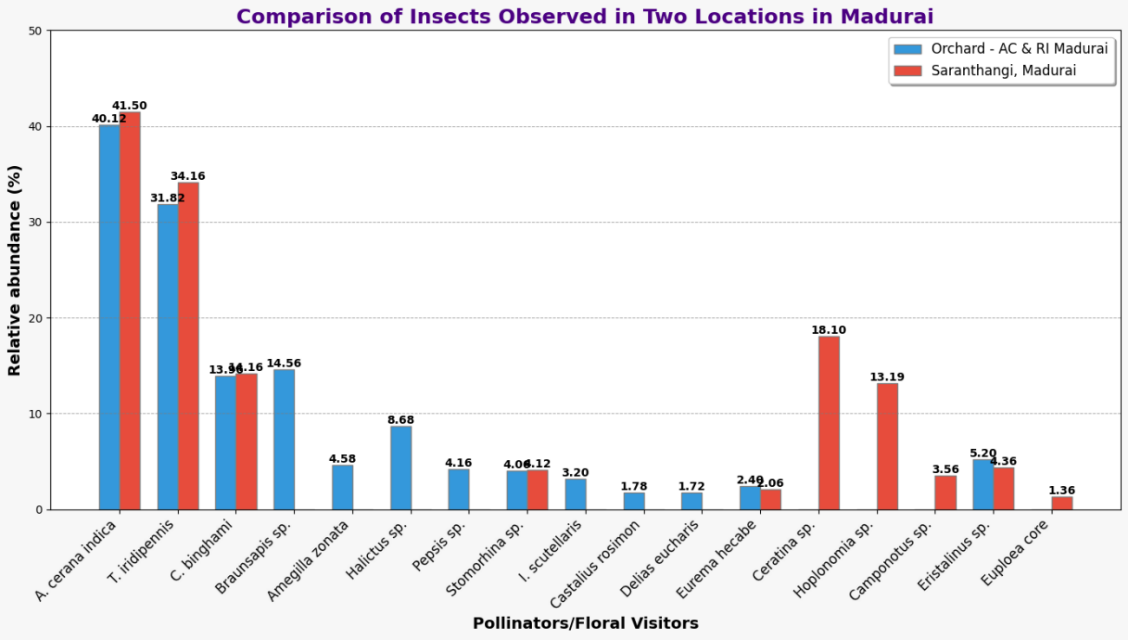

Figure 1. *Relative abundance of major pollinators/floral visitors of cashew were observed at Orchard, AC & RI, Madurai and Saranthangi, Madurai*

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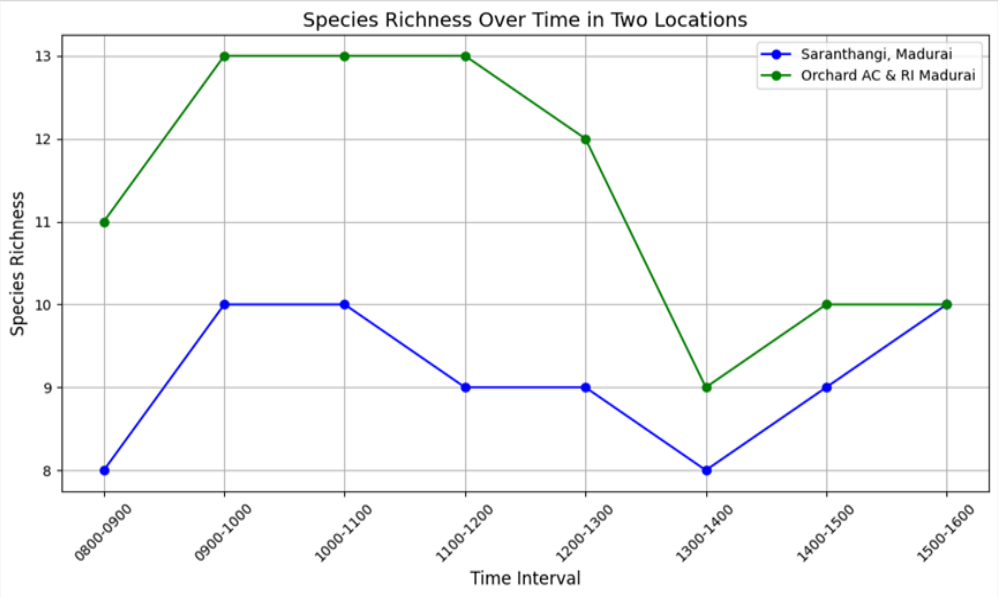

