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Research Article

Pollen source variation between agricultural areas and forest edges: a case study of the red dwarf honeybee (*Apis florea* Fabricius) in the Rarh region, West Bengal, India

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Abstract. Conserving native honeybees is vital for ecosystem stability and food security, yet the impact of changing landscapes on the pollen foraging of the red dwarf honeybee (*Apis florea*) remains poorly understood. The study investigated how landscape variation influences pollen foraging by *Apis florea* in West Bengal, examining its pollen resources and collection patterns across agricultural areas and forest edges. We conducted palynological analyses of corbicular pollen loads. The honeybee species exhibited floral constancy and polylecty, collecting a wide variety of pollen types (57 in total). The composition and predominant pollen sources varied between the two landscapes. In agricultural areas, predominant pollen sources were *Coriandrum sativum*, *Cucumis sativus*, *Cucurbita maxima*, *Luffa aegyptiaca*, and *Rhamphospermum nigrum*. In contrast, at forest edges, several tree species such as *Acacia auriculiformis*, *Eucalyptus tereticornis*, and *Terminalia arjuna* were dominant, along with some crop species, including *Coriandrum sativum* and *Rhamphospermum nigrum*. However, the monthly number and diversity of pollen types did not differ significantly between the two landscapes. Based on diverse characteristics of bee-visited flowers, the honeybee species was considered a generalist forager. In conclusion, the red dwarf honeybee was adapted to diverse habitats. Agricultural land use influenced the botanical composition of pollen collected by honeybees, but did not appear to restrict overall pollen flow to colonies.

Keywords: Generalist forager, floral constancy, pollen load, pollen type, polylectic forager

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Introduction

Honeybees forage on the flowers of a wide range of plant species to collect floral rewards, including nectar and pollen. Specifically, pollen serves as the sole natural source of protein for the development of honeybee brood (Liolios *et al.*, 2015; Pang *et al.*, 2022). In addition, it fulfils the bees' requirements for lipids, sterols, amino acids, carbohydrates, polyphenols, vitamins, pigments, antioxidants, and minerals (Campos *et al.*, 2008; Rzepecka-Stojko *et al.*, 2015; Alshallash *et al.*, 2023; Mărgăoan & Cornea-Cipcigan, 2024). Consequently, the survival of a honeybee colony is highly dependent on the pollen it collects. Pollen is required daily, as honeybees prefer freshly stored grains (Carroll *et al.*, 2017) and tend to store only small amounts of pollen in the hive, sufficient for a few months (Layek *et al.*, 2016). This limited reserve makes colonies particularly vulnerable to sudden fluctuations in environmental pollen availability (Pernal & Currie, 2001; Requier *et al.*, 2017), underscoring the crucial role of pollen in honeybee colony survival. Gradually, various landforms are being converted into built-up areas for human habitation and agricultural land to meet rising food demand, leading to a decline in forested areas. Changes in landscape use patterns can significantly influence the foraging behaviour of honeybees (Steffan-Dewenter &

Kuhn, 2003; Danner *et al*., 2016). Moreover, pollen foraging patterns can affect colony distribution, survival, and the spatial extent of pollination services (Joseph *et al*., 2020). Consequently, assessing honeybees' pollen collection patterns across different landscapes is essential for both humanity and global food security (Garibaldi *et al*., 2011; Van der Sluijs *et al*., 2016). Nonetheless, the extent to which resource distribution and habitat composition influence pollen collection at the landscape scale remains poorly understood. Understanding pollen foraging patterns is, however, invaluable for agricultural landscape planning, as it supports the development of optimised landscape designs that enhance pollination services, promote sustainable biodiversity, and improve crop yields (Brosi *et al*., 2008).

Identifying the floral resources utilised by honeybees is essential for developing conservation strategies and optimising the ecosystem services associated with pollination (Aguiar *et al*., 2013; Melin *et al*., 2018). Palynological analysis of pollen loads is a reliable and widely employed method for determining the pollen sources of a bee species (Campos *et al*., 2008; Barth *et al*., 2010). It also provides insights into the foraging preferences of honeybees, ecological interactions (between plants and pollinators, as well as among different pollinator species), and the floral composition of the vegetation surrounding the colony. The red dwarf honeybee (*Apis florea* Fabricius) is native to Asia, with its natural range extending from Southeast Asia to the Persian Gulf, encompassing several countries, including India, Pakistan, Sri Lanka, China, Malaysia, and Thailand. This honeybee species is an important pollinator of many wild and cultivated plants (Abrol, 2010), and plays a vital role in conserving biodiversity and sustaining food security. Numerous researchers have conducted palynological studies to characterise the pollen foraging behaviour of this honeybee species (e.g., Kalpana *et al*., 1990; El Shafie *et al*., 2002; Suwannapong *et al*., 2013; Layek *et al*., 2015a, 2026). However, the pollen foraging patterns of this species remain poorly understood in West Bengal (e.g., Layek *et al*., 2015a, b, 2026). Information on how landscape composition (vegetation) affects the collection of floral resources by red dwarf honeybees is scarce. In particular, the extent to which landscapes influence pollen collection by honeybee species remains to be determined. However, this information is crucial for conserving native honeybee species in a changing landscape.

In this study, we aimed to uncover the impact of landscape composition (especially entomophilous flora) on pollen host selection of red dwarf honeybee (*Apis florea*); for this, we identified the polleniferous plants utilised by *Apis florea* across two distinct landscapes (agricultural and forest areas) through palynological analysis of pollen loads in the Rarh region of West Bengal. Specifically, we sought to address the following research questions: (1) Which plant species provide pollen for *Apis florea*? (2) Which are the key polliniferous plants for this honeybee species? (3) Does the palyno-diversity of their pollen diet vary between landscapes? We hypothesised that landscape composition may influence the pollen diets of honeybees and that agriculture-prone and forest-edge zones both have the potential to provide honeybees with pollen of different botanical compositions.

