PLANT SCIENCE TODAY
ISSN 2348-1900 (online)
Vol 11(sp4): 01–13
https://doi.org/10.14719/pst.5066

HORIZON
e-Publishing Group
HePG

REVIEW ARTICLE

A review of the roles, importance, and threats of *Apis florea*

Premika Ramasamy[1], Suresh Krishnasamy[2]*, Usharani Balakrishnan[3], Asokan Ramsamy[4], Nalini Ramiah[1] & Arul Arasu Palanisamy[2]

[1]Department of Agricultural Entomology, Agricultural College and Research Institute, Tamil Nadu Agricultural University, Madurai, Tamil Nadu, India
[2]Indian Council of Agricultural Research - Krishi Vigyan Kendra, Tamil Nadu Agricultural University, Madurai, Tamil Nadu, India
[3]Indian Council of Agricultural Research - Krishi Vigyan Kendra, Tamil Nadu Agricultural University, Aruppukottai, Tamil Nadu, India
[4]Indian Council of Agricultural Research -Indian Institute of Horticultural Research, Bengaluru, Karnataka, India

*Email: suresh.k@tnau.ac.in

OPEN ACCESS

ARTICLE HISTORY
Received: 31 August 2024
Accepted: 21 October 2024
Available online
Version 1.0 : 31 December 2024

Check for updates

Additional information

Peer review: Publisher thanks Sectional Editor and the other anonymous reviewers for their contribution to the peer review of this work.

Reprints & permissions information is available at https://horizonepublishing.com/journals/index.php/PST/open_access_policy

Publisher's Note: Horizon e-Publishing Group remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Indexing: Plant Science Today, published by Horizon e-Publishing Group, is covered by Scopus, Web of Science, BIOSIS Previews, Clarivate Analytics, NAAS, UGC Care, etc
See https://horizonepublishing.com/journals/index.php/PST/indexing_abstracting

CITE THIS ARTICLE

Ramasamy P, Krishnasamy S, Balakrishnan U, Ramsamy A, Ramiah N, Palanisamy AA. A review of the roles, importance, and threats of *Apis florea* . Plant Science Today.2024;11 (sp4):01-13. https://doi.org/10.14719/pst.5066

Abstract

Apis florea and its closely related sister species, *Apis andreniformis*, within the subgenus Micrapis, represent one of the most evolutionarily primitive lineages in the genus Apis. Unique features of *A. florea* include the elongated "thumb" on the drones' bifurcated basitarsus, smooth abdominal tergites with reddish pigmentation, and behaviours such as wax salvage, prolonged foraging, aggressive territoriality, and high genetic diversity attributed to its polygamous queens. *A. florea* nests are typically more giant and are often located on exposed surfaces such as trees, walls, and buildings, with preferred nesting plants including *Pongamia pinnata*, *Mangifera indica*, and *Bougainvillea* species. While *A. florea* can accept queens of *A. andreniformis*. *A. florea* dominates in various horticultural settings due to its resilience and significant role in pollinating crops like bitter gourd, carrot, moringa, coriander, and phalsa. The queen chamber of *A. florea* measures 1.41 ± 0.15 cm in depth and 0.47 ± 0.09 cm in diameter, while the worker bee cells measure 0.29 ± 0.15 cm in diameter and 0.93 ± 0.07 cm in depth. The dimensions of *A. florea* hives are generally larger. The bees gathered pollen and nectar from the same sources or in successive foraging visits from all the plant species except *Spathodea campanulate*. In India, domestication trials for *A. florea* have been attempted, though with limited yield, as honey is valued more for its medicinal properties than quantity. *A. florea* honey, rich in dextrins, levulose, and antioxidants such as proline and phenols, demonstrates high therapeutic potential. Due to the critical role of *A. florea* in natural and horticultural ecosystems and its distinct ecological adaptations, further research is encouraged to explore this species' impact in greater depth. Despite their phylogenetic similarity, *A. florea* stands out due to specific morphological and behavioural characteristics, which have not received substantial scientific attention. This review aims to consolidate information on *A. florea*, detailing its morphology, nesting habits, and ecological contributions, particularly in pollination and horticultural systems.

Keywords

Apis andreniformis; *Apis florea*; foraging calendar; little bee; nest architecture; pollination efficiency

Introduction

Honeybees are crucial for human prosperity and ecosystem functioning. Their pivotal roles in pollination, biodiversity, the economy, and environmental monitoring make their conservation crucial. Bees are the sole producers of valuable honey, pollen, bio-wax, and royal jelly. Honey bees and plants have co-evolved with a mutualistic relationship, as bees depend on plants for pollen and nectar, while plants rely on bees for pollination. Insect pollination contributes around 153 billion USD to global agricultural productivity (1). The honey bee species found in India include the Indian bee (*Apis cerana indica* F.), Italian bee (*Apis mellifera* L.), Rock bee (*Apis dorsata* F.), little bee (*Apis florea* F.), and stingless bee or dammer bee (*Tetragonula irridipenis* S). There are a few more species like *Apis koshevnicovi, Apis nigrocincta*, *Apis laboriosa* and *Apis andreniformis* (2). *A. indica* and *A. mellifera* are reared in artificial hives primarily for honey (5kg/comb/year and 45 to 160 kg/comb/year, respectively). *A. florea* and *A. dorsata* are considered wild bees and have not been domesticated. In the case of *A. florea,* attempts have been made to domesticate with partial success. The sister species of *A. florea* is called *A. andreniformis*; these two are collectively called dwarf bees. Together, *A. florea* and *A. andreniformis* are from the subgenus Micrapis and are considered the most evolutionarily primitive of the extant *Apis* species. *A. florea* yields only a tiny amount of honey (0.5 to 1 kg/comb/year) with high medicinal value. In addition, *A. florea* plays an essential role in pollinating numerous agricultural and horticultural crops.

One of the least expensive and eco-friendly ways to boost agricultural yield is through insect pollination, mainly by honey bees (3). This method enhances crops' quantitative and qualitative parameters, such as seed vigour and germination percentage (4). Flowering plants bloom in different seasons, and nectareous plants might have varying flowering times based on climate, topography, and soil type. Consequently, for sustained practical beekeeping, it is essential to have full knowledge of the floral diversity in that area (5). One-third of the global food supply relies primarily on insect pollination, particularly in one-third of the crops (6). The only agriculture-based industry that maximizes income with minimal expenses is beekeeping. Successful beekeeping depends on the availability of bee-foraging plants (7).

Compared to prior studies on other bee species, *A. florea* receives less attention from scientists. However, due to its vital role in pollination, ecological dynamics, and impact on agriculture, this species is an intriguing subject for further research. This review paper aims to highlight all the aspects of *A. florea* in both natural and anthropogenic locations by exploring the biology, behaviour, nest architecture, division of labour, domestication, floral calendar and preference, foraging time, enemies, pollination efficiency, qualities of honey and their unique features.

Morphology of *A. florea*

Worker bees have bodies that vary in length from 7 to 10 mm, while queen bees are approximately twice the size of workers, measuring between 13 and 15 mm. Drones in this species have bodies that measure 11 to 13 mm (8). The morphometric characteristics of *A. florea* are presented in Table 1.

Morphometric identification of *A. florea* and *A. andreniformis*

In the 1990s, it was definitively shown that *A. florea* and *A. andreniformis* are two different species. *A. andreniformis* is often darker and has the first abdomen segment entirely black in elder bees. *A. florea* exhibits a more pronounced reddish colouration, with older workers displaying a distinctly red abdomen, while younger workers are pale, like the colouration observed in larger honeybee species (8). The most reliable distinguishing features for identifying *A. florea* and *A. andreniformis* include the significantly

Table 1. Morphometric characters of little bee, *Apis florea*

Characters	Morphometric characters of little bee, *A. florea*		
	(91)	(92)	(93)
Head length (mm)	2.38 ±0.10	-	-
Body length (mm)	11.47 ±0.74		
Length of thorax (mm)	3.67 ±0.22		
Length of abdomen (mm)	5.72 ±0.61		
Proboscis length (mm)	2.14±0.05	3.57±0.020	4.00±0.01
Antennal length (mm)	-	-	-
Hind tibial length (mm)	-	-	-
Length and width of metatarsus (mm)	0.72±0.05 0.25 ±0.05	-	1.50±0.01
Length of forewing (mm)	6.94±0.28	6.76±0.034 (Vietnam) 6.11±0.117 (Thailand)	6.25±0.03
Breadth of forewing (mm)	2.40±0.06	2.31±0.010 2.24±0.009	2.05±0.01
Length of hindwing (mm)	4.77±0.13	-	4.25±0.02
Cubital index (mm)	2.87±0.09	3.57±0.198(Vietnam) 6.11±0.117(Thailand)	1.75±0.00
No. of hamuli	11.0±1.06 11.0±0.57*	-	13.00±0.02
Width of 4th tergite (mm)	1.40±0.06 2.3 ± 0.83*	-	1.80±0.01
Length of 3rd sternite (mm)	2.69±0.07	-	2.15±0.02

longer "thumb" of the bifurcated basitarsus on the hind leg of *A. florea* drones compared to that of *A. andreniformis* (9). Additionally, notable differences in the structure of the endophallus can be observed in worker bees (10, 11). The jugal-vannal ratio of the hind wing in *A. florea* is approximately 75, more significant than the roughly 65 seen in *A. andreniformis*. Furthermore, the cubital index of *A. florea* is about 3, significantly lower than the index of approximately 6 in *A. andreniformis*. The second abdominal tergite of *A. andreniformis* is characterized by deep punctation, whereas that of *A. florea* remains smooth**.** The marginal setae on the hind tibiae of *A. florea* are typically entirely white, contrasting the dark brown to blackish setae found on the hind tibiae of sclerotized *A. andreniformis***.** Historical literature often emphasizes that the first and second abdominal tergites of *A. florea* are reddish, while other segments are at least partially reddish; in contrast, *A. andreniformis* exhibits uniformly black tergites. The comparative morphometric identification of *A. florea* and *A. andreniformis* is furnished in Table 2.