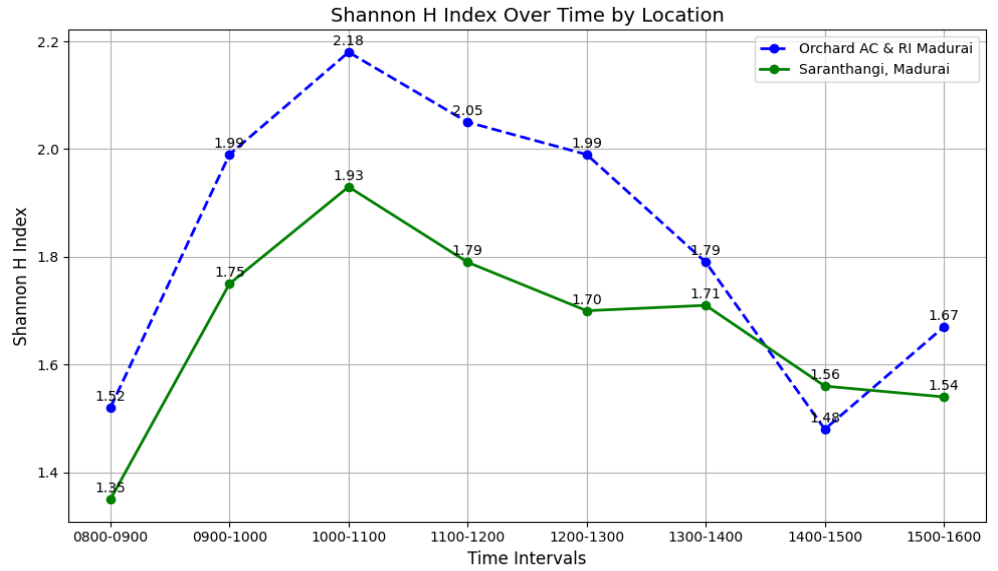

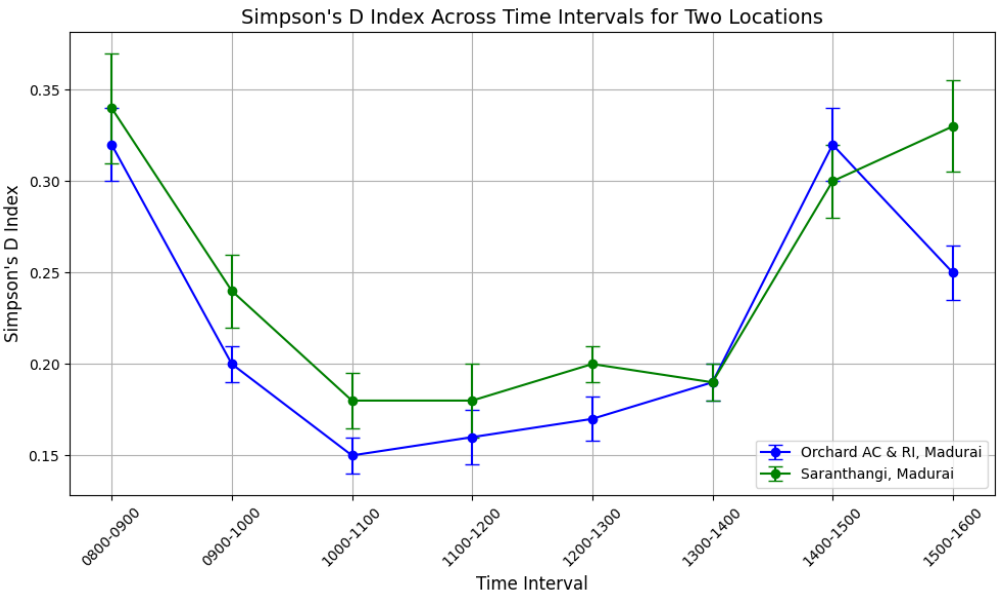