Materials and methods

Experimental site

The study was carried out in the Rarh region (in Bankura district) of West Bengal, India, over two consecutive years, from 2023 to 2024 (Fig. 1). The Rarh region of West Bengal lies in the western part of the state, extending over districts such as Bankura, Purulia, Paschim Bardhaman, and parts of Birbhum. It is characterised by undulating uplands, lateritic soils, sparse vegetation, and a relatively dry climate compared to the humid Gangetic plains. The region forms a transitional zone between the Chota Nagpur Plateau and the alluvial plains of eastern West Bengal. The Rarh region, including Bankura district, has different landscape compositions, including forest, forest edge, and agricultural zones. Sampling sites were selected across two types of landscapes: (i) agricultural areas and (ii) forest areas. The agricultural sampling sites included Golakpur, Lalbandh, Mandi, Mamra, Rajpur, and Saldaha, while the forest sites comprised Bankadaha, Benachapra, Dhabani, Kharkharee, Koniary, Lachna, Majuria, Panchmura, and Telerajpur. The agricultural landscapes were primarily characterised by crop fields containing species such as *Coriandrum sativum* L., *Cucumis sativus* L., *Luffa acutangula* (L.) Roxb., *Luffa aegyptiaca* Mill., *Momordica charantia* L., *Oryza sativa* L., *Rhamphospermum nigrum* (L.) Al-Shehbaz, and *Sesamum indicum* (L.).

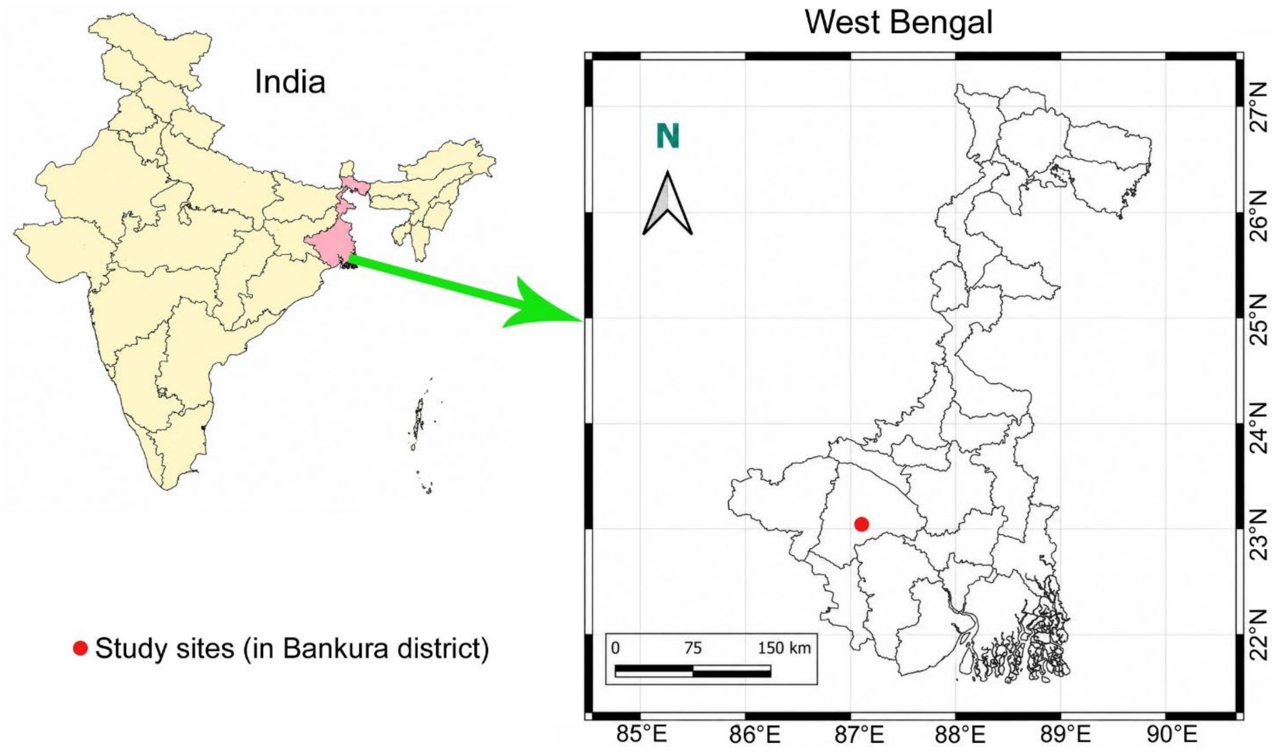

Fig 1. The map shows study sites within the Rarh region of West Bengal, India.

In contrast, the forest areas were dominated by tree species, including *Acacia auriculiformis* A. Cunn. ex Benth., *Eucalyptus tereticornis* Sm., *Shorea robusta* C. F. Gaertn., and *Terminalia chebula* (Retz.). Pedologically, the soils of the study sites are dominated by lateritic and red soils, with alluvial soils occurring in the eastern riverine plains. These soils are generally acidic, low in fertility, and sandy loam in texture, with laterization as the dominant soil-forming process in this humid tropical region. The region has a tropical climate with clearly defined seasons: summer (April–June), monsoon (July–August), post-monsoon or autumn (mid-September–mid-October), and winter (December–January). Summers are hot, with daytime temperatures ranging from 35 to 42 °C, whereas winters are relatively cool, with daytime temperatures between 7 and 15 °C. The study area receives approximately 1,400 mm of annual rainfall, the majority of which falls during the monsoon season.

Honeybee species

This study focused on the red dwarf honeybee, *Apis florea*, a species belonging to the family Apidae. This honeybee constructs single-comb, open nests on the branches of trees and shrubs, as well as on man-made structures (Layek & Karmakar, 2020). It exhibits migratory behaviour, and its occurrence (colony density) varies seasonally, reaching its peak from winter to summer (Layek & Karmakar, 2020).

Pollen load collection

We collected corbicular pollen samples by directly capturing returning pollen foragers. With appropriate safety measures (using a bee veil), we approached the nests closely during foraging periods — in the morning (08:00–10:00 h), around noon (11:30–12:30 h), and in the afternoon (15:30–17:00 h). On each sampling day, 10–15 pollen foragers were captured using forceps, and the two corbicular pollen loads from each forager were transferred into a glass vial. FAA solution was then added to the vial, and the samples were preserved for subsequent analysis. Pollen samples were collected throughout the year from both agricultural and forest areas. In total, 806 pairs of pollen loads were collected (427 pairs of loads from agricultural areas and 379 pairs of loads from forest edges), comprising 20–49 pairs of loads per month for each vegetation zone (Table 1).