Table 2. Comparative morphology of *A. florea* and *A. andreniformis*

S.No.	Characters	*A. florea*	References	*A. andreniformis*	References
1.	Cuticular colour	Yellow bees	(95)	Black bees	(95)
2.	Hair on hind tibia	White colour		Black colour	
3.	Wing venation	Cubital Index 2.86	(12)	Cubital Index 6.37	(12)
4.	Male metathoracic legs	Basitarsus is quite long, more than two–thirds of the length of the tibia	(8)	Comparatively short and more than half of the length of the tibia	(10)
5.	Proboscis	3.273 ± 0.18 mm	(96)	2.797± 0.09 mm	(96)
6.	Endophalli	Fimbriate lobe has 3 protrusions	(97)	Fimbriate lobe has 6 protrusions	(10,8)
7.	Virgin queen	Queen does not produce a piping sound	(11)	Queen produces a pipingsound	(98)
8.	Mating of queens	Queen mating with 4 drones. Mate 5- 14 times	(11)	Mate 10-20 times	(75)
9.	Fanning behaviour	Fanned shorter 5-35s	(99)	Fanned longer 15s – 2mins	(99)
10.	Absconding behaviour	Increased heat / sunlight	(100)	Seasonal migration pattern	(100)
11.	Defensive behaviour	Less defensive	(12)	More defensive	(12)
12.	Wax collecting behaviour	Collect wax from the old comb		No collection	

Habitat/nesting site

The nesting height of *A. florea* is approximately 15 m (12). Most of the time, the nesting height of *A. florea* is reported to be between 0.5 and 10 m above the ground in urban environments (13). *A. florea* is thought to have a quicker nest-choosing process when compared to *A. mellifera* (14). *A. florea* determines a new nesting site through a dance communication method (15). While searching for new sites is a much quicker process for *A. florea*, it may not necessarily be more accurate. *Tamarindus indica, Hibiscus rosa sinensis, Nerium sp,* and *Moringa ovalifolia* are the most common nesting plants in tropical conditions. In contrast, the uncommon nesting plants are *Artocarpus heterophyllus*, *Tecoma stans*, *Bambusa bambos*, *Magnolia champaka* and *Pulmonaria longifolia*. Pongamia pinnata, *Mangifera indica*, and *Bouganvillea sp* are the preferred nesting plants. The nesting locations of *A. florea* include 14 distinct plants from 13 genera and 12 families. *P. pinnata, M. indica, Ceiba petandra, T. indica,* and *M. ovalifolia* are the most common nesting plants, and the nesting heights are recorded at 20–25, 22, 15-20, 12 and 8–20 feet, respectively. Compared to other species, *A. florea* comb sizes are smaller than 1.00 × 1.00 ft. The comb constructs in *T. indica* have the largest size of 1.25 × 1.00 ft, followed by *A. heterophyllus* (1.00 × 0.75 ft), *P. pinnata* (1.00 × 0.50 ft), *C. petandra* (0.75 × 1.00 ft) and *Bouganvillea* sp. (1.50 × 0.75). *A. florea* has developed a particular strategy for choosing their nesting habitats. It constructs a single vertical comb that hangs from a bush or tree branch at a moderate height on slender branches interspersed with light-moderate winds, with a pleasant temperature (16). The nesting sites of *A. florea* depend upon the environmental conditions, including woody areas and areas with an agroecosystem (17). The decision on a new site is made when the highest number of individuals perform a dance indicating the direction of that site. During the swarm's departure, the top ascends into the air first, followed by the bottom, and finally, the middle section lifts off, all within a minute of the initial take-off. Unlike other species, *A. florea* does not re-evaluate a site before several individuals relocate. Instead, the bees swarm collectively to the new location and will abandon it if it is later found unsuitable**.** When abundant floral resources are available, *A. florea* quickly swarms to a new location. When the resources become scarce, they relocate to other locations (18). Nesting sites and structure of *A. florea* in different plants are shown in Fig. 1.

Nest architecture

A. florea and *A. andreniformis* are phylogenetically similar and can accept the queen of the other species. *A. florea* and *A. andreniformis* are primarily identical except for the crown structure. The crown of *A. andreniformis* extends vertically from the twigs' midrib, and A. florea is exposed outward from the twig. It shows that the cells in the crown are directly attached to the twig. Nest architecture helps distinguish dwarf bees, *A. florea* and *A. andreniformis* (19). The nest architecture of eusocial bees depends upon the colonys' phenotype. Lastly, there are notable differ-

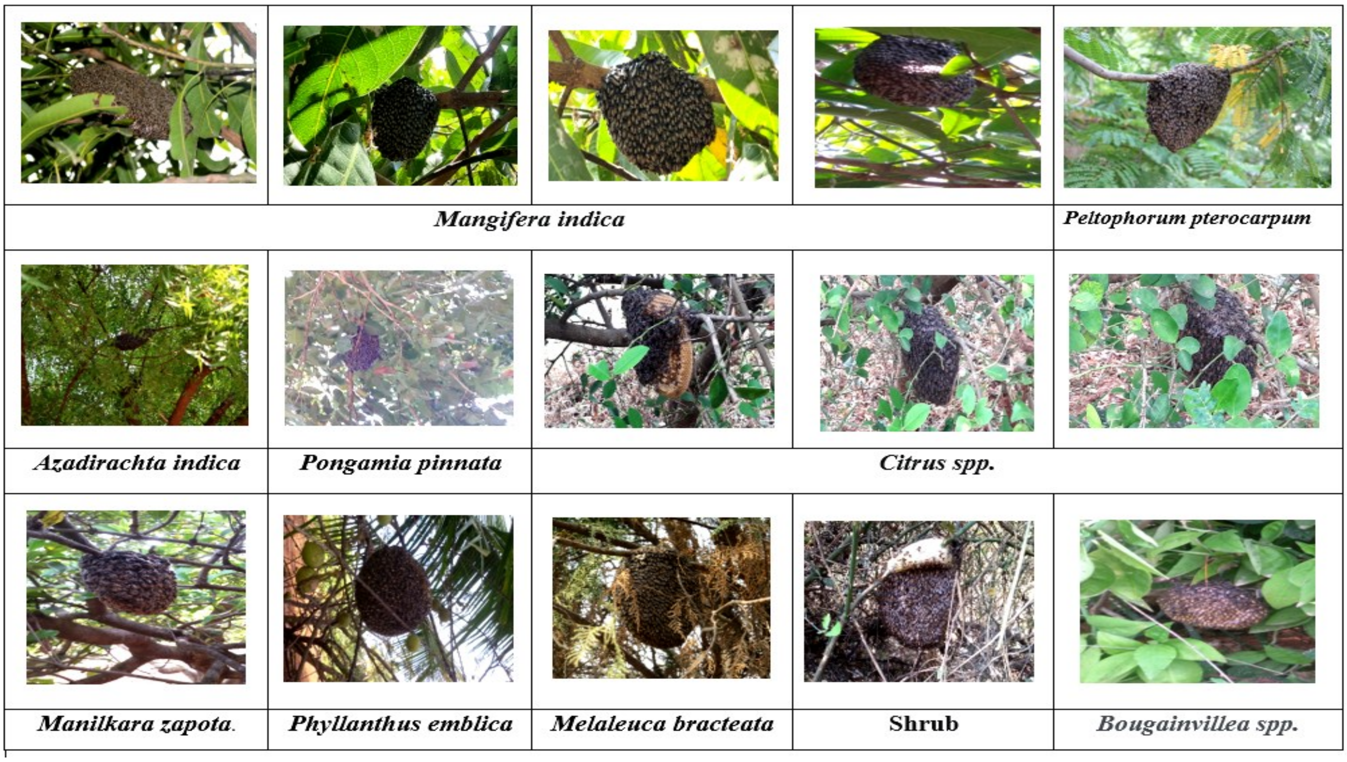


Fig. 1. Nesting sites and structure of *Apis florea* in different plants. This figure displays original images captured by the author.

ences between the two species' combs (20).