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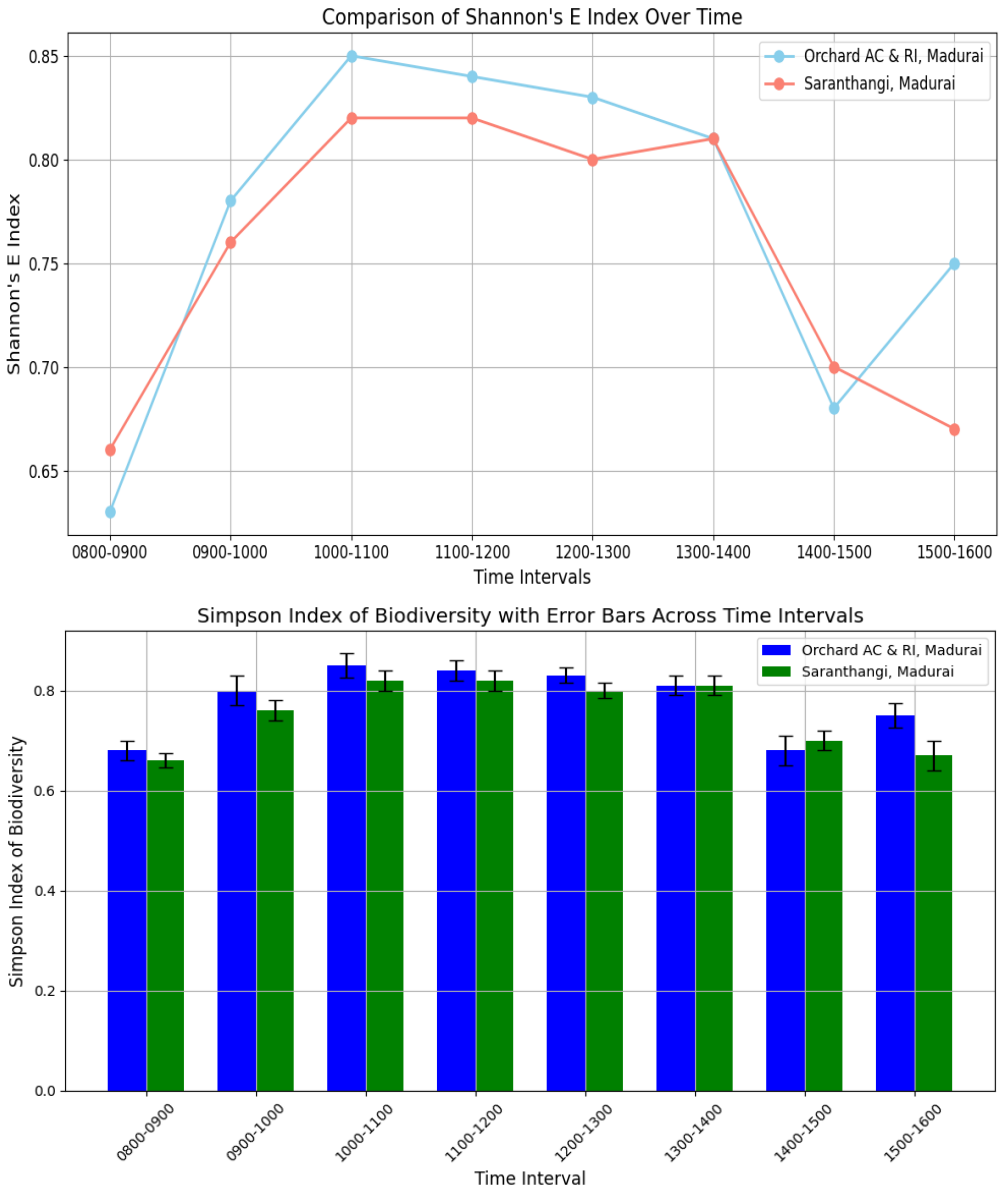