Palynological analyses

The vials containing pollen samples were vigorously shaken to homogenise the solution. The samples were then centrifuged at 3,000 rpm for 5 minutes. After removing the supernatant, 2 mL of glacial acetic acid was added to the pollen sediment and stirred thoroughly. The mixture was again centrifuged at 3,000 rpm for 5 minutes. Following the removal of the supernatant, the resulting pollen sediment was treated with an acetolysis mixture of acetic anhydride and concentrated sulphuric acid in a 9:1 ratio (Erdtman, 1960). The mixture was well stirred, and the tube was placed in a water bath at 100 °C for 3 minutes. The acetolysed pollen sample was then centrifuged at 3,000 rpm, after which the sediment was rinsed with distilled water and centrifuged twice more. A small portion of the pollen sediment was transferred to the centre of a glass slide along with a drop of glycerine jelly. The jelly containing the pollen was gently warmed to melt it, then covered with a coverslip, and the edges were sealed with nail polish. The prepared slides were examined under a light microscope (Primo Star, Zeiss), and pollen micrographs were captured (with objective lenses of 20x [200x magnification], 40x [400x magnification] and 100x [1000x magnification]). Pollen grains were identified by comparing their morphological characteristics (including shape, size, aperture features, and exine ornamentation) with reference pollen slides prepared from the pollen of entomophilous plants found at the study sites. In most cases, identification was carried out to the species level (i.e., pollen species) for pollen obtained from bee pollen loads; however, when species-level identification was not possible, a pollen-type approach was adopted (Joosten & Klerk, 2002). We estimated the relative abundance (RA) (also referred to as occurrence) of each pollen species or type based on the total number of corbicular pollen loads recorded over the study period (Layek *et al.*, 2026).

$$\text{RA}\ (\%) = \frac{\text{n}i}{\text{N}} \times 100$$

n*i* represents the number of pollen loads counted for the *i* pollen type, while N denotes the total number of pollen loads analysed.

The monthly percentages of the pollen types obtained were calculated. The pollen types were then categorised into five groups (with slight modification of Layek *et al.*, 2026): (1) very frequent (>30%), (2) frequent (>20–30%), (3) moderate frequent (>10–20%), (4) less frequent (3–10%), and (5) rare (<3%). Regarding the landscape, we recorded the number of pollen types obtained from analysing bee pollen loads for each month. Month-wise pollen diversity was also calculated using the Shannon–Weaver diversity index (*H'*) (Shannon & Weaver, 1949), and the evenness of pollen collection — that is, the extent to which different pollen types were equally represented — was assessed using Pielou's (1977) evenness index (*J'*) as follows:

$$H' = -\sum_{i}^{n} (\text{pi}.\, ln\ \text{pi})$$

$$J' = H'/ln\ S$$

Here, p_i denotes the proportion of each pollen type within a given month, *ln* represents the natural logarithm, and S is the total number of pollen types recorded in that month. The value of H' ranges from 0 to greater than 1, with higher values indicating greater diversity. The value of J' ranges from 0 to 1, reflecting resource use from highly uneven (heterogeneous) to completely even (homogeneous).

Field surveys

Field surveys were conducted at regular intervals (approximately every 10–15 days) across the vegetation of the study sites. These surveys were used to prepare reference pollen slides from bee-visited entomophilous plants and to identify the collected pollen loads, primarily to species level. For each honeybee-visited plant species, we recorded the growth habit, inflorescence type, and floral traits, including flower size, shape, and colour. Flowers were classified into five size categories based on the length of floral parts: very small (<5 mm), small (5–15 mm), medium (>15–30 mm), large (>30–50 mm), and very large (>50 mm) (Layek *et al.*, 2026). Flower shapes were categorised following Dafni (1992), with minor modifications. For capitula and umbels, the overall size and shape of the inflorescence were considered rather than individual flowers. Flower colours were recorded according to human visual perception.

Statistical analyses

We performed descriptive statistics to estimate the mean and standard deviation of the datasets. Within each group, we first assessed the key assumptions for parametric tests: normality (using the Shapiro–Wilk test), homoscedasticity (via scatter plots), homogeneity of variances (using Levene's test), and the absence of outliers (through box plots). If the assumptions were not satisfied, the non-parametric Mann-Whitney U test was used to compare means between groups (for example, number of pollen types, values of the pollen diversity index H' and equitability index J' in agricultural areas versus forest edges). The obtained p-values were considered significant at the 0.05 level. All analyses were carried out using SPSS software (version 26.0).

Results

Pollen types in pollen loads

Each pair of pollen loads (collected from a single returning pollen forager) was monofloral in origin. A total of 57 pollen types, belonging to 23 plant families, were identified from the analysis of 806 pairs of corbicular pollen loads (Table 2, Fig. 2). Thirty-seven pollen types originated from agricultural areas, while 41 were from forest edges. The most represented plant families were Cucurbitaceae (8 pollen types), Fabaceae (8 pollen types), Anacardiaceae (5 pollen types), Asteraceae (4 pollen types), and Lamiaceae (4 pollen types). The families contributing the highest proportions of pollen loads were Apiaceae (6.66%), Arecaceae (7.82%), Brassicaceae (8.44%), Cucurbitaceae (22.20%), Fabaceae (12.28%), and Myrtaceae (9.80%). In agricultural areas, the most abundant pollen types were *Rhamphospermum nigrum* (RA = 11.24%), *Cucurbita maxima* (RA = 9.84%), *Luffa aegyptiaca* (RA = 9.13%), *Coriandrum sativum* (relative abundance, RA = 7.96%), and *Cucumis sativus* (RA = 7.72%). In contrast, in forest edges, the dominant pollen types were *Eucalyptus tereticornis* (RA = 11.60%), *Acacia auriculiformis* (RA = 9.76%), and *Terminalia arjuna* (RA = 6.06%). On a monthly basis, in agricultural areas, pollen types with higher frequencies (classified as very frequent and/or frequent) included *Acacia auriculiformis*, *Coccinia grandis*, *Cucumis sativus*, *Cucurbita maxima*, *Helianthus annuus*, *Luffa aegyptiaca*, *Rhamphospermum nigrum*, *Sesamum indicum*, and *Trichosanthes curcumina* (Table 3). In forest edges, the more frequent pollen types were *Acacia auriculiformis*, *Eucalyptus tereticornis*, *Pithecellobium dulce*, *Rhamphospermum nigrum*, *Terminalia arjuna*, and *Ziziphus mauritiana* (Table 4).