Hives of A. florea

A. florea exhibits versatile nesting habits and constructs hives in various locations, such as the tops of tall trees, on walls, and along the edges of building roofs (21). The hive height and width of *A.andreniformis* are 16 and 25 percent lower than that of *A.florea*. The branch diameter is approximately 0.8 cm. The worker cell measures 0.93 cm, the drone cell 1.33 cm, and the queen cell 1.41cm. *A. florea* constructs a single comb that is highly exposed to the sun, with one side receiving sunlight for several hours daily. Thus, *A. florea* hives are more significant than those of *A. andreniformis*. The queen chamber of *A. florea* is 1.41 ± 0.15 cm deep and has a diameter of 0.47 ± 0.09 cm. The diameter of worker bee cells is 0.29 ± 0.15 cm, and their depth is 0.93 ± 0.07 cm. The diameter and depth of the queen cell of *A. andreniformis* are 0.54 ± 0.08 cm and 1.24 ± 0.26 cm, respectively. On the other hand, worker bee cells have a diameter of 0.27 ± 0.11 cm and a depth of 0.76 ± 0.14 cm. In comparison, *A. florea* hives have much larger worker bees and drone cells in depth (19). The main characteristic feature that identifies *A. florea* is its nest architecture (22). The nest is constructed by the worker bee's ability to adjust in the comb (15). The hive width of *A. florea* is around 16.9 cm, with a height ranging from 35 to 40 cm. In contrast, *A. andreniformis* hives have a width of 12.2 cm and a height ranging from 25 to 35 cm (23). The architecture of 139 *A. florea* typical colonies and 60 abandoned combs reveals three shapes of the colony: asymmetrical (82), round (43), and oval (14). They record a comb width size of 17.6 ± 3.2 cm in the upper region, 18.4 ± 1.9 cm in the middle region, and 14.3 ± 2.0 cm in the bottom region. The queen cell size ranges from 1.3 cm × 1.3cm × 1.4 cm, while the drone cell's diameter and depth vary between 1.1 cm and 2.1 cm, respectively. The depth and diameter of the worker cells range from 0.8 cm to 1.0 cm. The depth and diameter of the honey-storing cells ranged from 1.1 cm to 2.5 cm, and the crest size ranged from 14.4 ± 9.14cm × 4.67± 2.68 cm. The comb architecture of *A. florea* and *A. andreniformis* is primarily similar. In the case of *A. florea* queen-less colonies, drone-sized cells are constructed to produce drones instead of worker cells to lay unfertilized eggs (24). The nest architecture of eusocial bees is determined by the phenotype of the colony (20).

Division of Labour

The ability of the colonies to withstand a greater variety of environmental situations may make them more fit than genetically homogeneous colonies (25). The adults of *A. florea* are responsible for protection and foraging, while the younger species work inside the nests doing upkeep. Certain workers are driven by genetics to do activities, such as fanning the comb to keep the temperature steady. This could explain how polyandry develops and persists (26, 27). When a queen mates with several unrelated males, workers with different genotypes arise in the colony (28). Patrilines complete this because diverse family species respond to a specific temperature threshold (29). In certain situations, the highly related daughters of a haploid male may adopt genetically based task specialization when the females are genetically predisposed to perform activities.

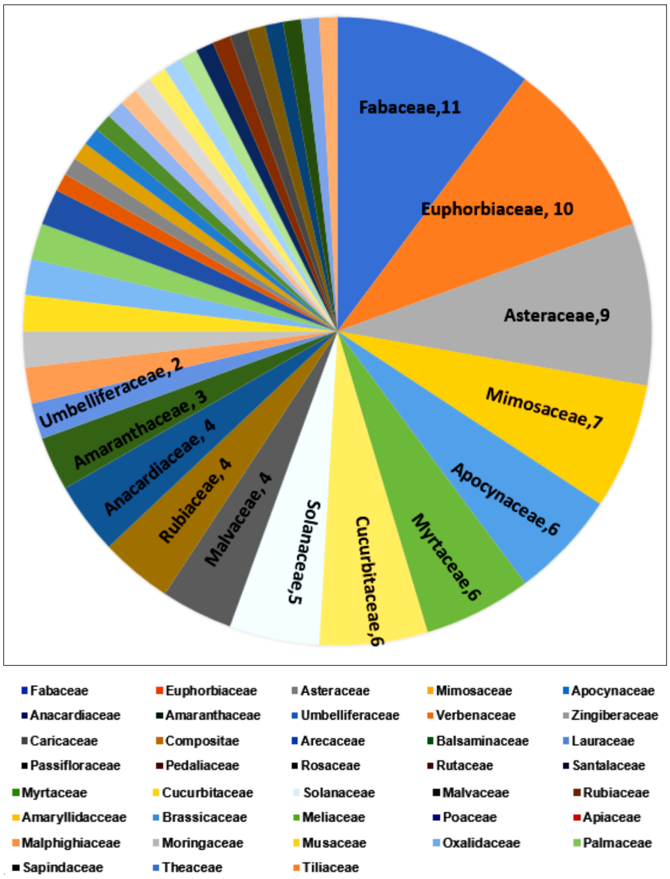
Domestication of *A. florea*

In Oman, *A. florea* colonies are initially managed very effectively (30). They provide additional awareness for beekeeping practices (31). The farmers gathered wild colonies from the side of the mountain and placed them in man-made chambers or the openings of trees. Several recorded attempts in India have been made to domesticate *A. florea*, but none became successful (32). These bees respond well to careful handling. When the honey cap is cut, the comb can be safely tied up in an *A. cerana indica* brood frame, and the bees attach it to the top frame. Above the brood frame, there would be a superframe where the bees construct a honeycomb and stuff it full of honey. However, there is no documentation of this technology validation. In Ranipokhari, Dehradun, Uttar Pradesh maintains the *A. florea* colony in a 4-frame nucleus box of *A. cerana indica* for two months (33).

Foraging vegetation of *A. florea*

Across various regions of Oman, pollen is collected from 249 different plant species. The samples are analyzed by using light and scanning electron microscopy. It shows the presence of 67 species of pollen pellets from 39 families in the honey samples. It indicates that there are many sources of pollen and nectar. Exclusively, 20 pollen types are found in the honey samples, mainly pollen feeders (34). The nectar-providing plants are *P. pinnata, C. petandra, T. indica,* and *Nerium* sp. *M. indica, B. bambos, H.r. sinensis, M. ovalifolia, P. longifolia,* and *M. champaca,* which provide honey bees with both pollen and nectar, while *T. stans* and *Bouganvillea* sp. did not function as a source of both pollen and nectar for *A. florea.* Around 51 plant species (29 crops and 22 wild trousers) are reported as bee foraging plants. Major foraging plants include *Azadirachta, Pongamia, Syzygium, Citrus, Cassia, Cocos, Brassica, Albezia, Polinathus, Areca, Lagerstroemia, Guizotia,* and *Helianthus* (16). *A. florea* mainly depends on these plant families for collecting pollen and nectar which was shown in Fig. 2.

Floral calendar of *A. florea*



The honey flow periods are identified as mid-July to mid-September, mid-December to mid-February, and mid-April to mid-June (35). *Ziziphus spinachristri, Proposis juliflora, Acacia tortilis, Zygophyllum* spp., *Prosopis cineraria, Citrus* spp., *Fagonia* spp. and *Maerua crassifolia* are considered as primary bee foraging plants (36). The number of 165 plant species that belonged to 53 families are reported as foraging plants for *A. florea* in Andhra Pradesh. Among them, tree species contribute more, followed by herbs, shrubs, and creepers (37). The honey flow period is determined to be from January to March (38). *M. indica*, *Trifolium exandrum*, *Calotropis procera,* and *Helianthus annuus* are the most common *A. florea* foraging plants, where early March to late May is noted as the highest blooming period (39). Honey bees are good pollinators of a variety of fruits. The foraging calendar of *A. florea* is given in Supplementary Table 1.

Floral preference of *A. florea*

The bee pollinator is usually associated with flower species that possess blue or yellow colour. The flower colours of the plant species foraged by the dwarf bee include white, yellow, purple, blue, green, and red. At flower level, *A. florea* foraging plants produce pollen in large amounts. The pollen production is higher in *Couroupita guianensis*, which serves as an excellent source of pollen for the bee. The flowering periods of these plant species are spread over a year, and this flowering sequence enables the bee to get pollen and nectar throughout the year. The bee collects pollen and nectar in the same or successive foraging visits from all the plant species except *Spathodea campanulate* (40). The floral colours and forage plants of *A. florea* are given in Table 3 and Fig. 3.

Foraging time of *A. florea*

Pollinators with high energy requirements tend to favour plants high in sucrose, while those with low energy requirements favour plants high in glucose or fructose (41). *A. florea* (av. 4700) has less loose carrot pollen grains than *A. dorsata* (av. 5200) (42). Insect pollinators of hybrid cauliflower show that honey bees are the primary pollinator. Among these honey bee species, *A.dorsata*, *A. mellifera*, *A. cerana indica,* and *A. florea* are the most important pollinators, and they contribute 28.23%, 26.32%, 24.20%, and 21.23%, respectively, in pollination (43). The 14 insect species visit the flowers of *Sesamum*. Of these, ten species belong to Hymenopteran, and four belong to Dipterans. Among Hymenopterans, honey bees such as *A. dorsata*. *A. cerana indica*, *A. florea,* and *T. irridipennis* are the predominant pollinators found during flowering time. The abundance of insect pollinators is about 6.28 bees/plant/5 min. *A. cerana indica* is followed by *A. dorsata* (6.21 bees/plant/5 min), *A. florea* (3.64 bees/plant/5 min) and *T. iridipennis* (2.26 bees/plant/5min) (44). During summer, the foraging activity of *A. florea* in lucerne crop is observed, and it found that foraging activity is higher during morning hours of about 1.27 bees/m^2/5 minutes and less during evening hours of about 1.23 bees/m^2/5 minutes. During monsoon, the foraging activity is recorded higher (1.02 bees/m^2/5 minutes) in the evening hours, while in