Figure 2. *Diversity indices of major pollinators/floral visitors of cashew were observed at Orchard, AC & RI, Madurai and Saranthangi, Madurai*

Discussion

The peak foraging activity of *A. cerana indica* was maximum at 0900-1200 h and there was decrease in their activity between 1200-1400 h, thereafter, it showed a slight increase in their activity during 1400-1600 h of the day. The foraging activity of *T. iridipennis* was higher from 0800-1300 h, but drastically decreases from 1300-1600 h of the day. Maximum activity of *Ceratina* sp. and *Braunsapis* sp. was recorded during 1000-1300 h. Dipterans activity was maximum during morning hours of 0800-1200 h, whereas it was minimum during the afternoon hours. Lepidopteran activity reached its peak during the morning hours of 0800-1100 h of the day.

Foraging activity was observed to be lowest between 1300 and 1500 h in the afternoon. This aligns with the findings of Joshi and Joshi (2010), who reported that the

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DOI: http://dx.doi.org/10.15666/aeer/2206_60976112

peak foraging activity of *Apis cerana indica* on apple flowers occurred between 1100 and 1300 h.

In a similar study, Benachour and Louadi (2013) observed that the visitation rate of hymenopterans, particularly honey bees, on plum flowers peaked at 1200 h. Lepidopterans, on the other hand, were more abundant during the morning hours compared to the afternoon. These findings are further supported by Naik (2014), who reported that the number of *Apis cerana indica* individuals per panicle was highest at 1000 h, followed by 1200 and 0800 h, with visitation rates of 0.36 and 0.04 bees per panicle per 5 min, respectively.

The study by Vishwakarma and Singh (2017) revealed that pollinator foraging activity on mango flowers peaked at 1200 h, surpassing the activity observed at both 0700 and 1500 h. This highlights a midday peak in foraging behavior, suggesting that pollinators are most active during this time compared to the early morning and late afternoon.

These findings are consistent with the present study. Furthermore, the current results are supported by the reports of Jyothi (1994) and Sung et al. (2006), who also observed similar foraging patterns on mango flowers.

According to Shivaram et al. (2012), there was a noticeable diurnal variation in insect foraging activity, with peak pollinator activity on rambutan flowers occurring between 1000 and 1100 h. This finding aligns with the present study's observations.

In this present finding, the total number of individuals/m^2/10 min was maximum i.e., 27.5 individuals at 1000-1100 h. The second highest number was between 1100 to 1200 h of the day, when 24.8 individuals/m^2/10 min were observed. The relative abundance per cent of *A. cerana indica* was higher, 26.18 followed by *T. iridipennis* and *Braunsapis* sp. with 20.95 and 11.49 per cent during 1000-1100 h of the day at AC & RI, Madurai. In case of 1100-1200 h, the relative abundance of pollinators was in the order of *A. cerana indica*, *T. iridipennis*, *C. binghami*, *Braunsapis* sp., *Halictus* sp. with 24.60, 16.29, 17.82, 18.63 and 5.73 per cent, respectively.

These findings are in partial agreement with the results of Madhurima and Sattagi (2018), who observed that the relative abundance of *Apis cerana indica* and *Tetragonula iridipennis* on guava flowers was 22.35% and 12.32%, respectively, compared to other pollinators. Similarly, a study by Vanitha and Raviprasad (2019) revealed that the relative abundance of *Braunsapis* sp. was the highest, constituting 31.42% of the total pollinators, while *Ceratina binghami* and *Tetragonula* sp. accounted for 13.03% and 6.51%, respectively. These results are comparable to the present findings.