Table 1. Month-wise number of pollen loads collected from agricultural areas and forest edges in the Rarh region of West Bengal, India.

Month	Number of pollen loads (in pairs)	
	Agricultural areas	Forest edges
January	42	47
February	44	22
March	24	46
April	44	45
May	24	43
June	43	25
July	49	21
August	24	45
September	21	22
October	20	21
November	45	22
December	47	20
Total	427	379

Supplementary Table 1. Characteristics of red dwarf honeybee (*Apis florea*) visited plants in the Rarh region of West Bengal, India.

Parameters	Types with proportion
Origin of plant species	Wild (75%), agricultural (23.21%), ornamental (1.79%)
Plant habit	Tree (53.57%), herb (17.85%), shrub (14.28%), climber (14.28%)
Inflorescence	Cyme (25%), raceme (14.28%), solitary (14.28%), panicle (12.50%), spike (12.50%), capitulum (8.93%), umbel (5.35%), spadix (3.57%), corymb (1.78%), verticillaster (1.78%)
Flower size	Small (55.36%), medium (26.79%), large (12.5%), very large (5.35%)
Flower shape	Dish (28.57%), brush (19.64%), stellate (17.86%), gullet (10.71%), globose (8.93%), saucer (7.14%), irregular (3.57%), cruciform (1.78%), vase (1.78%)
Flower colour	White (23.21%), cream (21.43%), yellow (21.43%), greenish yellow (14.28%), greenish white (12.50%), red (7.14%)

Month-wise, the number of pollen types ranged from 6 to 11 (8.33 ± 1.44) in agricultural areas and from 5 to 11 (7.08 ± 2.27) at forest edges (Table 5). In agricultural areas, the lowest number of pollen types was recorded in September and October compared with other months. At forest edges, a greater number of pollen types were observed in March, April, May, and August. The number of pollen types did not differ significantly between the two landscape types (agricultural areas and forest edges) (Table 5). Monthly values of the Shannon–Weaver diversity index (H') ranged from 1.71 to 2.15 (1.92 ± 0.14) in agricultural areas and from 1.50 to 2.19 (1.75 ± 0.28) at forest edges; Pielou's evenness index (J') ranged from 0.85 to 0.96 (0.91 ± 0.04) in agricultural areas and from 0.86 to 0.94 (0.91 ± 0.03) at forest edges. Landscape-wise, the values of both H' and J' showed no variation.

Characteristics of honeybee-visited plants

The red dwarf honeybee species visited a wide range of plants (56 species identified at the species level based on pollen types), exhibiting considerable diversity in plant origin, growth habit, inflorescence type, and floral traits such as size, shape, and colour. They foraged on both wild (75%) and cultivated plants, including agronomic–horticultural (23.21%) and ornamental species (1.79%) (Supplementary Table 1). Among the visited plants, the majority were trees (53.57%), followed by herbs, shrubs, and climbers. The honeybees showed a preference for a variety of inflorescence types, with cymes (25.00%), racemes (14.28%), solitary (14.28%), panicles (12.50%), and spikes (12.50%) being the most common. Flower sizes ranged from small to very large, although small (55.36%) and medium-sized (26.79%) flowers were the most frequently visited. Flower shapes were also diverse, with dish-shaped (28.57%), brush-shaped (19.64%), and stellate forms (17.86%) being the most prevalent. In terms of flower colour, white (23.21%), cream (21.43%), and yellow (21.43%) were the most commonly visited colours.

Discussion

Considering the composition of individual bees' pollen loads (each pair collected by a single forager), all were monofloral in botanical origin, indicating that the foragers exhibited marked floral constancy during their foraging trips. Floral constancy is a well-documented phenomenon among various honeybee species, including *Apis cerana* (Raj *et al.*, 1993; Mondal *et al.*, 2023), *Apis dorsata* (Layek *et al.*, 2023), *Apis florea* (Layek *et al.*, 2015a,b), and *Apis mellifera* (Grüter *et al.*, 2011; Layek *et al.*, 2020). The constancy of flower visitation strongly influences a pollinator's efficiency and its contribution to ecosystem services. The honeybee species collected pollen from a wide range of plant species in both agricultural areas and forest edges, indicating its polylectic nature, which has also been recognised by other researchers (e.g., Layek *et al.*, 2015a,b, 2020). Such polylectic behaviour enhances the nutritional quality of pollen diets, improves adaptability across diverse habitats, and supports colony sustainability.

In the present study, Anacardiaceae, Cucurbitaceae, and Fabaceae were recorded as having the highest number of pollen types, likely due to their abundance in the study area and honeybees' preference for their flowers. The principal pollen-contributing families were Apiaceae, Arecaceae, Brassicaceae, Cucurbitaceae, Fabaceae, and Myrtaceae. The significance of these families as major pollen sources for honeybees is well recognised globally (Andrada & Tellería, 2005; Layek *et al.*, 2015a,b, 2020; Alves & Santos, 2017; Mondal *et al.*, 2023). Many crop species in Apiaceae, Brassicaceae, and Cucurbitaceae were cultivated within the study areas, resulting in their dominance in the pollen spectra. In contrast, the families Arecaceae, Fabaceae, and Myrtaceae mainly include wild and cultivated trees that were common within the study zones, accounting for their substantial representation in the collected pollen loads.