Table 3. Floral colours and forage plants of *A. florea*

S.No.	Plant species	Floral colours	References
1.	*Alangium salviifolium, Tamarindus indica*	Dirty white	(40)
2.	*Tridax procumbens, Terminalia cattappa, Sapindus marginatus*	Cream	(40)
3.	*Spathodea campanulate, Tagetes patula*	Red	(40,103)
4.	*Semecarpus anacardium*	Light green	(40)
5.	*T. tomentosa*	Greenish white	(40)
6.	*Jatropha curcas*	Greenish yellow	(40)
7.	*Tribulus terrestris, Euphorbia tortilis, Brassica campestris, Eruca sativa, Caesalpinia lutea, Verbesina encelioides, Cleome viscosa, Vigna radiata*	Yellow	(40,103)
8.	*Sterculia foetida*	Greenish red	(40)
9.	*Ocimum americanum, O. basilicum, Azadirachta indica, Acacia caesia, Zizyphus mauritiana, Morinda tomentosa, Cardiospermum halicacabum, Pisum sativum*	White or Dusty White	(40,103)
10.	*Anisomeles indica, Jacquemontia pentathos*	Purple Violet	
11.	*J. gossypliifolia*	Purplish red	(40)
12.	*Antigonon leptopus*	Purple white	
13.	*Tagetes erecta, Pyrostegia venusta*	Orange	(103)
14.	*Rosa chinensis*	Pink	(103)
15.	*Gaillardia* sp	Yellow-orange	(103)

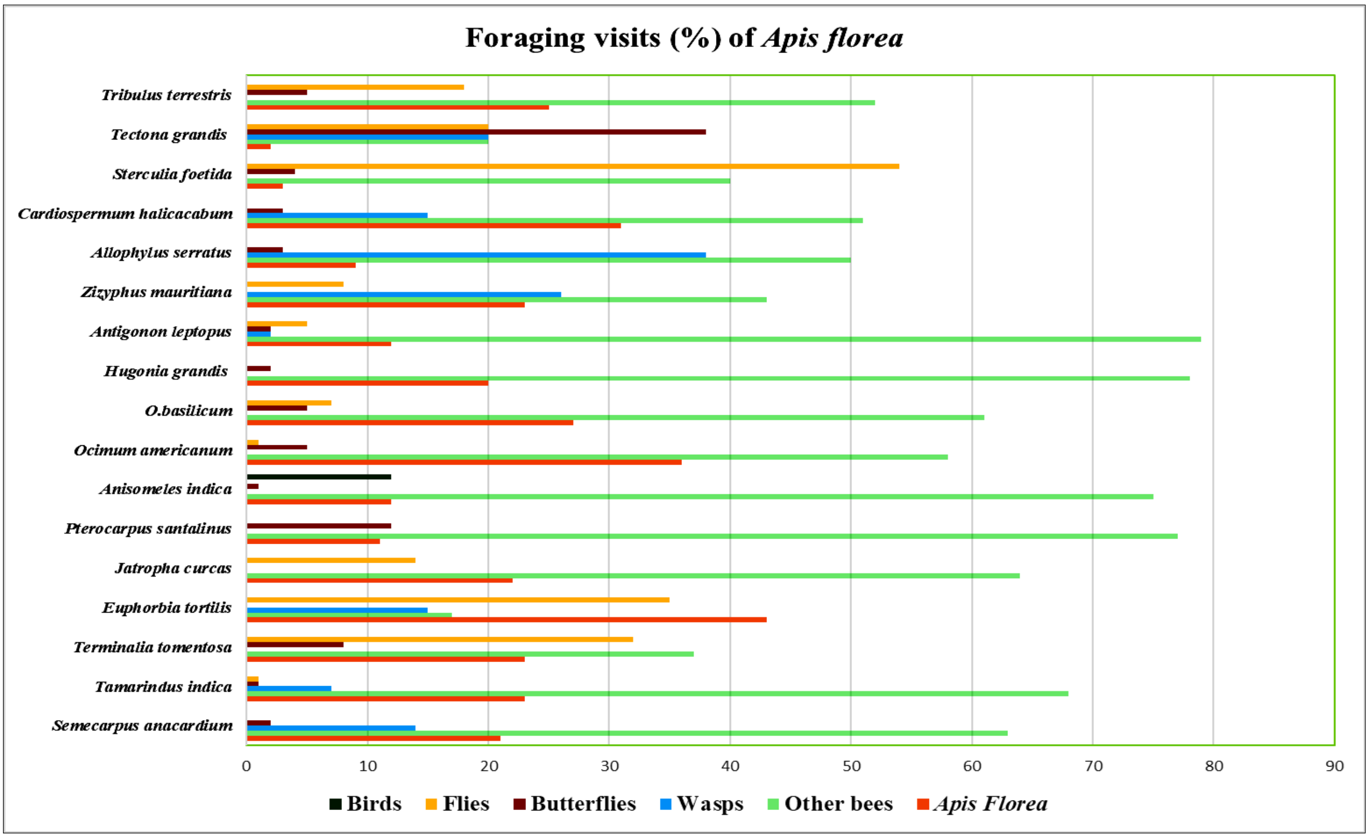


Fig. 3. Foraging visits of *A. florea* relative to other foragers on different plant species.

winter, it is recorded higher in the morning hours (1.16 bees/m^2/5 minutes) (45). The foraging behaviour of *A. florea* on coriander flowers. The findings show that *A. florea* foraging peaked during morning hours, 10.00 and 14.00 h, with an estimated 19 to 23.1bees/m^2. After that, the activity begins to decline at evening hours 18.00h. Despite less foraging activity, *A. florea* is more abundant on coriander flowers than *A. dorsata* and *A. mellifera* (46). *A. florea* is the most important pollinator of *Ocimum basilicum*, and it shows foraging activity from 07.30 to 17.30h. *A. florea* is found to be most abundant during the morning at 09.45 h (24 bees/m2/min), and they are found to be less abundant during the evening at 17.00 h (4 bees/m^2/min). The abundance of bees is averaged about 12 bees/ m^2/min. A rich source of floral nectars and pollens and a strong attraction to the bloom is the higher abundance of *A. florea*. The foraging frequency is 10.2 flowers/min. *O. basilicum* serves as both nectar and pollen yielders (47). The pollinator diversity of *M. oleifera* is studied, and it shows that thirteen species of hymenopterans, seven species of dipterans, and lepidopterans are considered significant pollinators. Among all these, *A. cerana indica* is the primary pollinator with a mean of 3.36 bees / 25 inflorescence/ 5 mins, followed by *A. dorsata* (1.51) and *A. florea* (0.08). The population ranged from 0.4 bees / 25 inflorescences/ 5 min at 06.00 to 07.00 h to 4.8 bees/ 25 inflorescences/ 5 min at 08.00 to 09.00 h. Among the days, the population was 2.25 to 4.42 /25 inflorescences/ 5 min with a mean of 3.36 bees / 25 inflorescences/ 5 min (48). *A. florea* produces both unifloral and multifloral honey. The pollen spectral analysis of 33 honey samples reveals that 15 are unifloral and 18 are multifloral (49).

Pollination efficiency of *A. florea*

Bees are considered the most effective pollinators, while butterflies are occasional pollinators, transferring pollen between flowers as they feed on nectar. Flies, hoverflies, and wasps also act as efficient pollinators, as they visit flowers to gather nectar—or, in some species, pollen - to obtain essential nutrients(3). Being a cross-pollinated crop, its fruit set is expected to be affected by insect visitors. Developing insect pollinators is regarded as one of the most cost-effective and eco-friendly methods for maximizing the yield of cross-pollinated crops. The pollination efficiency of an insect pollinator is mainly based on the size of the insect and foraging behaviour. The loose pollen grains adhere to the honey bees' bodies (50)**.** It is estimated that in nature, only 5 % of the flowers are self-pollinated, and 95% are cross-pollinated, of which 10 % depend upon the wind, and 85 % are on animals (51). In Hisar, India, the diversity and abundance of insect pollinators are investigated in nine cruciferous and four umbelliferous crops. The predominant pollinators are *A. dorsata*, *A. florea*, *A. mellifera,* and six additional solitary species. Reports are made about the influence of pollinator effectiveness on agricultural productivity indices. It indicates that the weight of seeds/plant/ha in both cruciferous and umbelliferous crops is higher in the open condition. Similarly, umbelliferous crops have more seeds per plant, while cruciferous plants that are openly pollinated have longer mean pod lengths and more seed sets per pod (52). Animal pollinators contribute 15~30% of the global food production (53).

Pollination is essential in flowering plants' reproduction and fruit set, particularly for cross-pollinated crops (54,55). The pollination index is also greater in *A. florea* (22989.2). The foraging activity of *A. florea* mainly depends upon the various environmental factors. The foraging activity of *Apis florea* shows a positive correlation with several factors, including temperature (r = 0.360), light intensity (r = 0.4554), solar radiation (r = 0.527), and nectar sugar concentration. Among all these factors, solar radiation shows a higher contribution in the foraging on flight activity of *A. florea,* followed by light intensity and temperature, and the nectar sugar concentration is least positively correlated. Relative humidity shows a negative correlation with the foraging activity of *A. florea,* which confirms that relative humidity affects the foraging activity of *A. florea* (56). In bitter gourd, *A. florea* made the largest contribution (43%), followed by *A. dorsata* (13%), *A. cerana indica* (26%), and other pollinators (18%). *A. florea* is observed to be foraging in bitter gourd from 08.00 to 18.00 hours per day (57).