The results of the current study revealed that species richness was higher at 0900-1200 h and lower at 1300-1400 h. Species richness was in the range of 9 to 13 at AC & RI, Madurai, whereas, it was in the range of 8-10 at Saranthangi, Madurai. During 1000-1100 h, Shannon's H index and Shannon's E index was maximum, followed by 1100-1200 h and minimum value was obtained during 1400-1500 h of the day. Same trend was also noticed in Simpson's D index at various intervals of the day. Lower Berger Parker index was recorded as lower during 1000-1100 and 1100-1200 h, indicated the higher diversity of pollinators at this time period.

A similar trend was observed in the Simpson's D index at various intervals of the day, although this conflicts with the results of Sowmiya et al. (2018), who analyzed the diversity indices of moringa pollinators and found that Shannon and Simpson indices were highest between 1400 and 1500 h. The present findings are partially in agreement with the reports of Nayak et al. (2020), who calculated the Simpson's diversity indices of mango pollinators under the conditions in Odisha.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
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From an agricultural perspective, enhancing pollinator diversity and abundance is critical for maintaining sustainable cashew production. The role of non-Apis pollinators, such as dipterans and lepidopterans, although less significant than that of honeybees, should not be overlooked. These pollinators contribute to the overall pollination network and provide resilience to the ecosystem, especially under conditions where honeybee populations may fluctuate due to environmental stressors like climate change, pesticide use, or habitat destruction. Management strategies should prioritize the conservation of pollinator habitats, the reduction of pesticide use during critical foraging periods, and the planting of flowering plants that provide alternative foraging resources when cashew is not in bloom. Additionally, providing nesting sites for native pollinators like *T. iridipennis* can further enhance pollinator services.

Conclusion

In conclusion, our study sheds light on the diversity and abundance of insect pollinators in the cashew ecosystem of Madurai district, Tamil Nadu, India. Through observations and analysis, identified *Apis cerana indica* and *Tetragonula iridipennis* as the dominant pollinators in cashew ecosystem. Their foraging behavior, particularly during the morning hours, coincided with the peak activity of cashew flowers, highlighting their crucial role in the pollination process. The examination of diversity indices provided valuable insights into the dynamics of pollinator populations, revealing variations in species richness and abundance across different times of the day and locations within the study area. These findings underscore the importance of effective pollinator management strategies for optimizing cashew crop yields.

The findings of this study on pollinator diversity and foraging behavior in cashew orchards offer several important implications for future research and agricultural management, particularly regarding pollinator conservation and sustainable farming practices. In future steps may also be taken to explore methods for enhancing the diversity of non-*Apis* pollinators in cashew ecosystem. This study underscores the importance of reducing the use of chemical pesticides that may harm non-target pollinators, including butterflies, hoverflies, and wild bee species. Future research should investigate the effects of commonly used pesticides in cashew orchards on local pollinator populations and explore integrated pest management (IPM) strategies that are pollinator-friendly. IPM practices, which prioritize biological control agents and reduced pesticide usage, can help maintain healthy pollinator populations and improve fruit set and yield. The insights from this study could inform sustainable farming practices that integrate pollinator-friendly approaches into cashew production systems. Promoting organic farming and conservation agriculture in cashew orchards could improve both pollinator health and agricultural productivity.

Author contributions. Suresh Krishnasamy, Deepika Nalavan, Usha rani Balakrishnan, Premika Ramasamy planned the research work and designed the methodology including treatments. Conceptualization and formulation of project, field design, measurements, curation of data. All authors have written various chapters of the research paper, reviewed and approved.

Acknowledgements. All authors are thankful to Agriculture College and Research Institute, Madurai. Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu, India for the facilities provided to carry out the research.

Conflict of interests. The authors declare no competing interests.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
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