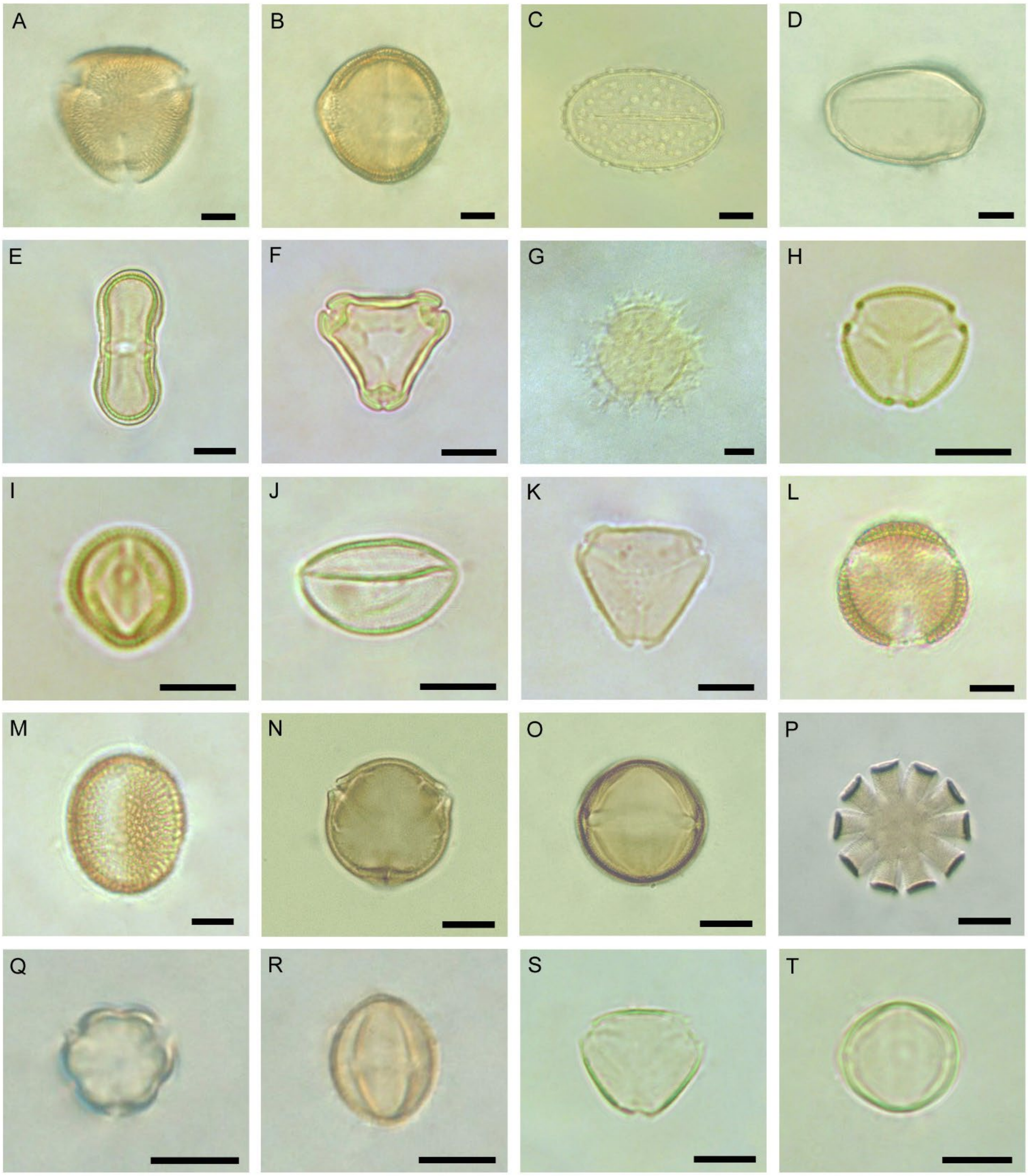

Fig. 2. Photomicrographs of pollen types obtained from pollen loads of *Apis florea* in Bankura district, West Bengal, India. (A–B) *Anacardium occidentale*, (C) *Borassus flabellifer*, (D) *Cocos nucifera*, (E) *Coriandrum sativum*, (F) *Eucalyptus tereticornis*, (G) *Helianthus annuus*, (H–I) *Neolamarckia cadamba*, (J) *Phoenix sylvestris*, (K) *Psidium guajava*, (L–M) *Rhamphospermum nigrum*, (N–O) *Ricinus communis*, (P) *Sesamum indicum*, (Q–R) *Terminalia arjuna*, (S–T) *Ziziphus mauritiana*. Scale bars = 10 µm.

Table 2. Pollen types obtained from pollen load analysis of *Apis florea* in the Rarh region of West Bengal, India.

Plant family	Pollen type	Relative abundance (%)	
		Agricultural areas	Forest edges
Acanthaceae	*Hygrophila auriculata*	0.23	-
	Justicia adhatoda	0.23	-
Amaryllidaceae	*Allium cepa*	0.47	-
Anacardiaceae	*Anacardium occidentale*	-	0.52
	Buchanania latifolia	-	0.26
	Mangifera indica	2.11	-
	Semecarpus anacardium	0.47	1.58
	Spondias pinnata	-	0.52
Apiaceae	*Coriandrum sativum*	7.96	5.27
Arecaceae	*Borassus flabellifer*	0.47	2.11
	Cocos nucifera	4.92	5.27
	Phoenix sylvestris	0.94	2.11
Asteraceae	*Helianthus annuus*	3.51	2.11
	Mikania micrantha	2.11	1.05
	Tagetes petula	0.47	-
	Tridax procumbens	1.64	0.79
Brassicaceae	*Rhamphospermum nigrum*	11.24	5.27
Combretaceae	*Terminalia arjuna*	-	6.06
	Terminalia bellirica	-	1.58
	Terminalia chebula	-	0.26
Cornaceae	*Allangium salviifolium*	0.70	1.58
Cucurbitaceae	*Citrullus lanatus*	0.23	-
	Coccinia grandis	4.45	-
	Cucumis sativus	7.72	-
	Cucurbita maxima	9.84	-
	Luffa aegyptiaca	9.13	1.58
	Momordica charantia	3.04	-
	Trichosanthes cucumerina	3.98	-
	Trichosanthes dioica	0.47	-
Euphorbiaceae	*Croton bonplandianum*	0.47	1.58
	Jatropha gossypifolia	-	1.05
	Ricinus communis	0.23	0.79
Fabaceae	*Acacia auriculiformis*	3.51	9.76
	Albizia lebbeck	0.23	-
	Mimosa pudica	-	0.26
	Peltophorum pterocarpum	0.46	4.48
	Pithecellobium dulce	-	4.22
	Pterocarpus marsupiam	-	0.26
	Tamarindus indica	-	1.05
	Vachellia nilotica	-	1.84
Lamiaceae	*Gmelina arborea*	-	1.31
	Ocimum tenuiflorum	0.47	-
	Tectona grandis	-	2.90
	Vitex negundo	0.23	-
Loganiaceae	*Strychnos nux-vomica*	-	0.52
Meliaceae	*Azadirachta indica*	-	2.63
Moringaceae	*Moringa oleifera*	0.94	1.05
Myrtaceae	*Eucalyptus tereticornis*	5.85	11.60
	Psidium guajava	-	2.63
	Syzygium cumini	0.23	1.32
Pedaliaceae	*Sesamum indicum*	3.51	2.90
Rhamnaceae	*Ziziphus mauritiana*	1.17	3.69
Rubiaceae	*Neolamarckia cadamba*	-	1.05
Rutaceae	*Aegle mermelos*	0.23	-
	Citrus type	2.34	1.05
Santalaceae	*Santalum album*	-	2.90
Sapotaceae	*Madhuca longifolia*	-	1.05