Insect pollinators from four orders and 13 families visit the flowers of the carrot, *Daucus carota*. Among all these species, *A. florea* dominates the foraging activity, constituting about 98% of foraging visits. The foraging activity is higher during this time 07.26 to 07.44 h, when the temperature is about 19.4 to 25˚C. Solar radiation is 38 to 68 MW/cm^2, relative humidity is between 51 to 75 % and light intensity is 1300 – 4700 lux**.** *A. florea* foraging cycles have an impact on *Daucus carota* pollination, with open pollination reporting a greater seed rate (92.6%) (58). Most crops are cross-pollinated and feature entomophilous flowers, with pollination facilitated by various insect pollinators such as honey bees (*A. dorsata*, *A. mellifera*, *A. cerana indica*, *A. florea*), hoverflies, yellow wasps, carpenter bees, weevils, black ants, and butterflies *etc*., (59) . The pollination efficiency of *A. dorsata*, *A. florea*, and *A. mellifera* is investigated in Phalsa flowers within semi-arid regions. It shows that the abundance of *A. florea* is found to be a maximum of about 4.88 bees/ branch / 5 minutes, followed by *A. dorsata* (2.70 bees/ branch/ 5 minutes) and *A. mellifera* (0.96 bees/ branch/ 5 minutes). At forestry and environment arboretum *A. florea* are the primary pollinators of *M. oleifera*. The diversity and abundance of various pollinators are recorded in *M. oleifera* (60). The foraging time of pollinators was around 6.00 am to 6.00 pm and also reported six species of the Apidae family, two species of Vespidae, two species of Papilionidae, and one species of Nymphalidae. Among them, *A. florea* is the predominant pollinator in the moringa, followed by *A. dorsata*, *Amegilla* sp., *Megachile* sp. and *Xylocopa* sp. (61). The pollination efficiency of *A. florea* in various crops and their performance indicators are presented in Table 4.

Qualities of *A. florea* honey

The honey produced by dwarf bees resembles dammer bees, exhibiting a high dextrin content and a low granulation tendency. Dextrins are four times more when com-

Table 4. Pollination efficiency of *A. florea* in various crops

S.No	Crop	Scientific name	Performance indicator	Reference
1.	Carrot	*Daucus carota*	Higher seed yield (92.6%). More seeds with heavier weights	(106,58)
2.	Onion	*Allium cepa*	Increased yield. More seeds with heavier weights	(107,108)
3.	Cauliflower	*Brassica oleracea var. botrytis*	Increased seed production	(109)
4.	Chickpea	*Cicer arietinum*	Increasing yield	(110)
5.	Marigold	*Tagetes erecta*	Increasing yield	(103)
6.	Radish	*Raphanus sativus*	Increased seed production	(111)
7.	Spices	All spp.	Increased yield	(112)

pared to other *Apis* honey. The content of levulose is also high. The differences in the composition of dwarf bee honey can be attributed to several factors (62). Large colonies in areas abundant with bee forage can produce up to 4 kg of honey. Within the nest, the storage capacity of the honey cap ranges from 500 to 1,000 g or more. Honey hunters often remove entire combs to collect honey, resulting in the destruction of a significant number of colonies. *A. florea* is a poor honey yielder. The yield ranges from 200-900g. The nature of honey is thin and consistent. This honey is regarded for its exceptional medicinal qualities, while the nests are valued for the sweet honey and nutritious brood, which are consumed raw (63). In other countries such as Oman, *A. florea* honey is sold at very high prices (64).

Antioxidant qualities

Antioxidant activity in honey is primarily influenced by amino acids, with proline being a significant contributor rather than phenolic compounds. (65). Turkeman reports that the honey samples possess higher antioxidant activity when heated at 70˚C rather than 50˚C and 60˚C (66). There is a positive correlation between the antioxidant activity and the browning of samples. The phenolic compounds and glucose oxidase, which produce hydrogen peroxide compounds, are responsible for the antimicrobial activity of the honey. In a study, 27 honey samples are analyzed for the total phenols, flavonoids, proline contents, and radical scavenging activity (RSA). Among these 27 samples, 18 are multifloral, two are honeydew and seven samples are unifloral honey obtained from the flowers of Combretaceae, *Vitellaria*, *Acacia,* and *Linnea* plant species. The analysis states that the total phenolic content ranges from 32.59 mg (multi-floral honey) to 93.66 mg (honeydew honey). The proline content ranges from 437.8 to 2169.4 mg/g, showing an average value of 989.5mg/g. Proline content is highest in *Vitellaria* honey and the lowest recorded in multifloral honey. Similarly, the DPPH radical scavenging activity (RSA) is higher in *Vitellaria* honey samples and lowest recorded in multifloral honey. *Vitellaria* honey sample shows higher antioxidant content of 31.01 mg to 33.34 mg QEAC/100g and 57.72 mg to 65.86 mg AEAC/100 g. In contrast, the multifloral honey sample shows the lowest antioxidant content of 4.27 mg to 17.30 mg QEAC/100 g and 10.20 mg to 37.87 mg AEAC/100g (67).

The physicochemical properties of A. florea honey samples, i.e., the electrical conductivity of 0.823, free acidity of 11.56 meq/kg, lactose content of 4.81 meq/kg, proline content of 559.15 mg/kg and HMF (5, Hydroxy methyl furfural) content of 118.22 mg/kg. The lactose content is recorded higher in *A. florea* honey (68).

A comparative study of the total phenolic contents, antioxidant activity, and colour intensity of honey samples obtained from various sources, including Acacia (*Robinapseudo acacia*), Chestnut (*Castanea sativa*), Lime (*Tilia* sp.), Spruce (*Picea abbies*), fir (*Abies alba*), multifloral, and forest honey (honeydew of *coniferous* and *latifoliae* trees shows that fir honey (241.1 mg/kg) and forest honey (233.9 mg/kg) have higher total phenolic content, while acacia honey (44.8 mg/kg) has lower total phenolic content. A positive correlation (r=0.996) exists between the honey samples' total phenolic content and antioxidant activity. This shows that the primary determinant of the honey's antioxidant properties is its phenol content (69).

Proline and phenols are found to play a vital role as antioxidants. Phenol levels are higher in *Tetragonula* sp (784.3 mg GAE/kg) honey when compared to *Apis* sp. (590.5 mg GAE/kg) (70). The concentration of phenols, flavonoids, and antioxidant qualities increases the colour shade of the honey samples. Biochemical and antioxidant analysis of *A. florea* honey samples are collected from the arid areas, showing that flavonoids had a strong correlation with FRAP (r=0.60), AEAC (r=0.62), and RSA (r=0.81). In contrast, phenol strongly correlates with FRAP (r=0.60) (71). The study also found a positive correlation (r^2=0.086) between colour intensity and phenolic content. This indicates that the higher the phenolic concentration in the honey samples, the deeper the colour of the honey. The level of antioxidant activities and total phenols in the honey obtained from flowers is higher in multifloral honey than in unifloral honey (72). The antioxidant, flavonoid, and phenolic characteristics positively correlate with colour intensity. Phenols have an influential association with antioxidant characteristics (73).

Unique features of *A. florea*

A. florea exhibits several unique behaviours. These bees always construct their exposed nests using a comb on a single branch. They salvage wax from the old nest if they build a new nest near an old one, a behaviour not observed in other honey bee species, possibly due to the risk of contaminating pathogens. *A. florea* also demonstrates aggressive behaviours when competing for territory. This aggression naturally aids in defending flowers within their smaller territories (74). During mating, male *A. florea* grasp the queens' leg with a clasper organ on their hindlegs, supporting the hypothesis that they mate *via* direct sperm transfer. Queens typically mate with 3 to 4 males, employing an energetically efficient method of sperm transfer (75). Compared to other bees in this genus, *A. florea* tends to have more extended foraging periods. They occupy smaller territories at lower altitudes, building open combs on branches or twigs. Due to their tiny size and limited capacity to carry food, they spend more time foraging for pollen or nectar, making the longer foraging duration worthwhile for a highly nutritious food source (76). When ants are nearby, they produce and deposit sticky barriers obstructing the ant's path. Defender bees cover this sticky zone and alert others with specific hissing sounds to prevent full-blown raids. More bees eventually join to reinforce this sticky zone barrier defence (77). *A. florea* uses a defensive strategy called "piping", where a single bee emits an initial warning signal followed by a collective ("hissing") 0.3-0.7 seconds later reaction from many bees. Piping is audible to the human ear with a frequency of 384 ± 31 Hz, lasting 0.82 ± 0.35 seconds. Hissing is a noisy, broad-band signal audible to the human ear and produced by subtle movements of the bees' wings. This signal, audible to the human ear, creates a coordinated crescendo throughout the colony, causing workers to cease activities like foraging and dancing (78). The duration of the waggle dance correlates with distance, while the orientation of the dance indicates direction. This suggests that *A. florea* does not prioritize nesting sites or food patch information by altering the precision of their dance communication (79). To hide from predators, *A. florea* displays hissing and shimmering behaviours and builds its nests within thick vegetation (24). *A. florea* conveys important spatial information about foraging through their waggle dance, indicating direction and distance to a site. Even in a single nest, *A. florea* exhibits high genetic diversity due to the polygamous nature of honey bee queens. Additionally, they are easily susceptible to swarming and absconding when environmental conditions are unfavourable.

Enemies of *A. florea*

Vertebrate animals such as rodents and monkeys seriously threaten honey bees. The entire nest of *A. florea* is eaten by many insectivorous mammals, particularly tree shrews (*Tupaia glis*) (80). The honey bee's enemies include ants, spiders, birds, etc.

Mite

Euvarrora sinhai from *A. florea* is first documented in India and causes more damage (81). Mites are free-living predators (82). Some are present in honey bee colonies, feeding on other mites, insects, fungi, and pollen. This mite is mainly found on trees and flowers and feeds on pollen (83). Five kinds of honey bees are thought to be connected to *Euvarroa.* The cavity nesters are *A. florea*. The mite species associated with *A. florea* is discussed in Table 5.

Moths

Table 5. Mite species associated with *A. florea*

Mite species	Distribution	Reference
Euvarroa sinhai	India, Nepal and Burma	(81)
Tropilaelaps clareae	India	(104)
Acarapis woodi	India	(105)

The Indian meal moth (*Plodia interpunctella)* and greater wax moth (*Galleria mellonella)* are the two significant pests of *A. florea* colonies. *Galleria* occurs throughout the world wherever honey bees are kept. Galleria larvae can quickly demolish the comb through a pile of webbing and debris because *A. florea* colonies become weak (84).

Wasp

Wasp attacks are not limited to individuals in flight. Occasionally, entire colonies are eradicated**.** *V. tropica* destroys the colonies of *A. florea* in three hours (80). *Vespa affnis* attacks the drones of *A. florea* (85).

Ants

Oecophylla smaragdina is a more severe enemy of *A. florea. A. florea*, a resinous material, has a potent repellent effect on *O. smaragdina*. Ants fall/enter the A. florea colony and can be mob and crushed by the workers. Bees employ buzzing flights and air bursts to fend off ant attacks. The worker bees build a barrier against walking insects by lining up in multiple rows (80, 77, 86).

Birds

Merops orientalis and Microspiasis supercilious is bee-eater birds that contain 30 percent of A. florea as part of their diet. The birds feed on bees and stay much longer time around the hives on cold and sunny days (87).

Microbial pathogens

Black Queen Cell Virus (BQCV) is found in a sample of sick drone larvae due to a viral illness in *A. florea* colonies. This virus is typically linked to *A. mellifera* queen cells that produce cell walls that are dark brown to black. In 1986, Ball identified the virus in *A. florea* dead honey bee drone larvae. Infect larvae fail to pupate, become soft and liquefied, and no adult emerges from the cells. The larval body colour changes from pearly white to pale brown (84).

Hygienic behaviour of *A. florea*

The host hygienic behaviour of the dwarf honey bee workers is first observed (88). Insufficient food causes the dwarf honey bees' brood cell diameter to shrink, contributing to a mite decline (19). *A. florea* removes the dead broods infected by mites (89). This is the first evidence of the hygienic behaviour of *A. florea.* They removed the freeze-killed (89%) and pin-killed brood (95%) in 24 and 48 h, respectively (90).

Conclusion

A. florea honey bees play a crucial role in pollinating various plant species. Their removal from ecosystems would significantly damage agricultural production, underscoring their economic importance. These bees exhibit a remarkable ability to tolerate high temperatures and adapt to diverse environmental conditions compared to other bees. Conservation efforts for *A. florea* are essential, given their efficiency as pollinators, which directly contribute to agricultural productivity and ecosystem sustainability. Managed bee pollination, utilizing *A. florea*, emerges as the best approach for farmers' and beekeepers. For farmers, it would enhance crop yield by ensuring adequate pollination, while for beekeepers, it would boost honey production. This dual benefit highlights the importance of *A. florea* in agricultural practices, emphasizing their role in maintaining biodiversity and supporting economic viability through improved agricultural outputs and honey yields. Ensuring the conservation and effective management of *A. florea* populations is therefore vital for the sustainability of natural ecosystems and farming industries.

Acknowledgements

All authors are thankful to Agriculture College and Research Institute, Madurai, and Indian Council of Agricultural Research - Krishi Vigyan Kendra, TNAU, Madurai, Tamil Nadu, India, Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu, India for the facilities provided to carry out the review paper.

Authors' contributions

PR, SK, UB, AR, NR, and AAP collected all the literature, compiled, edited, and improved the language of this review paper. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: The authors declare no conflict of interest.

Ethical issues: **:** This review paper does not report or involve using animal or human data or tissue.

Supplementary data

Supplementary Table 1. Foraging calendar of little bee, *A. florea*

References

1. Gallai N, Salles JM, Settele J, Vaissière BE. Economic valuation of the vulnerability of world agriculture confronted with pollinator decline. Ecological Economics. 2009;68(3): 810-821. https://doi.org/10.1016/j.ecolecon.2008.06.014
2. Crane E. Apis species:(honey bees). In: Resh VH, Cardé RT, editors. Encyclopedia of insects. Academic Press Elsevier; 2009. p. 31-32. https://doi.org/10.1016/B978-0-12-374144-8.00009-6
3. Free JB. Insect pollination of crops. London and New York:Academic Press;1970
4. Melnichenko A. Role of insect-pollinators in increasing yields of agricultural plants. In: Melnichenko AM, editor. Pollination of agricultural Crops by bees. NewDelhi:Amerind Publishing Co. Pvt. Ltd. New Delhi; 1997
5. Rodionov VV. The fascinating world of bees: Mir Publishers;1986
6. Riscu A, Bura M. The impact of pesticides on honey bees and hence on humans. Journal of Animal Science and Biotechnology. 2013;46(2):272-77.
7. Devi A, Mattu VK.Preparation of floral calendar of honey plants of Kangra and adjoining areas of Himachal Pradesh. International Journal of Science and Research. 2017;(2):371-78.
8. Yan-Ru W, Bangyu K. Two species of small Honey bee-a study of the genus *Micrapis*. Bee World. 1987;68(3):153-55. https://doi.org/10.1080/0005772X.1987.11098924
9. Ruttner F, Ruttner F. *Apis florea* Fabricius 1787. Biogeography and Taxonomy of Honey bee; 1988.
10. Wongsiri S, Limbipichai K, Tangkanasing P, Mardan M, Rinderer T, Sylvester H, Otis G. Evidence of reproductive isolation confirms that *Apis andreniformis* (Smith 1858) is a separate species from sympatric *Apis florea* (Fabricius, 1787). Apidologie. 1990;21 (1):47-52. https://doi.org/10.1051/apido:19900106
11. Koeniger G, Koeniger N, Mardan M, Otis G, Wongsiri S. Comparative anatomy of male genital organs in the genus *Apis*. Apidologie. 1991;22(5):539-52. https://doi.org/10.1051/apido:19910507109
12. Wongsiri S, Lekprayoon C, Thapa R, Thirakupt K, Rinderer T, Sylvester H, Booncham UJ.Comparative biology of *Apis andreniformis* and *Apis florea* in Thailand. Bee World. 1997;78(1):23-35. https://doi.org/10.1080/0005772X.1997.11099328
13. Nagaraja N, Rajagopal D. Colony establishment, nesting and foraging activity of little honey bee, *Apis florea* F (Hymenoptera: Apidae). Journal of Entomological Research. 1999;23(4):331-38.
14. Villa JD. Swarming behavior of Honey bees (Hymenoptera: Apidae) in southeastern Louisiana. Annals of the Entomological Society of America. 2004;97(1):111-16. https://doi.org/10.1603/0013-8746(2004)097[0111:sbohbh]2.0.co;2 71
15. Oldroyd BP, Gloag RS, Even N, Wattanachaiyingcharoen W, Beekman M. Nest site selection in the open-nesting honey bee *Apis florea*. Behavioral Ecology and Sociobiology. 2008;62:1643-53. https://doi.org/10.1007/s00265-008-0593-5
16. Basavarajappa S. Nesting plants of dwarf honey bee, *Apis florea* F. under tropical conditions of Karnataka, India. Animal Biology. 2010;60(4):437447.https://doi.org/10.1163/157075610X523305
17. Moritz RF, Haddad N, Bataieneh A, Shalmon B, Hefetz A. Invasion of the dwarf Honey bee *Apis florea* into the near East. Biological Invasions. 2010;12:1093-99. https://doi.org/10.1007/s10530-009-9527-z62.
18. Makinson JC, Schaerf TM, Wagner N, Oldroyd BP, Beekman M. Collective decision making in the red dwarf honey bee *Apis florea*: do the bees simply follow the flowers. Insectes Sociaux. 2017;64:557-66. https://doi.org/10.1007/s00040-017-0577-4
19. Rinderer TE, Wongsiri S, Kuang B, Liu J, Oldroyd BP, Sylvester HA, de Guzman L. Comparative nest architecture of the dwarf honey bees. Journal of Apicultural Research. 1996;35(1):19-26. https://doi.org/10.1080/00218839.1996.1110090926
20. Dawkins R. The extended phenotype:the long reach of the gene. Oxford University Press; 2016
21. Akratanakul P. The natural history of the dwarf honey bee, *Apis Florea* F. Thailand:Cornell University; 1997
22. Franck P, Cameron E, Good G, Rasplus JY, Oldroyd BP. Nest architecture and genetic differentiation in a species complex of australian stingless bees. Molecular Ecology. 2004 Aug;13 (8):2317-31.https://doi.org/10.1111/j.1365-294X.2004.02236.x
23. Hepburn HR, Radloff SE. Honey bees of Asia. Springer Science and Business Media; 2011. https://doi.org/10.1007/978-3-642-16422-4
24. Narayanaswamy R, Basavarajappa S. Nesting attributes of dwarf bee, *Apis florea* F. under urban ecosystem of Manasagangotri campus, Mysore, India. European Zoological Journal Research. 2013;2(6):6-15.
25. Crozier RH. Polyandry in the genus *Apis*, particularly *Apis andreniformis*. Behavorial Ecology and Sociobiology. 1985;40:1726.
26. Page RE, Gene RE. The genetics of division of labour in honey bee colonies. Advance in Insect Physiology. 1991;23:117-69.
27. Oldroyd BP, Rinderer TE, Buco SM. Intra-colonial foraging specialism by honey bees (*Apis mellifera*) (Hymenoptera: Apidae). Behavorial Ecology and Sociobiology. 1992;30(5):291-95.
28. Oldroyd BP, Sylvester HA, Wongsiri S, Rinderer TE. Task specialization in a wild bee, *Apis florea* (Hymenoptera: Apidae), revealed by RFLP banding. Behavorial Ecology and Sociobiology. 1994;34:25-30.
29. Beshers SN, Huang ZY, Oono Y, Robinson GE. Social inhibition and the regulation of temporal polyethism in honey bees. Journal of Theoretical Biology. 2001;213(3):461-79.
30. Dutton R, Simpson J. Producing honey with *Apis florea* in Oman. Bee world.1977;58(2):71-76. https://doi.org/10.1080/0005772X.1977.11097647
31. Dutton RW, Free JB. The present status of beekeeping in Oman. Bee world. 1979;60(4):176-85. https://doi.org/10.1080/0005772X.1979.11097756
32. Bhardwaj SC, Kapil RP. Domestication and training of *Apis florea* Fabr. to visit an artificial feeding station. Indian Journal of Entomology. 1980;42:290-92.
33. Pundir R . Hiving *Apis florea*. Indian Bee J. 1971;33(3/4):63.
34. Jayavasti S, Wongsiri S. Scanning electron microscopy analysis of honey bees (*Apis florea*, *Apis dorsata*, *Apis cerana*, *Apis mellifera*, *Apis andreniformis* and *Apis koschevnikovi*) stings. Journal of Advanced Research. 1992;2:193-204.