The mother plants that produced (and provided to honeybees) pollen grains differed between agricultural areas and forest edges. In agricultural areas, a large proportion of pollen originated from crops such as *Coriandrum sativum*, *Cucumis sativus*, *Cucurbita maxima*, *Luffa aegyptiaca*, and *Rhamphospermum nigrum*.

In the present study, Anacardiaceae, Cucurbitaceae, and Fabaceae were recorded as having the highest number of pollen types, likely due to their abundance in the study area and honeybees' preference for their flowers. The principal pollen-contributing families were Apiaceae, Arecaceae, Brassicaceae, Cucurbitaceae, Fabaceae, and Myrtaceae. The significance of these families as major pollen sources for honeybees is well recognised globally (Andrada & Tellería, 2005; Layek *et al.*, 2015a, 2020; Alves & Santos, 2017; Mondal *et al.*, 2023). Many crop species in Apiaceae, Brassicaceae, and Cucurbitaceae were cultivated within the study areas, resulting in their dominance in the pollen spectra. In contrast, the families Arecaceae, Fabaceae, and Myrtaceae mainly include wild and cultivated trees that were common within the study zones, accounting for their substantial representation in the collected pollen loads. The mother plants that produced (and provided to honeybees) pollen grains differed between agricultural areas and forest edges. In agricultural areas, a large proportion of pollen originated from crops such as *Coriandrum sativum*, *Cucumis sativus*, *Cucurbita maxima*, *Luffa aegyptiaca*, and *Rhamphospermum nigrum*. In contrast, at forest edges, a greater share came from tree species including *Acacia auriculiformis*, *Eucalyptus tereticornis*, and *Terminalia arjuna*.

Table 3. Month-wise pollen types obtained from pollen loads of *Apis florea* in agricultural areas of the Rarh region of West Bengal, India.

Months	Pollen types				
	Very frequent	Frequent	Moderate frequent	Less frequent	Rare
January	*Rhamphospermum nigrum*		*Cocos nucifera, Coriandrum sativum, Eucalyptus tereticornis*	*Allium cepa, Mangifera indica, Phoenix sylvestris*	*Ricinus communis*
February		*Helianthus annuus Rhamphospermum nigrum*	*Coriandrum sativum, Mangifera indica*	*Allangium salvifolium, Cocos nucifera, Justicia gendarussa*	*Eucalyptus tereticornis, Phoenix sylvestris*
March		*Rhamphospermum nigrum*	*Coccinia grandis, Cucumis sativus, Helianthus annuus, Momordica charantia*	*Luffa aegyptiaca, Tagetes patula*	
April		*Cucurbita maxima*	*Coriandrum sativum, Luffa aegyptiaca, Momordica charantia, Sesamum indicum*	*Borassus flabellifer, Helianthus annuus*	*Albizia lebbeck, Justicia adhatoda*
May		*Luffa aegyptiaca, Sesamum indicum*	*Cocos nucifera, Coriandrum sativum, Mikania micrantha*	*Citrullus lanatus, Syzygium cumini*	
June		*Cucumis sativus*	*Citrus* type, *Coccinia grandis, Cucurbita maxima, Luffa aegyptiaca*	*Causonis trifolia, Tridax procumbens, Trichosanthes cucumerina*	*Vitex negundo*
July		*Cucurbita maxima, Luffa aegyptiaca*	*Coccinia grandis, Cucumis sativus, Trichosanthes cucumerina*	*Acacia auriculiformis, Citrus* type, *Croton bonplandianum, Peltophorum pterocarpum, Semecarpus anacardium*	*Aegle mermelos*
August		*Coccinia grandis, Trichosanthes cucumerina*	*Cucurbita maxima, Luffa aegyptiaca*	*Citrus* type, *Cocos nucifera, Tridax procumbens, Ziziphus mauritiana*	
September		*Cucumis sativus*	*Cucurbita maxima, Luffa aegyptiaca, Ziziphus mauritiana*	*Citrus* type, *Cocos nucifera, Ocimum tenuiclorum*	
October		*Acacia auriculiformis*	*Cocos nucifera, Cucumis sativus, Eucalyptus tereticornis, Luffa aegyptiaca, Momordica charantia*		
November		*Eucalyptus tereticornis*	*Acacia auriculiformis, Cucumis sativus, Cucurbita maxima, Luffa aegyptiaca*	*Cocos nucifera, Mikania scandens, Momordica charantia, Trichosanthes dioica, Tridax procumbens*	
December		*Eucalyptus tereticornis, Rhamphospermum nigrum*	*Coriandrum sativum*	*Cocos nucifera, Cucurbita maxima, Mikania micrantha, Moringa oleifera*	*Hygrophila auriculata, Phoenix sylvestris*

Table 4. Month-wise pollen types obtained from pollen loads of *Apis florea* in forest edges of the Rarh region of West Bengal, India.

Months	Pollen types				
	Very frequent	Frequent	Moderate frequent	Less frequent	Rare
January	*Eucalyptus tereticornis*		*Cocos nucifera, Coriandrum sativum, Phoenix sylvestris, Rhamphospermum nigrum*	*Azadirachta indica, Ricinus communis*	
February	*Eucalyptus tereticornis*	*Helianthus annuus*	*Coriandrum sativum, Moringa oleifera*	*Rhamphospermum nigrum*	
March	*Pithecellobium dulce*		*Allangium salviifolium, Coriandrum sativum, Rhamphospermum nigrum*	*Helianthus annuus, Luffa aegyptiaca, Spondias pinnata*	*Buchanania latifolia, Madhuca longifolia*
April			*Gmelina arborea, Peltophorum pterocarpum, Sesamum indicum, Terminalia arjuna*	*Borassus flabellifer, Jatropha gossypifolia, Madhuca longifolia, Santalum album, Strychnos nux-vomica, Syzygium cumini*	*Coriandrum sativum*
May			*Peltophorum pterocarpum, Psidium guajava, Santalum album*	*Anacardium occidentale, Azadirachta indica, Borassus flabellifer, Sesamum indicum, Syzygium cumini, Terminalia bellirica*	*Luffa aegyptiaca*
June	*Terminalia arjuna*	*Croton bonplandianum*	*Citrus* type, *Psidium guajava*	*Jatropha gossypifolia*	
July	*Vachellia nilotica*	*Terminalia arjuna*	*Semecarpus anacardium, Tectona grandis*	*Terminalia chebula*	
August	*Acacia auriculiformis*		*Cocos nucifera*	*Luffa aegyptiaca, Neolamarckia cadamba, Tamarindus indica, Tectona grandis, Terminalia bellirica, Ziziphus mauritiana*	*Santalum album, Semecarpus anacardium*
September	*Ziziphus mauritiana*	*Acacia auriculiformis*	*Tectona grandis*	*Cocos nucifera, Semecarpus anacardium, Tridax procumbens*	
October	*Acacia auriculiformis, Eucalyptus tereticornis*		*Ziziphus mauritiana*	*Cocos nucifera, Pterocarpus marsupium*	
November	*Acacia auriculiformis*	*Eucalyptus tereticornis*	*Azadirachta indica, Mikania scandens*	*Cocos nucifera, Mimosa pudica*	
December	*Eucalyptus tereticornis*	*Rhamphospermum nigrum*	*Coriandrum sativum, Phoenix sylvestris*	*Moringa oleifera, Tridax procumbens*	

Table 5. Month-wise number of pollen types, diversity and equitability of obtained pollen types from pollen loads of *Apis florea* in the Rarh region of West Bengal, India.

Month	Number of pollen types		*H'*		*J'*	
	Agricultural areas	Forest edges	Agricultural areas	Forest edges	Agricultural areas	Forest edges
January	8	7	1.87	1.83	0.85	0.94
February	9	5	1.88	1.50	0.86	0.93
March	7	9	1.88	2.01	0.96	0.91
April	9	11	1.96	2.19	0.89	0.92
May	7	10	1.77	2.16	0.90	0.94
June	9	5	2.05	1.49	0.93	0.93
July	11	5	2.14	1.46	0.89	0.90
August	8	10	1.96	1.98	0.94	0.86
September	7	6	1.84	1.64	0.94	0.92
October	6	5	1.71	1.38	0.95	0.86
November	10	6	2.15	1.64	0.93	0.92
December	9	6	1.86	1.68	0.85	0.94
Range	6–11	5–11	1.71–2.15	1.50–2.19	0.85–0.96	0.86–0.94
Mean ± SD	8.33 ± 1.44	7.08 ± 2.27	1.92 ± 0.14	1.75 ± 0.28	0.91 ± 0.04	0.91 ± 0.03
Statistics	U = 44.50, p = 0.11		U = 37.50, p = 0.06		U = 75.50, p = 0.84	

H': Shannon–Weaver diversity index; *J'*: Pielou's evenness index; SD: standard deviation; Statistics: Mann-Whitney test.

The importance of several of these species (e.g., *Acacia auriculiformis*, *Eucalyptus tereticornis*, *Rhamphospermum nigrum*, and *Terminalia arjuna*) as valuable pollen sources for honeybees has been documented in earlier studies (Laxmikant & Devendra, 2014; Layek *et al.*, 2015a). However, the identification of *Cucurbita maxima* as an important pollen source for honeybees is newly reported from West Bengal.

Month-wise, the number of pollen types remained largely consistent across the two landscape types, agricultural areas and forest edges. In agricultural areas, monoculture is unlikely to be extensive, allowing honeybee species to collect pollen from a wide range of plant species. This may positively reflect the benefits of nutritionally diverse pollen diets and the conservation of wild honeybee populations. The month-wise values of H' and J' were also comparable between the two landscapes (in agricultural areas: H' = 1.92 ± 0.14, J' = 0.91 ± 0.04; in forest edges: H' = 1.75 ± 0.28, J' = 0.91 ± 0.03). These values are consistent with those reported in other studies on social bees (e.g., Sosa-Najera *et al.*, 1994; Novais *et al.*, 2013; Layek *et al.*, 2021). The consistently high H' values suggest a considerable diversity of bee-visited plants. The diversity of pollen types depends on the availability of floral resources, the flowering duration of utilised plant species, and the foraging behaviour of the bees. Moreover, the high values of Pielou's evenness (J') index indicate limited dominance by any single or a few pollen types and a nearly equal representation of all pollen types within the pollen spectra. Such a diversity of bee forages and reduced dominance of any particular floral resource within a landscape could enhance bee activity and diversity (Moreira *et al.*, 2015) and may contribute to improved honeybee survival and honey production.