35. Bhalchandra W, Baviskar RK, Nikam TB. Diversity of nectariferous and polleniferous bee flora at Anjaneri and Dugarwadi hills of Western Ghats of Nasik district (MS) India. Journal of Entomology and Zoology Studies. 2014;2(4):244-49.

36. Sajwani A, Farooq SA, Bryant VM. Studies of bee foraging plants and analysis of pollen pellets from hives in Oman. Palynology. 2014;38(2):207-23. https://doi.org/10.1080/01916122.2013.871652

37. Sambasiva RK, Mallikarjuna RM, Sulakshana M, Dileep Kumar B, Solomon Raju AJ. Morphometric analysis, floral rewards and floral calendar of the dwarf honey bee, *Apis florea* F. 2015;33:115 -207. http://hdl.handle.net/10603/390155

38. Pushpalatha S, Hariprasad Y. Foraging behaviour of indian honey bee (*Apis cerena indica* Fab) in bee pasturaging plants at Annamalainagar eco system. International Journal of Recent Scientific Research. 2015;6:6974-76.

39. Sajjad A, Ali M, Saeed S, Bashir MA, Ali I, Khan KA, Ansari MJ. Yearlong association of insect pollinator, *Pseudapis oxybeloides* with flowering plants: planted forest vs agricultural landscape. Saudi Biological Science. 2019;26(7):1799-803. https://doi.org/10.1016/j.sjbs.2018.02.019

40. Raju AS, Rao SP, Kumari PK. The role of *Apis florea* in the pollination of some plant species in Andhra Pradesh, India. Korean Journal of Apiculture. 2003;18(1):37-42.

41. Abrol DP, Kapil R. Foraging strategies of honey bees and solitary bees as determined by nectar sugar components. Proceedings of the Indian National Science Academy. Part B, Biological Science. 1991;57:127-32.

42. Sharma SK, Singh JR. Pollination efficiency of *Apis dorsata* F and *A. florea* F. on carrot (*Daucus carota* L.). Indian Bee Journal. 1999;61(1):1-4.

43. Selvakumar P, Sinha S, Pandita V, Srivastava RM. Foraging behavior of honey bee on parental lines of hybrid cauliflower pusa hybrid-2. Apimondia Journal. 2001.

44. Sajjanar S, Eswarappa G. Sesame (*Sesamum indicum* L.) crop insect pollinators with special reference to the foraging activity of different species of honey bees. Journal of Agriculture and Veterinary Sciences. 2015;8(11):9-14.

45. Chavan VT. Pollinator fauna, foraging activity and effect of bee attractants on seed yield of lucerne (Doctoral dissertation); 2017

46. Sharma K, Balraj S, Meena NK, Meena RS. Foraging behavior of major *Apis* species on coriander. International Journal of Current Microbiology and Applied Sciences. 2018;7(1):2928-32.

47. Dalio JS. Foraging activity of dwarf honey bee (*Apis Florea*) on bloom of *Ocimum basilicum* L. Journal of the Renin-Angiotensin-Aldosterone System. 2018;5(1):11-14.

48. Sowmiya C, Srinivasan M, Saravanan PA. Diversity of pollinators in drumstick, *Moringa oleifera* Lam. ecosystem. Madras Agricultural Journal. 2018;105:1-3. https://doi.org/10.29321/MAJ.2018.000127

49. Layek U, Karmakar P. Pollen analysis of *Apis dorsata* (Fabricius) honeys in Bankura and Paschim Medinipur districts, West Bengal.Grana.2018;57(4):298-310. https://doi.org/10.1080/00173134.2017.139060495

50. Free JB, Williams IH, Longden PC, Johnson MG. Insect pollination of sugar-beet (*Beta vulgaris*) seed crops. Annals of Applied Biology. 1975;81(2):127-34. https://doi.org/10.1111/j.1744-7348.1975.tb00529.x

51. Tewari GN, Singh K. Role of insect pollinators in vegetable seed production. Indian Bee Journal. 1985

52. Sihag RC, Abrol DP. Correlation and path-coefficient analysis of environmental factors influencing flight activity of *Apis florea* F. Journal of Apicultural Research.1986; 25(4): 202-08. https://doi.org/10.1080/00218839.1986.11100718

53. Roubik DW. Pollination of cultivated plants in the tropics. Food and Agriculture Organisation. 1995;118.

54. Corbet SA, Williams IH, Osborne JL. Bees and the pollination of crops and wild flowers in the european community. Beeworld. 1991;72(2):4759. https://doi.org/10.1080/0005772X.1991.11099079

55. Buchmann S, Nabhan GP. The forgotten pollinators. Island. Washington, DC;1996

56. Gill S, Kaushik H, Sharma S. Effect of modes of pollination on fruit set and insect pollinators of phalsa (*Grewia subinaequalis* DC). Research on Crops. 2001;2(2):193-96.

57. Nidagundi BR, Sattagi H. Pollinator fauna and foraging activity of bees in bitter gourd; 2005.

58. Abrol DP. Factors influencing flight activity of *Apis florea* F, an important pollinator of *Daucus carota* L. Journal of Apicultural Research. 2006;45(2):2-6. https://doi.org/10.1080/00218839.2006.11101317

59. Singhal VK, Salwan A, Kumar P, Kaur J. Phenology, pollination and breeding system of *Aegle marmelos* (Linn.) correa (Rutaceae) from India. New Forests. 2011;42:85-100. https://doi.org/10.1007/s11056-010-9239-3

60. Chukunda F, Ukoima H, Abere S, Ebere N. Abundance and diversity of insect visitors to flower of *Moringa oleifera* at forestry and environment arboretum. Research Journali's Journal of Forestry. 2016;3(2):1-15.

61. Bhatnagar S, Rathore LS, Khan AU, Vishnoi G, Sharma N, Kumar B. Record of insect pollinators of *Moringa oleifera* lam. Journal of Entomology and Zoology Studies. 2018;6(3):389-91.

62. Abrol DP, Kapil R. Nectar dilution pattern of bees in semi-arid environments. Current Science. 1987;13:681.

63. Abrol DP. Beekeeping: a compressive guide to bees and beekeeping. Sci Pub; 2013..

64. Abrol DP. The future role of dwarf honey bees in natural and agricultural Systems. Boca Raton:CRC Press; 2020.

65. Taormina PJ, Niemira BA, Beuchat LR. Inhibitory activity of honey against foodborne pathogens as influenced by the presence of hydrogen peroxide and level of antioxidant power. International Journal of Food Microbiology. 2001;69(3):217-25. https://doi.org/10.1016/S0168-1605(01)00505-0

66. Turkmen N, Sari F, Poyrazoglu ES, Velioglu YS. Effects of prolonged heating on antioxidant activity and colour of honey. Food Chemistry. 2006;95(4):653-57.

67. Meda A, Lamien CE, Romito M, Millogo J, Nacoulma OG. Determination of the total phenolic, flavonoid and proline contents in Burkina Faso honey, as well as their radical scavenging activity. Food Chemistry. 2005;91(3):571-77. https://doi.org/10.1016/j.foodchem.2004.10.006

68. Qamer S, Muzaffar N, Ali S, Shakoori AR. Physicochemical analysis of pakistani unifloral honey from different nectar sources. Proceedings of Pakistan Congress of Zoology. 2005;25:123-30.

69. Bertoncelj J, Doberšek U, Jamnik M, Golob T. Evaluation of the phenolic content, antioxidant activity and colour of slovenian honey. Food Chemistry. 2007;105(2):822-28. https://doi.org/10.1016/j.foodchem.2007.01.060

70. Saxena S, Gautam S, Sharma A. Physical, biochemical and antioxidant properties of some indian honey. Food Chemistry. 2010;118(2):391-97. https://doi.org/10.1016/j.foodchem.2009.05.001

71. Pontis JA, Costa LAMAD, Silva SJRD, Flach A. Color, phenolic and flavonoid content and antioxidant activity of honey from Roraima, Brazil. Journal of Food Science and Technology. 2014;34:69 -73. https://doi.org/10.1590/S0101-20612014005000015

72. Kek SP, Chin NL, Yusof YA, Tan SW, Chua LS. Total phenolic contents and colour intensity of malaysian honeys from the *Apis* spp. and *Trigona* spp. bees. Agriculture and Agricultural Science Procedia. 2014;2:150-55. https://doi.org/10.1016/j.aaspro.2014.11.022

73. Vaghela J, Reddy A. Antioxidant potential of *Apis florea* honey from dryland ecosystem in western India. Journal of Advance Reserach. 2016;4(2):1392-402.