Regarding categorisation of honeybee-visited plants, it was observed that the red dwarf honeybee species primarily visited wild plants, as well as some agri-horticultural and ornamental species. Within the selected zones, particularly in agricultural areas, the honeybee species collected pollen from several crop plants (e.g., *Allium cepa*, *Coriandrum sativum*, and *Rhamphospermum nigrum*). The significance of agri-horticultural and ornamental plants as sources of floral rewards for honeybees is well established (e.g., Abrol, 2010; Layek *et al.*, 2015a; Gupta *et al.*, 2020). Hence, in addition to wild plants, a diverse range of cultivated species plays a crucial role in sustaining native honeybee populations. Among the bee-visited plants, trees were the most frequently foraged. Our findings corroborate previous studies on honeybees (e.g., Layek & Karmakar, 2020; Layek *et al.*, 2020), which suggest that foraging on tree flowers may offer greater security and reduced disturbance for the foragers. The honeybee species exploited a variety of inflorescence types, with cyme, raceme, solitary, panicle, and spike flowers being the predominant types. These inflorescence types may be more attractive to, or more readily available around, honeybee colonies. Most bee-visited plants possessed small or medium-sized flowers. Although a single small flower may contain a limited amount of pollen, pollen host selection in honeybees is governed by multiple factors, including flower availability, pollen quantity and quality, rather than the pollen content of individual flowers (Pernal & Currie, 2001; Layek *et al.*, 2020; Lan *et al.*, 2021). The red dwarf honeybees visited flowers of diverse shapes, with a predominance of dish-, brush-, and stellate-shaped flowers. In brush-shaped flowers, bees can easily gather pollen from numerous exposed stamens (Nates-Parra & Rodríguez, 2011), while dish- and stellate-shaped flowers provide a stable landing platform for collecting floral rewards. The bee-visited flowers exhibited a variety of colours, with white, cream, and yellow being the most common. This finding is consistent with previous studies on honeybees (e.g., Layek *et al.*, 2020) and stingless bees (e.g., Vossler, 2012; Obregón & Nates-Parra, 2014). Considering the wide range of characteristics of bee-visited plants, it may be concluded that the red dwarf honeybee species is a generalist forager. Such generalist behaviour enables honeybees to exploit a broad spectrum of plants to meet their nutritional requirements and enhance the sustainability of their colonies (Kaluza *et al.*, 2017).

Conclusion

The present study demonstrated that the red dwarf honeybee (*Apis florea*) foraged on a wide variety of pollen sources across both agricultural areas and forest edges. Certain plant families, such as Apiaceae, Arecaceae, Brassicaceae, Cucurbitaceae, Fabaceae, and Myrtaceae, were consistently dominant within the pollen spectra. In agricultural areas, a substantial proportion of pollen loads originated from crop plants (e.g., *Coriandrum sativum*, *Cucumis sativus*, *Cucurbita maxima*, *Luffa aegyptiaca*, and *Rhamphospermum nigrum*). In contrast, at forest edges, the majority were derived from trees (e.g., *Acacia auriculiformis*, *Eucalyptus tereticornis*, and *Terminalia arjuna*). The number and diversity of pollen types did not differ significantly between the two landscapes. Based on the characteristics of the bee-visited plants, the honeybee species was identified as a generalist forager, collecting floral resources from a wide variety of flower types. These findings highlight the ecological adaptability of *Apis florea* in utilising available floral resources across diverse habitats and emphasise the importance of maintaining heterogeneous landscapes to meet foraging requirements and conserve native honeybee populations.

Author's Contributions

Suman Kumar De: methodology, investigation, formal analysis, data curation, writing – original draft. **Ujjwal Layek:** investigation, formal analysis, writing, review & editing. **Prakash Karmakar:** conceptualization, supervision, writing- review and editing.

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All data supporting the findings of this study are available in the paper or in the supplementary files.

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This article does not contain any studies with human participants performed by any of the authors.

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Conflict of Interest

The authors declare that they have no known competing interests.

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Research Article

تنوع منابع گرده در مناطق کشاورزی و حاشیه جنگل‌ها: مطالعه موردی زنبور عسل کوتوله قرمز (*Apis florea* Fabricius) در منطقه رار بنگال غربی، هند

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چکیده: حفاظت از جمعیت زنبورهای عسل بومی، نقشی حیاتی در پایداری اکوسیستم و امنیت غذایی دارد، با این حال اثر تغییرات چشم‌اندازهای طبیعی بر رفتار گرده‌جویی زنبور عسل کوتوله‌ی قرمز (*Apis florea*) هنوز به‌خوبی شناخته نشده است. این پژوهش، نشان داد که چگونه تفاوت بین چشم‌اندازهای طبیعی روی گرده‌جویی این گونه در بنگال غربی تأثیر می‌گذارد. تحقیق با هدف مطالعه منابع گرده و الگوهای جمع‌آوری آن در مناطق کشاورزی و حاشیه‌های جنگلی طراحی شد. برای این منظور، ارزیابی گرده‌شناسی بر روی بارهای گرده ی جمع‌آوری‌شده در سبد گرده‌ی پاهای زنبور انجام شد. این گونه زنبور عسل، پایداری گل‌گزینی و رفتار چندگل‌پسندی (Polylecty) از خود نشان داد و طیف گسترده‌ای از انواع گرده‌ها (در مجموع ۵۷ نوع) را جمع‌آوری کرد. ترکیب و منابع غالب گرده میان دو نوع چشم‌انداز متفاوت بود. در مناطق کشاورزی، منابع اصلی گرده شامل: گشنیز (*Coriandrum sativum*)، خیار (*Cucumis sativus*)، کدو تنبل (*Cucurbita maxima*)، لوفا یا کدوی اسفنجی (*Luffa aegyptiaca*) و خردل سیاه (*Rhamphospermum nigrum*) بودند. در مقابل، در حاشیه‌های جنگلی چندین گونه درختی مانند: آکاسیا (*Acacia auriculiformis*)، اوکالیپتوس (*Eucalyptus tereticornis*) و ارجونا (*Terminalia arjuna*) به همراه برخی گیاهان زراعی مانند گشنیز و خردل سیاه، منابع غالب گرده محسوب می‌شدند. با این حال، تعداد گرده ها (در طول ماه) و تنوع انواع گرده‌ها بین دو چشم‌انداز، تفاوت معنی‌داری نشان نداد. بر اساس ویژگی‌های متنوع گل‌هایی که زنبورها از آن‌ها بازدید می‌کردند، این گونه زنبور عسل به‌عنوان یک گرده‌جوی عمومی (Generalist forager) در نظر گرفته شد. در نتیجه، زنبور عسل کوتوله‌ی قرمز یک گرده‌جوی عمومی است که توانایی سازگاری با زیستگاه‌های متنوع را دارد. توسعه کشاورزی بر ترکیب گیاهی گرده‌های جمع‌آوری‌شده توسط زنبورها تأثیر می‌گذارد، اما به نظر می‌رسد که روی جریان کلی گرده به سوی کلنی‌ها، تاثیری نمی‌گذارد.

کلمات کلیدی: گرده‌جوی عمومی ، ثبات گل‌گزینی، بار گرده، نوع گرده، جستجوگر چند منبعی

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