74. Koeniger N, Vorwohl G. Competition for food among four sympatric species of *Apini* in Sri Lanka (*Apis dorsata*, *Apis cerana*, *Apis florea* and *Trigona iridipennis*). Journal of Apicultural Research. 1979;182:95-109.

75. Koeniger N, Koeniger G, Wongsiri S. Mating and sperm transfer in *Apis florea*. Apidologie. 1989;20(5):413-18.

76. Dyer FC, Seeley TD. Dance dialects and foraging range in three asian honey bee species. Behavioral Ecology and Sociobiology. 1991 Apr;28:227-33.

77. Duangphakdee O, Koeniger N, Koeniger G, Wongsiri S, Deowanish, S. Reinforcing a barrier–a specific social defense of the dwarf honey bee (*Apis florea*) released by the weaver ant (*Oecophyll asmaragdina*). Apidologie. 2005;36(4):505-11.https://doi.org/10.1051/apido:2005036

78. Sarma MS, Fuchs S, Werber C, Tautz J. Worker piping triggers hissing for coordinated colony defence in the dwarf honey bee *Apis florea*. Zoology. 2002;105(3):215-23.

79. Beekman M. Dance precision of *Apis florea* - clues to the evolution of the honey bee dance language. Behavorial Ecology and Sociobiology**.** 2008;62(8):1259-65.

80. Seeley TD, Seeley RH, Akratanakul P. Colony defense strategies of the honey bees in Thailand. Ecological Monographs. 1982;52(1):43-63. https://doi.org/10.2307/2937344

81. Delfinado MD, Baker EW. Varroidae, a new family of mites on honey bees (*Mesostigmata: acarina*). Journal of the Washington Academy of Science. 1974;4-10.

82. Hunter PE, Rosario RMT. Associations of *Mesostigmata* with other arthropods. Annual Review of Entomology. 1988;33(1):393-417. https://doi.org/10.1146/annurev.en.33.010188.002141 27

83. Delfinado-Baker M, Baker E, Phoon ACG. Mites (Acari) associated with bees (Apidae) in Asia, with description of a new species. American Bee Journal. 1989;129(9):609-13.

84. Mossadegh MS. Some honey bee virus diseases in Iran. Journal of Agriculture Science. 1990;13(13):7-72. https://www.cabidigitallibrary.org/doi/full/10.5555/1994020030695

85. Koeniger N, Koeniger G, Mardan M. Mimicking a honey bee queen *Vespa affinis* indosinensis Perez 1910 hunts drones of *Apis cerana* F. 1793. Ethology. 1994;98(2):149-53. https://doi.org/10.1111/j.1439-0310.1994.tb01065.x

86. Duangphakdee O, Koeniger N, Deowanish S, Hepburn HR, Wongsiri S. Ant repellent resins of honey bees and stingless bees. Insectes Sociaux. 2009;56:333-39.

87. Fry CH. The bee-eaters: A and C black. UK:Poyser; 2010.

88. Kitprasert C. Parasitism by the brood mite, *Euvarroa sinhai* Delfinado and Baker (Acari: Varroidae) on the dwarf honey bee, *Apis florea* F. (Hymenoptera: Apidae) in Thailand.1994

89. Woyke J, Wilde J, Siviram N, Nagaraja N. Does open-air nesting honey bee *Apis florea* differ from the other bees of genus *Apis* in brood hygienic behaviour. Paper presented at the Global Conference on Entomology. 2011;164.

90. Woyke J, Wilde J, Phaincharoen M. First evidence of hygienic behaviour in the dwarf honey bee *Apis florea*. Journal of Apicultural Research. 2012;51(4):359-61. https://doi.org/10.3896/ibra.1.51.4.138

91. Haldhar SM, Singh KI, Gupta MK, Devi A. Morphometric analysis on different species of honey bees in NEH region of India. Journal of Agriculture and Ecology. 2021;12:62-73. http://doi.org/10.53911/jae.2021.12205

92. Niem NV, Trung LQ. Morphological comparison of three asian native honey bees (*Apis cerana, A. dorsata, A. florea*) in northern Vietnam and Thailand. Biotropia. 1999;14.

93. Makhmoor H, Ahmad, H. Biometric studies on four species of honey bees in Jammu region, India. Indian Bee Journal. 1998;60(3):141-42.

94. Mannivannan A, Madhumita B, Maheshwari M, David MM. Morphometric studies on indian honey bee *Apis cerana indica* and little bee *Apis florea* in Tamil Nadu. International Journal of Applied and Pure Science and Agriculture. 2016;2(1):8-11.

95. Smith F. Catalogue of the hymenopterous insects collected at Sarawak, Borneo, Mount Ophir, Malacca and at Singapore, by AR Wallace. Zoological Journal of the Linnean Society. 1857;2(6):42-88.

96. Rinderer TE, Oldroyd BP, Wongsiri S, Sylvester H, De Guzman LI, Stelzer JA, Riggio RM. A morphological comparison of the dwarf honey bees of southeastern Thailand and Palawan, Philippines. Apidologie. 1995;26(5):387-94. https://doi.org/10.1051/apido:19950504

97. Koeniger G, Koeniger N, Mardan M, Punchihewa R, Otis G. Numbers of spermatozoa in queens and drones indicate multiple mating of queens in *Apis andreniformis* and *Apis dorsata*. Apidologie. 1990;21(4):281-86. https://doi.org/10.1051/apido:19900402

98. Otis G, Patton K, Tingek S. Piping by queens of *Apis cerana* (Fabricius) 1793 and *Apis koschevnikovi* v Buttel - Reepen. Apidologie. 1995;26(1):61-65. https://doi.org/10.1051/apido:19950108

99. Thapa R, Wongsiri S. Distinct fanning behaviour of two dwarf honey bees *Apis andreniformis* (Smith) and *Apis florea* (Fab). In Proceedings of Second International Conference of the Asian Apicultural Association; 1994.

100. Booncham U, Wongsiri S, Thirakupt K. Niche differences between *A. florea* and *A. andreniformis* in dry-evergreen forest, Thailand. In International Conference on Tropical Bees Environment;1995.

101. Layek U, Karmakar P. Distribution, nesting biology and floral resources of red dwarf honey bee *Apis florea* (Fabricius) in West Bengal, India. The Future Role of Dwarf Honey Bees in Natural and Agricultural Systems. 2020;301-09.

102. Sihag RC. Crop hosts and pollination potential of the red dwarf honey bee (*Apis florea* F.) in the semi-arid environment of North West India. Journal of Applied Sciences Research. 2019;19(6):551-56. https://doi.org/10.3923/jas.2019.551-556

103. Kachhawa G. *Apis florea*, a dwarf honey bee [Insecta, Hymenoptera, Apoidea, Apidae] as major forager in the North eastern region of Rajasthan, India. Flora and Fauna. 2022;28(2):333-40. https://doi.org/10.33451/florafauna.v28i2pp333-340

104. Makkar GS, Chhuneja PK. In: Dhawan A, Sharma K, Kumar DR, editors. Extended abstract of 3rd Congress Science on pest management for food security and environmental health. PAU, India. Indian Advancement of Insect Scienc. Department of Entomology, PAU, Ludhiana India; 2011:272.

105. Chhillar B, Gulati R, Bhatnagar P. Agricultural acarology. New Delhi:Daya Books; 2007

106. Ahmad M, Aslam M. Pollinators visiting carrot *Daucus carota* L seed crop. Journal of Scientific Research. 2002;13(1):31-35.

107. Saeed S, Masood A. Pollinator community of onion (*Allium cepa* L.) and its role in crop reproductive success. Pakistan Journal of Zoology. 2008;40(6):451-56.

108. Abrol DP. Foraging behaviour of *Apis florea* F. an important polli-

nator of *Allium cepa* L. Journal of Apicultural Research. 2010;49 (4):318-25.https://doi.org/10.3896/IBRA.1.49.4.04

109. Karkute SG, Majumder S, Singh V. Diversity and foraging behaviour of insect pollinators in cauliflower. Ecology Environment and Conservation. 2023;29(2):964-71. http://doi.org/10.53550/EEC.2023.v29i02.070

110. Abdul LAL, Malik S, Shafqat SSS, Naeem INI, Qamar SQS, Khan K, Ghramh H. Diversity of pollinators and their role in the pollination biology of chickpea, *Cicer arietinum* L (Fabaceae). Journal of Asia-Pacific Entomology. 2019;22(2):597-601. https://doi.org/10.1016/j.aspen.2019.03.009

111. Divekar PA, Patel SK, Manimurugan C, Singh V. Insect pollinator diversity and their foraging behaviour in radish, *Raphanus sativus* L. Emergent Life Sciences Research. 2013;9:68-76. https://doi.org/10.31783/elsr.2023.926876

112. Kant K, Singh B, Meena S, Ranjan J, Mishra B, Solanki R, Kumar M. Relative abundances and foraging behaviour of honey bee species on minor seed spice crops. International Journal of Seed species. 2013;3(2):51-54.